Demand-Driven Technologies for Sustainable Maize Production in West and Central Africa

Editors

B. Badu-Apraku, M.A.B. Fakorede,
A.F. Lum, A. Menkir, and M. Ouedraogo

RESEAU MAIS
MAIZE NETWORK

IITA
Research to Nourish Africa

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West and Central Africa Collaborative Maize Research Network (WECAMAN)

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Preface

The West and Central Africa Collaborative Maize Research Network (WECAMAN) was formally inaugurated in 1987. The Network has served as an effective mechanism for all stakeholders in maize production and productivity to tackle the regional constraints. These include national and international scientists, extension workers, farmers, seed technologists, industrialists and policymakers. WECAMAN's approach to maize research and development has been unique. National research programs that are stronger than others in specific subject-matter areas are identified and designated Lead Centers (LCs). Constraints to maize production are identified in a participatory manner by all stakeholders. An Ad-hoc Research Committee screens proposals and allocates funds to the LCs for research projects to address the constraints. Technologies emanating from the research conducted in the LCs are made available to other member countries through on-farm tests and demonstrations.

Using this approach, scientists from WECAMAN member countries soon identified the technologies in high demand by maize farmers in their countries. For example, farmers in the northern fringes of the northern Guinea and Sudan savannas could not grow maize because early and extra-early varieties that would mature in the relatively short rainy season were not available. In addition, at about the time farmers in these areas are planting the new maize crop in June–July, most food reserves are depleted, leading to a period of low food supply, referred to as the *soudre* or hunger gap. WECAMAN scientists have developed early and extra-early maize varieties that have solved this problem and opened new frontiers for maize production. The early varieties are also planted by farmers in the forest zones, especially in peri-urban areas, to provide green maize before the main crop matures. With the availability of these varieties, green maize is now produced throughout the year in most countries in West and Central Africa (WCA), using hydromorphic soils or irrigation during the dry season.

Recurrent drought has been a major problem in the savannas as well as some parts of the forest zone. In addition to earliness and extra-earliness, which are drought-escaping mechanisms, WECAMAN scientists have developed drought tolerant varieties, especially for the savannas but also for the second season in the forest zone.

Farmers in the Guinea savanna urgently needed *Striga* tolerant varieties to combat the infestation by the parasitic weed that had compelled them to abandon their farms. The weed is particularly difficult to control because it attaches itself to the roots of the host plant and causes a lot of damage before it emerges from the soil.

Host-plant resistance has been found to be the most effective control method, with little or no cost to the farmer. Therefore, the strategy of the Network has been to develop *Striga* resistant varieties and hybrids. Introgression of sources of *Striga* resistance into existing early and extra-early maize populations and elite varieties has led to the development of varieties with moderate levels of resistance/tolerance to *Striga*. The populations are presently being further improved.

In addition to *Striga*, poor soil fertility has been one of the constraints to maize production in WCA. Generally, inorganic fertilizers are not easily available and, when available, are too expensive for most farmers. WECAMAN researchers have approached the problem in three ways: incorporation of legume–maize rotation into the farming system, development of improved cultural practices that more efficiently utilize the native soil fertility, and use of low-N tolerant varieties. Maize varieties and populations have been screened for low-N use efficiency. Improved cultural practices have been developed, including optimal plant populations and time of fertilizer application (top dressing) for increased yield of early and extra-early varieties, use of local sources of fertilizer and organic matter for soil improvement, appropriate number of maize rows to legume (e.g., groundnut) rows in maize–legume association and appropriate dates of planting in maize–legume intercrop. Maize–legume rotation has also been used to control *Striga,* improve soil fertility, and raise maize grain yield.

There is concern that an increase in maize production in WCA could lead to a glut in the marketing system that, in turn, would lead to lower prices, thereby making maize production less profitable and less attractive to farmers. There is a need to diversify maize utilization and marketing. Therefore, the Network has worked to develop appropriate linkages between NARS and producers, extension services, NGOs, and processors. As a first step, the Network has identified the marketing constraints and commissioned several studies on the maize marketing network and utilization in the subregion. Technologies for improved nutritional values of maize have been developed. Among these are varieties that produce better quality flour and Quality Protein Maize (QPM). Availability of these varieties has led to the development of new food products. For example, *baguettes* prepared from composite flour, consisting of 15% maize and 85% wheat, have been developed and widely adopted in Mali. Similar studies have been conducted in Cameroon and are reported in this volume. Couscous and semolina developed from QPM have also been widely accepted by Malian consumers. Furthermore, Malian scientists have developed maize syrup that is being produced commercially by a company called Foghass. Chadian scientists have prepared an infant formula from a composite flour of wheat and maize, and characterized four normal endosperm maize varieties, 95 TZEE-Y1, DMR ESR-Y, TZEE-W SR, and 97 TZEE-Y2C1, as suitable for the production of biscuits, *beignets*, pancakes, and doughnuts.

A workshop was organized at IITA–Cotonou, Bénin, in 2005, for presentations covering technology generation, transfer, adoption, and impact of the demand-driven technologies. These include the development of new varieties and agronomic practices, on-farm evaluation trials, economic analysis, and postharvest utilization. All the papers went through rigorous peer and editorial review processes, and are compiled in this volume.

We would like to express our appreciation to our main funding agency, USAID, and the executing agency, IITA. We are very grateful to CTA for providing the financial support for 10 scientists to participate in the workshop. We thank also the host country of the workshop, Bénin, and IITA–Cotonou for providing logistic support. Lastly, our sincere gratitude goes to all participants and to the following national and international scientists who reviewed the papers in this volume: R. Abaidoo (IITA-Nigeria), A. Agbo-Noameshie (ITRA, Togo), S.O. Ajala (IITA-Nigeria), A. Alene (IITA-Nigeria), P. Amaza (IITA-Nigeria), R.P. Aroga (IRAD, Cameroon), B. Badu-Apraku (IITA-Nigeria), D. Chikoye (IITA-Nigeria), O. Coulibaly (IITA-Bénin), J. Diels (Katholieke Universiteit, Belgium), M.A.B. Fakorede (OAU, Nigeria), A. Kamara (IITA-Nigeria), A.F. Lum (IITA-Nigeria), V.M. Manyong (IITA-Tanzania), K.A. Marfo (CRI, Ghana), A. Menkir (IITA-Nigeria), B. Nkamleu (IITA-Nigeria), S. Nokoe (UDS, Ghana), F. Nwilene (WARDA-Nigeria), M. Ouedraogo (OAU-STRC SAFGRAD, Burkina Faso), and A.O. Togun (UI, Nigeria).

Baffour Badu-Apraku
WECAMAN Coordinator

Préface

Le réseau de recherche collaborative sur le maïs en Afrique de l'ouest et du centre (WECAMAN) a été officiellement inauguré en 1987. Le Réseau a servi de mécanisme efficace à tous les acteurs intervenants dans la production et la productivité du maïs afin de combattre les contraintes régionales. Ceux-ci incluent les chercheurs internationaux et nationaux, les agents du développement, les agriculteurs, les technologues des semences, les industriels et responsables politiques. L'approche du WECAMAN a été unique pour la recherche et le développement du maïs. Les programmes nationaux de recherche qui sont plus solides que d'autres dans des domaines spécifiques sont identifiées et désignées centres leaders (CL). Les contraintes à la production du maïs sont identifiées de manière participative par tous les acteurs. Un comité de recherche Ad hoc analyse les propositions et affecte des fonds aux CL pour exécuter les projets de recherche afin d'éradiquer les contraintes. Les technologies émanant de la recherche conduite dans les CL sont rendues disponibles à d'autres pays membres à travers les tests et démonstrations en milieu paysan.

En utilisant cette approche, les chercheurs des pays membres du WECAMAN ont rapidement identifié les technologies dont la demande est forte auprès des producteurs de maïs dans leurs pays. Par exemple, les agriculteurs des zones de savane nord guinéenne et soudanaise ne pouvaient pas produire du maïs, car les variétés de maïs précoces et extra précoces, adaptées à une période de saison pluvieuse relativement courte, n'étaient pas disponibles. En outre, pour les agriculteurs de ces zones, lorsque vient le temps des semis de nouvelles cultures de maïs en Juin – Juillet, les réserves de nourriture sont réduites, conduisant à une période de faible disponibilité en nourriture, appelée période de soudure. Les chercheurs du WECAMAN ont développé des variétés de maïs précoces et extra précoces qui ont permis de résoudre ce problème et d'ouvrir de nouvelles frontières pour la production du maïs. Les variétés précoces sont aussi plantées par des agriculteurs des zones forestières, surtout dans les zones péries - urbaines, afin de fournir du maïs vert avant que la récolte principale ne soit mature. Avec la disponibilité de ces variétés, le maïs vert est maintenant produit pendant toute l'année dans la plupart des pays en Afrique de l'Ouest et du Centre (AOC), en utilisant des sols hydromorphiques ou l'irrigation pendant la saison sèche.

La recrudescence de la sécheresse a été un problème majeur aussi bien dans les savanes que dans certaines parties de la zone forestière. En plus de la précocité et l'extra précocité qui sont des mécanismes pour échapper la sécheresse, les chercheurs du WECAMAN ont développé des variétés tolérantes à la sécheresse, surtout pour les savanes, mais aussi pour la deuxième saison dans la zone forestière.

Les agriculteurs de la savane guinéenne requéraient rapidement des variétés tolérantes à *Striga* afin de combattre l'infestation par l'herbe parasite qui les avait obligé à abandonner leurs fermes. L'herbe parasite est particulièrement difficile à contrôler parce qu'il s'attache aux racines de la plante hôte et lui cause beaucoup de dommages avant d'émerger au dessus du sol. La résistance de la plante hôte a été identifiée comme étant la méthode de contrôle la plus efficace et qui engendre peu ou pas de coût à l'agriculteur. Donc, la stratégie du réseau a été de développer des variétés et hybrides résistants à *Striga*. L'introgression de sources de résistance à *Striga* dans des populations de maïs précoces et extra précoces et dans des variétés élites, a conduit au développement de variétés avec des niveaux modérés de résistance / tolérance à *Striga*. Les populations sont actuellement entrain d'être davantage améliorées.

En plus du *Striga,* la faible fertilité des sols a été une des contraintes à la production du maïs en AOC. Généralement, les engrais inorganiques ne sont pas aisément disponibles et, quand ils le sont, ils sont trop coûteux pour la plupart des agriculteurs. Les chercheurs du WECAMAN ont abordé le problème de trois manières: l'incorporation de la rotation maïs-légumineuse dans les systèmes de culture, le développement de pratiques culturales améliorées qui utilisent plus efficacement la fertilité native du sol, et l'utilisation de variétés tolérantes aux faibles taux d'N. Les variétés et populations de maïs ont été criblées pour l'efficacité à l'utilisation des faibles taux d'N. Des pratiques culturales améliorées ont été développées, incluant la densité de population optimale et le temps d'application de l'engrais (engrais de couverture) pour augmenter le rendement des variétés de maïs précoces et extra précoces, l'utilisation de sources locales d'engrais et de matière organique pour l'amélioration des sols, du nombre approprié de rangées de maïs par rapport aux rangées de légumineuses (ex. arachide) dans l'association maïs-légumineuse et les dates de semis appropriées dans les associations maïs-légumineuse. La rotation maïs-légumineuse a aussi été utilisée pour contrôler *Striga,* améliorer la fertilité des sols et augmenter le rendement grain du maïs.

Il y a des inquiétudes du fait qu'un accroissement de la production du maïs en AOC pourrait aboutir à une surabondance dans le système de commercialisation qui, en retour, conduirait à baisser les prix, et de ce fait, conduirait la production du maïs à être moins rentable et moins attrayante pour les agriculteurs. Il est donc nécessaire de diversifier l'utilisation et la commercialisation du maïs. Ainsi, le réseau a développé des liens appropriés entre les SNRA et les producteurs, les services de développement, les ONG, et les transformateurs. Dans un premier temps, le réseau a identifié les contraintes de commercialisation et a recommandé plusieurs études sur la commercialisation et l'utilisation en réseau dans la sous région. Les technologies d'amélioration des valeurs nutritionnelles du maïs ont été développées. Parmi celles-ci, il existe des variétés qui produisent de la farine de meilleure qualité et les variétés de maïs riche en protéines de qualité (MRP). La disponibilité de ces variétés a conduit au développement de nouveaux produits alimentaires. Par exemple, des baguettes préparées avec de la farine composite comprenant 15% de maïs et 85% de blé, ont été développées et largement adoptées au Mali. Des études similaires ont été conduites au Cameroun et sont rapportées dans ce volume. Du couscous et de la semoule faits avec du MRP ont aussi été largement acceptés par les consommateurs Maliens. De plus, les chercheurs Maliens ont développé un sirop à base de maïs qui est commercialement produit par une entreprise appelée 'Foghass'. Les chercheurs Tchadiens ont préparé une formule d'alimentation infantile à partir d'une farine composite de blé et de maïs et ont caractérisé quatre variétés de maïs à endosperme normale, 95 TZEE-Y1, DMR ESR - Y, TZEE - W SR, et 97 TZEE-Y2 C1, comme étant convenables pour la production de biscuits, beignets, crêpes, et des 'pets-de-nonne'.

Un atelier a été organisé à l'IITA-Cotonou, au Bénin en 2005, afin de présenter des exposés portant sur la génération de technologie, le transfert, l'adoption, et l'impact des technologies à la demande. Celles-ci incluent le développement de nouvelles variétés et de pratiques agronomiques, des tests d'évaluation en milieu paysan, l'analyse économique, et l'utilisation post récolte. Toutes les communications sont passées par un comité de lecture rigoureux et des procédés d'analyses éditoriales et sont compilés dans ce volume.

Nous voudrions exprimer notre appréciation à notre principale agence de financement, l'USAID, et l'agence d'exécution, l'IITA. Nous sommes très reconnaissants au CTA pour le financement de la participation de 10 chercheurs à l'atelier. Nous remercions aussi le pays hôte de l'atelier, le Bénin, et l'IITA-Cotonou pour avoir fourni le soutien logistique. Enfin, nous exprimons notre sincère gratitude à tous les participants et aux nombreux chercheurs internationaux et nationaux suivante qui ont révisé les articles de ce volume: R. Abaidoo (IITA-Nigeria), A. Agbo-Noameshie (ITRA, Togo), S.O. Ajala (IITA-Nigeria), A. Alene (IITA-Nigeria), P. Amaza (IITA-Nigeria), R.P. Aroga (IRAD, Cameroun), B. Badu-Apraku (IITA-Nigeria), D. Chikoye (IITA-Nigeria), O. Coulibaly (IITA-Bénin), J. Diels (Katholieke Universiteit, Belgium), M.A.B. Fakorede (OAU, Nigeria), A. Kamara (IITA-Nigeria), A.F. Lum (IITA-Nigeria), V.M. Manyong (IITA-Tanzania), K.A. Marfo (CRI, Ghana), A. Menkir (IITA-Nigeria), B. Nkamleu (IITA-Nigeria), S. Nokoe (UDS, Ghana), F. Nwilene (WARDA-Nigeria), M. Ouedraogo (OAU-STRC SAFGRAD, Burkina Faso), et A.O. Togun (UI, Nigeria).

Baffour Badu-Apraku
Coordonnateur du WECAMAN

Foreword

Maize (*Zea mays* L) is one of the most important staple crops in sub-Saharan Africa. Its role in the nutrition of the peoples of West and Central Africa (WCA) has increased tremendously during the last four decades. Consequently, research to improve the yield potential has been high in the agricultural agenda in the subregion, initially on an individual country basis. Unfortunately, most of the constraints to maize production were too formidable for individual countries to overcome. Because the constraints were crosscutting, there was an opportunity to pool the available resources to tackle the constraints and minimize duplication of efforts. One effective way to do this was to establish a maize research network for the subregion. The West and Central Africa Collaborative Maize Research Network (WECAMAN) was, therefore, inaugurated in 1987.

WECAMAN has been funded by the USAID since its inception to date. Between 1998 and 2001, UNDP and IFAD provided additional financial support for the execution of the Africa Maize Stress Project of the Network. The Nippon Foundation has, since 2002, provided additional financial support for the development and dissemination of Quality Protein Maize.

The major thrust of WECAMAN has been on the development of early and extra-early varieties and accompanying agronomic practices. The Network has been able to attract funds in phases and has had tremendous impact in developing and promoting the transfer of demand-driven technologies for maize farmers and end-users. A major breakthrough is the development of early and extra-early varieties for the marginal rainfall agroecological zones, such as the northern fringes of the northern Guinea savanna and the Sudan savanna, as well as the second season in the forest ecologies. Availability of these varieties has not only opened new frontiers for maize production but has also reduced the so-called "hunger gap" in the savannas. The rate of adoption of improved early and extra-early maize varieties in the savannas has gone far beyond the expectation of WECAMAN collaborators and has revolutionized maize production in WCA.

A major strategy has been to emphasize technology transfer and improve the research and development capacities of collaborators in all member countries. Over the years, nearly 50% of available collaborative research funds have been allocated to Technology Transfer and Community Seed Production. WECAMAN has organized workshops, training courses, consultation visits, visiting scientist schemes, and scientific monitoring tours to enhance the capacity of different cadres of research staff within the national agricultural research systems. Specifically, the Network has upgraded the skills of 174 national scientists and extensionists through training courses and workshops; 52 technicians have been trained in the technicians' course; five national scientists have benefited from the visiting scientist scheme. These are the secrets of the resounding success attained by the Network.

A workshop was held at IITA–Cotonou in 2005 to review achievements on the demand-driven research and development activities over the years, draw on the lessons learnt, highlight the challenges still ahead, and make recommendations for future research. The papers were peer-reviewed and edited, and are compiled herein under the title *Demand-driven technologies for sustainable maize production in West and Central Africa*. I encourage the reader to find from the pages that follow the many interesting discoveries made by the maize scientists.

Hartmann
Director-General, IITA

Avant propos

Le maïs (*Zea mays* L) est l'une des principales cultures de base les plus importantes en Afrique sub-Saharienne. Son rôle dans la nutrition des populations de l'Afrique de l'ouest et du central (AOC) a formidablement augmenté pendant les quatre dernières décennies. En conséquence, la recherche pour améliorer le potentiel de rendement tient une place importante dans les programmes agricoles de la sous région, initialement dans chaque pays. Malheureusement, la plupart des contraintes à la production du maïs étaient trop redoutables à surmonter par les pays individuellement. Puisse que les contraintes étaient similaires, il était possible de rassembler les ressources disponibles afin de surmonter les contraintes et minimiser la duplication des efforts. Une des voies les plus efficaces pour aboutir à cela a été de créer un réseau de recherche sur le maïs pour la sous région. Le réseau de recherche collaborative sur le maïs en Afrique de l'ouest et du Centre (WECAMAN) a donc été inauguré en 1987.

Le WECAMAN a été financé par l'USAID depuis sa création jusqu'à maintenant. Entre 1998 et 2001, le PNUD et l'IFAD ont apporté un appui financier supplémentaire pour l'exécution du projet de recherche sur les stress du maïs en Afrique (AMS), qui est un projet du réseau. La fondation Nippone a, depuis 2002, apporté un soutien financier supplémentaire pour le développement et la dissémination de variétés de maïs riches en protéines de qualité en AOC.

L'une des avancées majeures du WECAMAN a été le développement de variétés de maïs précoces et extra précoces et les pratiques agronomiques associées. Le réseau a été capable d'attirer des fonds pendant différentes phases et a eu des impacts extraordinaires sur le développement et la promotion de transfert de technologies liées à la demande en faveur des producteurs de maïs et des utilisateurs. Une percée majeure a été le développement de variétés de maïs précoces et extra précoces adaptées aux zones agro écologiques à précipitation marginale, telles que les franges du nord de la savane nord guinéenne et de la savane soudanaise, ainsi que la deuxième saison dans les écologies forestières. La disponibilité de ces variétés a non seulement permis l'ouverture de nouvelles frontières pour la production du maïs, mais a aussi contribué à réduire le phénomène appelé «période de soudure» dans les savanes. Le taux d'adoption des variétés de maïs améliorées, précoces et extra précoces en zone de savane est au-delà des attentes des collaborateurs du WECAMAN et cela a révolutionné la production du maïs en AOC.

Une stratégie majeure a été de soutenir le transfert de technologie et d'améliorer les capacités de recherche et de développement des collaborateurs dans tous les pays membres. Pendant des années, presque 50 % des fonds disponibles pour la recherche collaborative, ont été affectés au transfert de technologie et à la production communautaire des semences. Le WECAMAN a organisé des ateliers, des cours de formation, des visites de consultation, des schémas de visites de chercheurs et des voyages scientifiques afin d'améliorer la capacité des cadres de différents niveau du personnel de recherche des Systèmes Nationaux de Recherche Agricole (SNRA). Spécifiquement, le réseau a amélioré les connaissances de 174 chercheurs nationaux et les agents du développement à travers des ateliers et des cours de formation, 52 techniciens ont été formés lors des cours à leur attention, tandis que cinq chercheurs nationaux ont bénéficié du schéma de visite pour les chercheurs, institué par le WECAMAN. Ce sont les secrets de la réussite retentissante du réseau.

Un atelier s'est tenu à l'IITA-COTONOU en 2005 afin de réviser les acquis des activités de recherche et de développement conduites en fonction des demandes, pendant des années, d'échanger sur les leçons apprises, ressortir les défis à relever et faire des recommandations pour la recherche future. Les publications ont été révisées et rédigées, et sont compilés dans ce document sous le titre *´Technologies à la demande pour soutenir la production durable de maïs en Afrique de l'ouest et du centre´*. J'encourage le lecteur à trouver dans ces pages qui suivent les nombreuses découvertes intéressantes faites par les chercheurs travaillant sur le maïs.

Hartmann
Directeur Général, IITA

Fifth Biennial West and Central Africa
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Section 1

Breeding, Seed Systems and Statistics

A review of NARES–IARC–Donor collaboration to develop demand-driven technologies for improved maize production in West and Central Africa

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Abstract

Maize researchers in West and Central Africa (WCA) established the West and Central Africa Collaborative Maize Research Network (WECAMAN) in 1987 to tackle maize production constraints too formidable for individual national programs to overcome. The National Agricultural Research Systems (NARS) that were relatively strong for specific research areas were funded by the Network to generate improved technologies, which were evaluated in on-farm trials and adopted or adapted in other member countries of the Network. The Network allocated funds for research and other activities to member countries through competitive grants. USAID has been the major funding agency of WECAMAN since inception. In recent years, additional funding support came from IFAD and UNDP through the Africa Maize Stress Project, the Nippon Foundation QPM Project, and the HarvestPlus Challenge Program. The NARS of WCA provided research and development infrastructure, staff salaries, and logistics for research. International agricultural research centers, specifically, IITA and CIMMYT, have been providing the required source germplasm. IITA has been the executing agency of the Network since inception and has also provided advanced laboratory and other necessary research support facilities and experienced scientists for expert consultation, as necessary. The Network made major breakthroughs during the period under review by generating and transferring to farmers improved maize production technologies. Maize production increased in the traditional maize belts and was extended to new areas. Average productivity of maize increased by about 30% while total grain production in the region increased by nearly 400% during the two decades of WECAMAN's existence. Other benefits derived from the Network were improved research capacity of the NARS and capability of the research technicians and scientists, better research–extension–farmer linkage, improved research management and communication skills of the scientists and improved interpersonal relationships, with enhanced trust and confidence among maize scientists in the subregion. WECAMAN's success has resulted from the effective and efficient collaboration of the three major players, the NARS, IARCs, and donors.

Résumé

Les chercheurs travaillant sur le maïs en Afrique de l'Ouest et du Centre (AOC) se sont eux-mêmes regroupés en un réseau, dénommé Réseau de recherche collaborative sur le maïs en Afrique de l'Ouest et du Centre (WECAMAN), afin de combattre les contraintes de production du maïs, trop énormes à surmonter individuellement par les programmes nationaux. Les Systèmes Nationaux de Recherche Agricole (SNRA), qui étaient relativement plus outillés pour des sujets spécifiques de recherche, ont été financés par le réseau afin de générer des technologies améliorées qui étaient évaluées dans des tests en milieu paysan et adoptées ou adaptées dans tous les autres pays membres du réseau. Le réseau affectait des fonds pour la recherche et autres activités dans tous les pays membres à travers des subventions compétitives, qui étaient remarquablement distribuées uniformément entre tous les pays membres. L'USAID a été le principal bailleur de fond du WECAMAN depuis sa création. Au cours de ces dernières années, des fonds supplémentaires de soutien ont été reçus de l'IFAD et du PNUD à travers le Projet Stress pour l'Afrique (AMS), le projet QPM financé par la fondation Nipponne, et le Programme Challenge 'HarvestPlus'. Les SNRA de l'AOC ont fourni les infrastructures de développement et de recherche, les salaires du personnel et la logistique de recherche. Les centres internationaux de recherche agricole, spécifiquement l'IITA et le CIMMYT, ont fourni la source de germplasme nécessaire. L'IITA a été l'agence d'exécution du réseau depuis sa création et a aussi fourni les laboratoires équipés et autres infrastructures nécessaires au soutien de la recherche et des chercheurs expérimentés pour la consultation d'expertise lorsque le besoin survenait. Le réseau a obtenu des avancées majeures pendant la période concernée, en générant et en transférant aux agriculteurs les technologies de production améliorées sur le maïs. La production de maïs a augmenté de la ceinture traditionnelle de production à de nouvelles zones. La productivité moyenne du maïs a augmenté de près de 30% et la production grain totale de la région a augmenté de presque 400% pendant les deux décennies de l'existence du WECAMAN. D'autres bénéfices dérivés du réseau incluent l'amélioration de la capacité de recherche des SNRA et l'aptitude des chercheurs et techniciens de recherche, l'amélioration des liens recherche - extension - agriculteur, l'amélioration de la gestion de la recherche et des capacités de

communication des chercheurs et l'amélioration des rapports inter-individus, l'amélioration de la confiance entre les chercheurs travaillant sur le maïs dans la sous - région. La réussite du WECAMAN résulte de la collaboration effective et efficace de trois principaux acteurs, les SNRA, les IARCS et les bailleurs de fonds.

Introduction

Maize (*Zea mays* L.) is important in the human diet, livestock feed and some agro-allied industries in West and Central Africa (WCA). Grain yield of maize is seriously constrained by several abiotic and biotic factors, most of which are common to all countries in WCA. To effectively and efficiently tackle the constraints, the Semi-Arid Food Grain Development (SAFGRAD) Project comprising, among others, a maize network, was inaugurated for the countries of WCA in 1977. The maize component of SAFGRAD became autonomous in 1987 and was named West and Central Africa Collaborative Maize Research Network or WECAMAN. The ultimate goal of WECAMAN is to help improve the production and productivity of maize in WCA. For the nearly two decades of its existence, WECAMAN has consistently addressed this goal through several research and development activities in and by all participating countries.

WECAMAN's activities have involved three major partners: collaborating scientists from the National Agricultural Research and Extension Systems (NARES) of the participating countries; the International Agricultural Research Centers (IARC) that have been the facilitators, and donor agencies that have been providing funds for the activities.

NARES Collaborating Scientists

The NARES collaborating scientists are primarily those working in maize research and extension (technology transfer) in the participating countries. Their activities covered all aspects of maize research, breeding and seed production, agronomy and physiology, crop protection, agricultural economics, agricultural extension, postharvest handling, and maize utilization. Scientists who are employed in private industries as well as policymakers have also participated in some activities. Participation is open to all who are interested in maize research and development. There are no formal application forms for membership. Participation in some of the activities, such as collaborative research, is based purely on the submission of competitive research proposals. In some other aspects, such as training courses and workshops, member countries are invited to nominate a certain number of participants, usually on an equitable basis. Apart from research and development activities, management of the Network is completely handled by NARES collaborating scientists. This is done through a democratically elected Steering Committee, which is the policy making body of the Network. The number of WECAMAN member countries has changed over time. During the SAFGRAD era, all 17 WCA countries were members of the Maize Network. Because of funds limitation, membership was scaled down to the eight countries with the largest annual maize production, Bénin, Burkina Faso, Cameroon, Côte d'Ivoire, Ghana, Mali, Nigeria, and Togo. From 1999 to date, when additional funding has been available, Guinea, Senegal, and Tchad have been added.

IARC Facilitators

Two IARCs that have mandates for maize research and development activities, the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria and the International Maize and Wheat Improvement Center (CIMMYT), Mexico, have been active facilitators for WECAMAN. IITA has been the Executing Agency of WECAMAN since inception. In addition, the Institute has carried out the following responsibilities: provision of funds for the resident research of WECAMAN's Coordinator; provision of administrative and technical coordination; provision of technical reviews and technical backstopping; supply of useful germplasm to researchers; provision of consultants as necessary, and provision of accommodation for the Network and its activities; for example, hosting Steering Committee and Research Committee meetings. In short, IITA provides the necessary supervision for the Network. CIMMYT has also been a very important source of germplasm. During the time of the SAFGRAD Maize Network, CIMMYT collaborated with IITA by providing research scientists to assist the national scientists in WCA. The Institute also provides resource persons to WECAMAN, for example, at the Biennial Workshops held in IITA-Cotonou, Benin Republic. Both IITA and CIMMYT have been collaborating to execute the African Maize Stress (AMS) and the Nippon Foundation Quality Protein Maize (QPM) Projects. The two IARCs have provided indispensable leadership in conducting research on biotic and abiotic stresses in the subregion.

Donor Agencies

The United States Agency for International Development (USAID) has provided financial support for WECAMAN's activities since inception to date. Beginning in 1999, both the United Nations Development Project (UNDP) and the International Fund for Agricultural Development (IFAD) provided funds for the AMS Project, and in 2000, the Nippon Foundation (NF) made funds available for the QPM Project in the subregion. WECAMAN member countries executed both the AMS and the NF Projects in addition to the USAID-funded research and development projects.

Objectives

Several reports have been presented on the evaluation of the Network's progress towards achieving its goals through some of its activities, such as training (Badu-Apraku *et al*. 2004a), generation of new, sustainable technologies (Badu-Apraku *et al*. 2004c; 2004d; 2005), promotion of technology transfer (Badu-Apraku *et al*. 2004b), and overall impact on maize production in the individual member countries and the subregion as a whole (Fakorede *et al*. 2003). The objectives of the present study were to (i) review the performance of each partner over the 20-year period; (ii) summarize the achievements made thus far; and (iii) identify areas that need to be strengthened for further progress towards achieving the goals of the Network.

Network activities

Historical data on pertinent activities of WECAMAN since inception were retrieved from the archives and analyzed for the purpose of this study. Funds from USAID are made available for the research activities of the Network on an annual basis. Therefore, the Network annually sends out announcements to all collaborating countries for proposals on researchable project themes mapped in specific subjectmatter areas. To ensure objective allocation of research funds, the Network has set up an Adhoc Research Committee that screens research proposals, allocates funds to accepted proposals and later evaluates the progress reports of the approved projects. Funds allocated to research projects from 1993 to 2004 were summarized for each project theme per country and the total per year was computed.

The performance of each partner and the overall achievements of the Network during the 20-year period were evaluated in several ways, including (i) computation of performance indices (PI) of network collaborators each year, (ii) computation of trends in number of NARS participants and of papers they presented at the WECAMAN Biennial Workshops, (iii) quality of data from the Regional Uniform Variety Trials (RUVT) as indicated by the coefficient of variation (CV) for grain yield and (iv) trends in grain yield of varieties submitted to the RUVTs, commercial seed production, maize productivity and total production, and adoption rate of maize technologies developed by the Network.

Badu-Apraku *et al*. (2004b) has given a detailed description of the procedure used by the Network to generate PI data for individual member countries. For purposes of the present study, the PIs were plotted as bar graphs and regression analysis was used to determine the trends in mean PI of the progress reports of the research projects from 1994 to 2004.

The technical conferences organized by the Network are designated Biennial Regional Maize Workshops. The Workshops have provided a forum for scientists to acquire skills in communicating research findings to their peers. They are an invaluable means of motivating scientists towards professionalism as well as for promoting exchange of information, techniques, and technologies. Intending participants at the Workshop first submit abstracts of their papers. The abstracts are reviewed and screened by a panel of three scientists. Participants whose abstracts are selected are sponsored to the Workshop and are expected to submit the full papers, at the latest in the Workshop. After the Workshop, the papers are peer-reviewed and those accepted are published in the proceedings, subject to the authors having effected the reviewers' suggested modifications.

Since 1987, the Network has kept, among others, the records of participants and scientific papers presented at the Workshops. From the data, the proportion of NARS scientists that attended the Workshops and the number of technical papers relative to total number presented at the Workshop were computed from 1987 to 2001 and subjected to regression analysis (Badu-Apraku *et al*. 2003).

WECAMAN conducts two types of RUVTs. The two sets of trials are normally composed of drought tolerant varieties that mature in 90–95 (RUVT-Early) and 80–85 days (RUVT-Extra–early). Data obtained from RUVTs conducted from 1987 to 2002 were used to determine the relationship between CV and grain yield as well as trends in CV over the years. Similarly, grain yield data from the trials were plotted against years to determine the productivity trend over the years. Trends in the production of commercial seed in the Community Seed Production Scheme of the Network member countries from 1995 to 2001 were determined by linear, quadratic, or both models. Similarly, FAO data from 1980 to 2003 were regressed on the years to determine trends in maize productivity and production. The data were summarized for the individual member countries to obtain an indication of trends in the adoption of maize technologies developed by the Network.

Funding and expected outcomes

The proportion of the funds from USAID allocated to research and development projects varied among years; 1996, 2002, and 2003 had the largest amounts of about US $110, 000 each while 1993 had the smallest (Fig. 1).

Apart from the unusually small funding in 1993, at least US $70,000 was expended by the Network on maize research and development activities each year. Additional funding of collaborative research from the AMS and Nippon Foundation Projects is summarized in Fig. 2. Here also, about US $60,000 to $120,000 was allocated to research and development projects in the subregion each year. Thus a minimum of about $130,000 was available for maize research and development activities by Network members each year from 1999 to 2003.

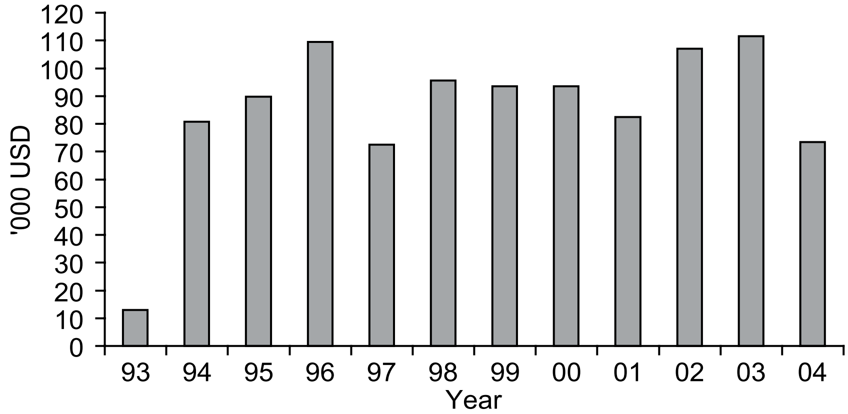

Figure 1. Funds allocated to collaborative research and development projects in the subregion, 1993–2004.

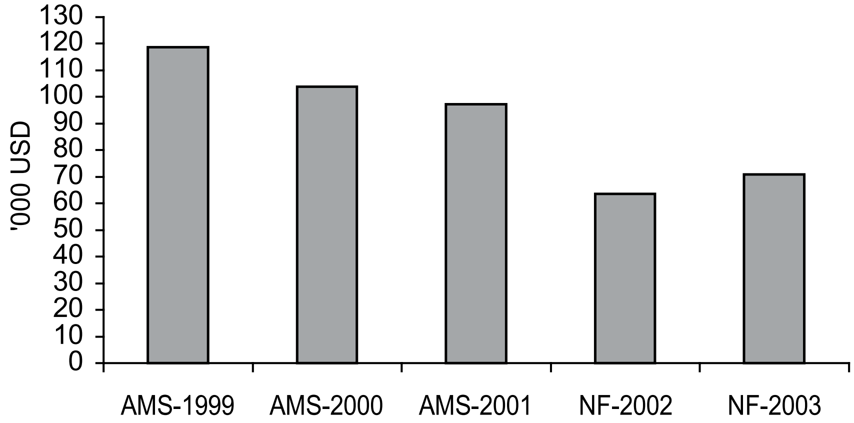

Figure 2. Funds allocated to collaborative research projects in WCA from the AMS (1999–2001) and NF (2002 and 2003) Projects.

Total funds received by the individual collaborating countries during the 12 years covered in this report are summarized in Figure 3. The eight countries that had been included in the Network since inception received about US $90,000 to $150,000 for research and development projects during the 12 years.

Funds were allocated to eleven research and development projects (Fig. 4). Technology Transfer (about 27%) and Community Seed Production (about 20%) received the largest proportion of the available funds. The more traditional technology-generating project areas, such as breeding, agronomy and *Striga* control, also received substantial proportions of the available funds. The more recent research areas, such as DNA markers, forage maize and maize for agro-industries, received the least.

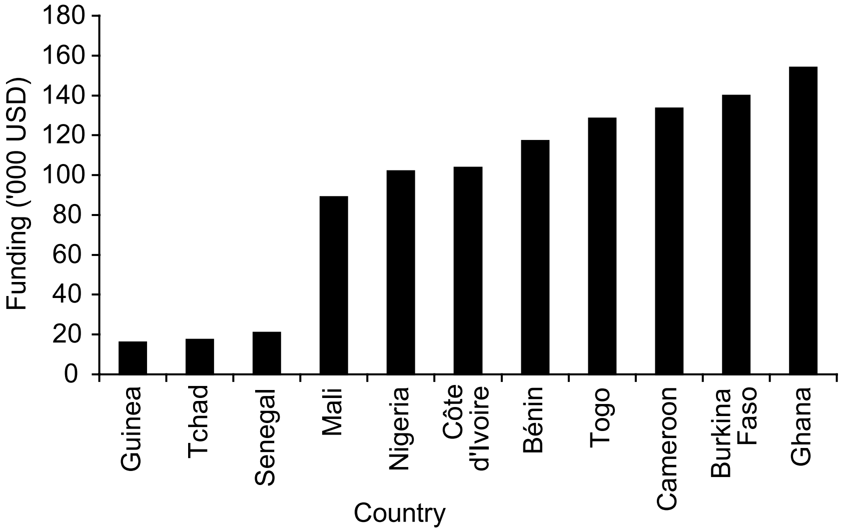

Figure 3. Funds received by individual countries for collaborative research and development projects, 1993–2004.

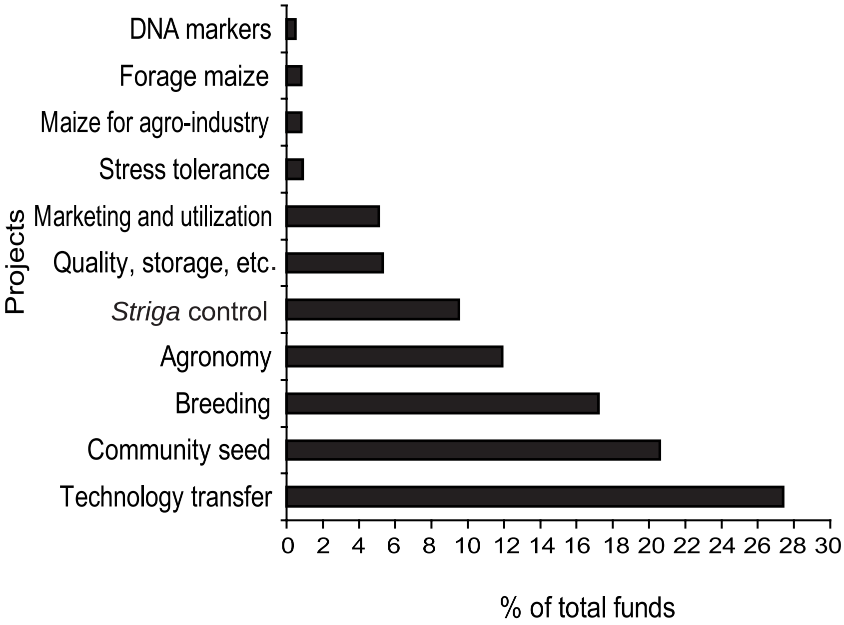

Figure 4. Percentage of collaborative research funds allocated to specific maize research and development projects in WCA, 1994–2004.

An overview of total funds allocated to the individual project themes for the eight countries that have consistently been Network members is presented in Table 1.

At varying rates, all countries received funds for Agronomic Research, Technology Transfer, and Community Seed Production projects. Most countries received funds for *Striga* control as well as Marketing and Utilization research. Only four countries were funded

Table 1. Total fund allocation ('000 US$) from 1994 to 2004 per project for eight WCA countries that have consistently been WECAMAN members from inception.

	Countries[1]							
Project theme	Bénin	BF	Cam	CI	GH	Mali	NG	Togo
Breeding	-	28.0	50.0	34.0	45.5	-	-	-
Agronomy	17.0	22.0	14.0	15.8	10.0	6.0	17.0	7.5
Tech.Transfer	28.6	31.0	12.5	32.0	23.0	37.0	46.0	40.5
Com. Seed Prod	27.5	27.5	25.5	16.5	22.5	25.5	15.0	29.0
Striga control	25.0	19.0	8.0	-	8.0	5.0	6.0	16.0
Marketing, Utilization	3.0	-	6.0	-	16.5	14.0	2.0	5.0
Quality, storage	-	-	7.5	-	23.0	-	-	18.0
Stress tolerance	4.0	-	-	-	2.0	-	2.0	-
Forage maize	-	-	-	-	-	-	7.0	-
Agro-industry maize	-	-	7.5	-	-	-	-	-
DNA markers	-	5.0	-	-	-	-	-	-

[1]BF=Burkina Faso, Cam=Cameroon, CI=Côte d'Ivoire, GH=Ghana, NG=Nigeria.

[2]- = No funds for the project in the country.

for Maize Breeding activities and three for Quality, Storage, and related research activities.

Based on fund allocation, new technologies and/or impact were expected from individual countries as follows:

Breeding – Primarily Cameroon and Ghana, but also Côte d'Ivoire and Burkina Faso.
Agronomy – All countries; fairly low in Ghana, Mali and Togo.
Technology Transfer – All countries; highest in Nigeria and Togo, low in Cameroon.
***Striga* control** – Primarily Bénin, Burkina Faso, Togo; low in other countries.
Community-based Seed Production – All countries; lowest in Nigeria and Côte d'Ivoire.
Marketing and Utilization – Ghana and Mali.
Quality, storage and related research – Ghana and Togo.

Research into forage maize, maize for agro-industry and DNA markers was considered to be at the infantile stage and, therefore, could not have generated any new technology or made noticeable impact at the time the present study was conducted.

For the Network as a whole, the following were the expected outcomes from the support received over the years:

i. Improved research management skills, which could be assessed through the quality of research proposals and reports submitted by the collaborators, attendance and presentation of scientific papers at conferences and workshops and the quality of data obtained from the RUVTs.

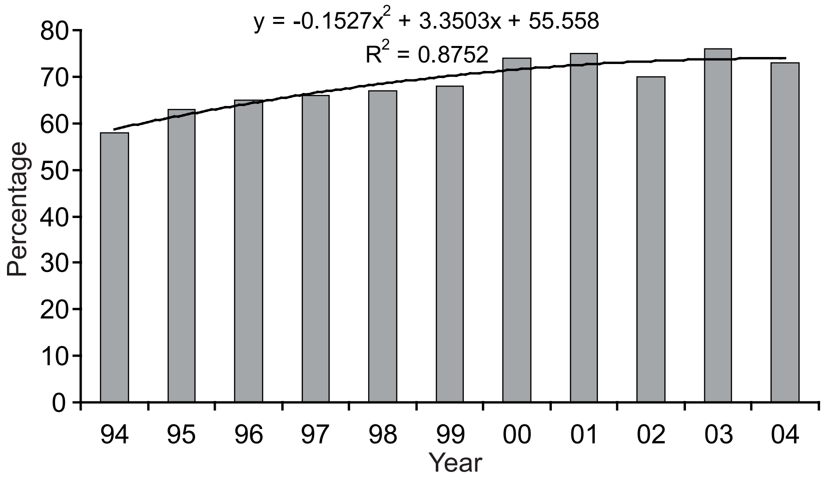

Figure 5. Performance indices (PI) on the research reports of WECAMAN collaborators, 1994–2004.

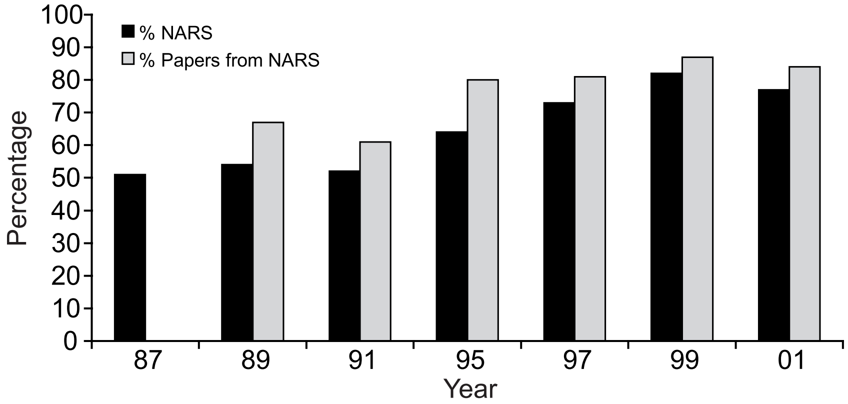

Figure 6. Proportion of participants and paper presentations at WECAMAN Biennial Workshops that are from NARS, 1987–2001.

ii. Production of high-quality maize seeds.
iii. Production of improved technologies.
iv. Improved productivity of the maize germplasm.
v. Increased maize production in the subregion.

Outcomes

Improved research management skills

Across all countries and research projects, PI increased from about 58% in 1994 when the ARC started using the new approach to assess progress reports, to about 76% in 2001 (Fig. 5). Although the linear model produced a good fit for the data (r^2=80%), the quadratic model improved the fit slightly more (R^2=87.5%). In 1987, no technical papers were presented at the Network's Biennial Workshop and only about 50% of the participants were NARS scientists (Fig. 6). The proportion of NARS participants remained about the same in the following two

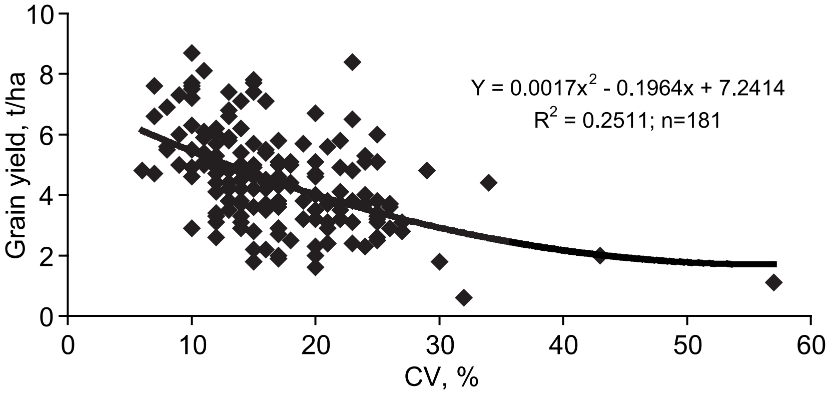

Figure 7. Relationship between grain yield and its CV for RUVT-early, 1987–2005.

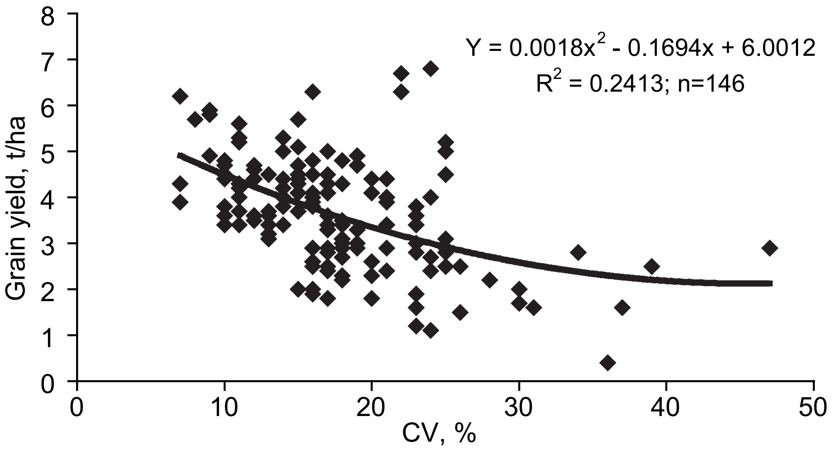

Figure 8. Relationship between grain yield and its CV for RUVT-extra early, 1987–2005.

Workshops, although 60–70% of the papers presented were technical reports. Beginning from the 1995 Workshop, the proportion of technical papers increased to 80% or more.

Similarly, from 1997 the proportion of NARS participants at the Workshop increased to 73% or more, with a peak of 82% in 1999. Linear regression analysis showed a 9% increase in the proportion of technical papers per additional Workshop with an r^2 value of 62.6%. Corresponding values for the proportion of NARS participants were 5% and 90.0%. The quadratic analysis produced a better fit (R^2=81.8%) for the proportion of technical papers at the Workshop, with a negative quadratic b-value (b= -0.694); a reflection of the peak observed in 1999 (Fig. 6).

For the two sets of RUVTs conducted by the Network, the CV had a curvilinear negative relationship with grain yield, with R^2 values of about 24–25% (Figs. 7 and 8), which were significant at P<0.01. Over the years, the CV for grain yield of the RUVTs did not show a definite

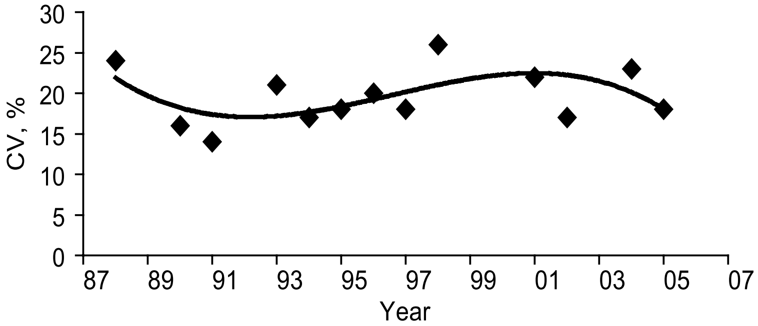

Figure 9. Coefficient of variation for grain yield in RUVT-early, 1988–2005.

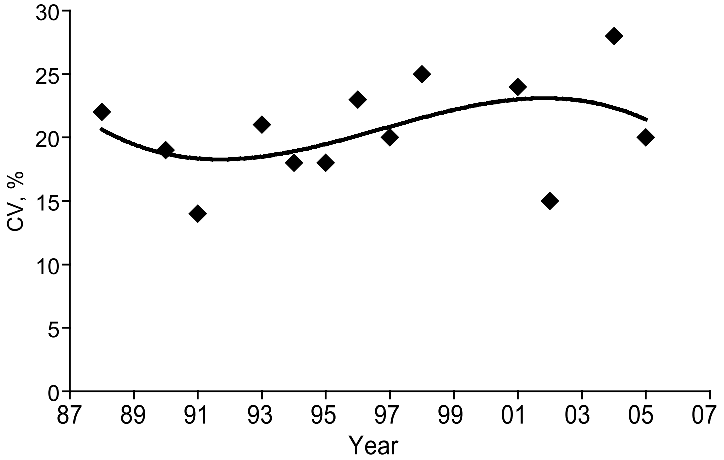

Figure 10. Coeficient of variation for RUVT-extra early, 1988–2005.

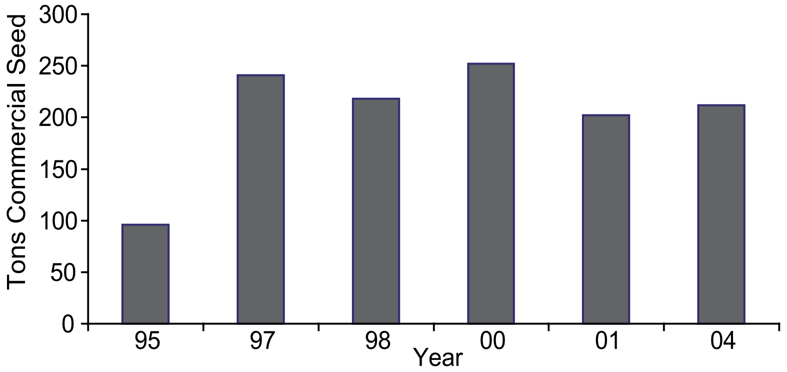

Figure 11. Commercial maize seed production in the Community Seed Production Scheme of WECAMAN member countries, 1995–2004.

trend (Figs. 9 and 10). Cubic regression models produced the best fit, with R^2 values of only 48 and 56%.

Production of high-quality maize seed

Total commercial maize seed production under the Community Seed Production Scheme ranged from about 100 t in 1995 to over 250 t in 2004 (Fig. 11). During the 11-year period analyzed in this study, commercial seed production increased linearly at the rate of about 220 t/year, with r^2 value of 99% (Fig. 12).

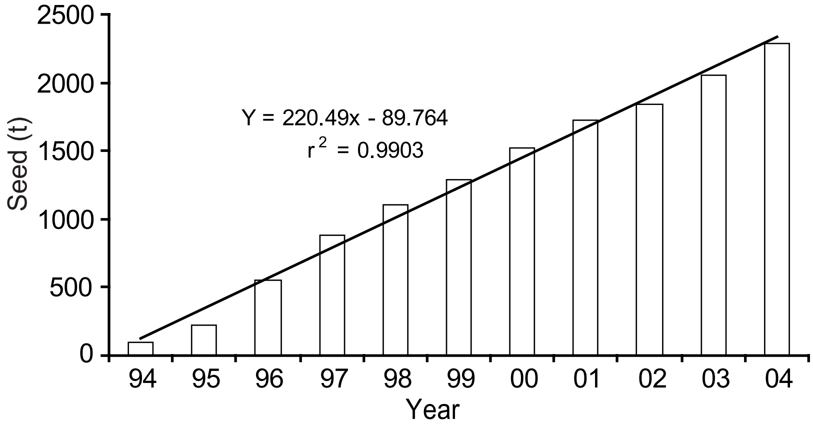

Figure 12. Cumulative certified seed produced from WECAMAN's Community Seed Production Project, 1994–2004.

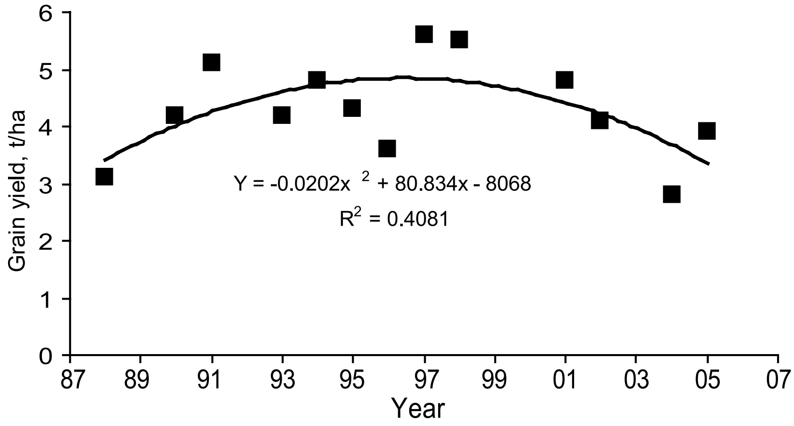

Figure 13. Mean grain yield of RUVT-early,1988–2005.

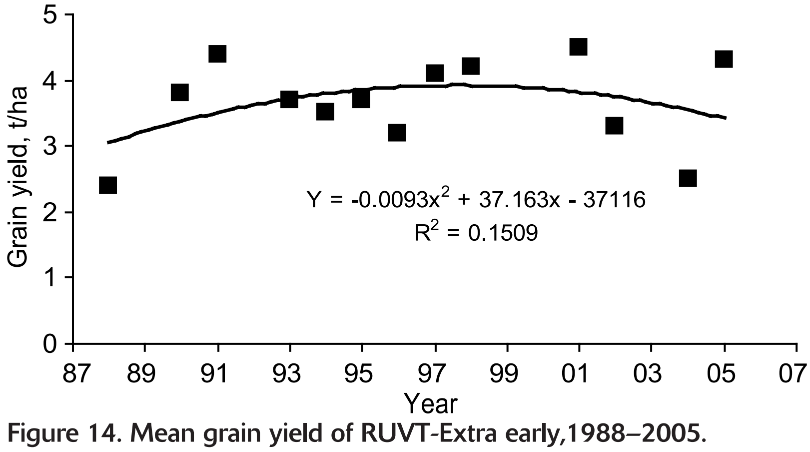

Figure 14. Mean grain yield of RUVT-Extra early,1988–2005.

Improved maize productivity and production

Mean grain yield in the two RUVTs showed curvilinear response when regressed on coded years as the independent variable, with R^2 values of 41% and 15% (Figs 13 and 14).

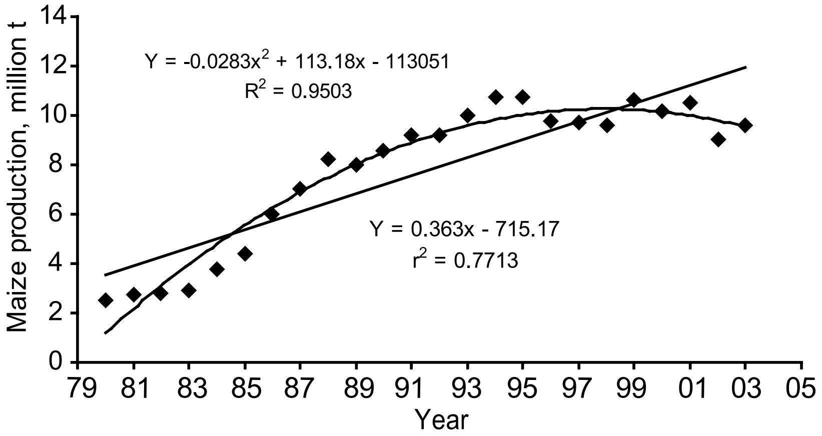

Figure 15. **Total maize grain production (million t) in WCA countries, 1980–2003 (FAO data, 2004).**

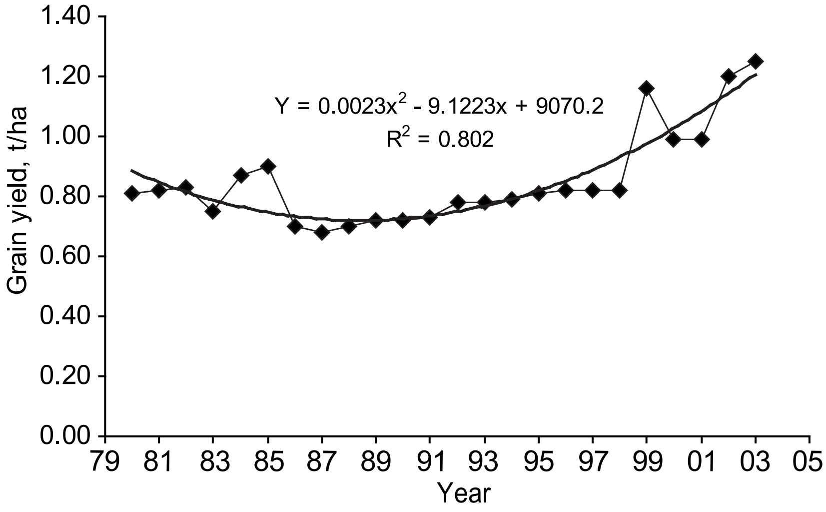

Figure 16. **Grain yield per unit land area in WCA from 1980 to 2003 (FAO data, 2004).**

For the subregion as a whole, total maize grain production increased from about 2.5 million t in 1980 to a peak of about 11 million t in 1994–1995 and remained at about 10–11 million t thereafter (Fig. 15). Linear regression of the production data on years showed an estimated increase of 0.36 million t/year (r^2=77.1%). A quadratic regression model, however, produced a better fit to the grain production data, with R^2 value of 95%.

According to the FAO data summarized in Fig. 16, the productivity of maize varieties in the fields of WCA farmers was below 1 t/ha from 1980 until about 1999 when it rose to 1.2 t/ha and has remained thereabouts since then.

A quadratic regression model produced a good fit to the data, with R^2 value of about 80% (Fig. 16). The quadratic b-value was positive thus indicating that the grain yield improvement in the later part of the period under study was larger than that for the earlier years.

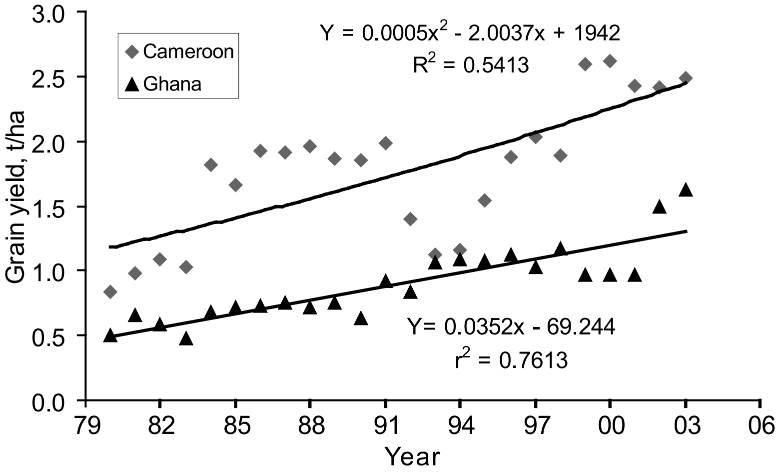

Figure 17. Grain yield/unit land area from 1980 to 2003 in two WECAMAN Lead Centers for maize breeding.

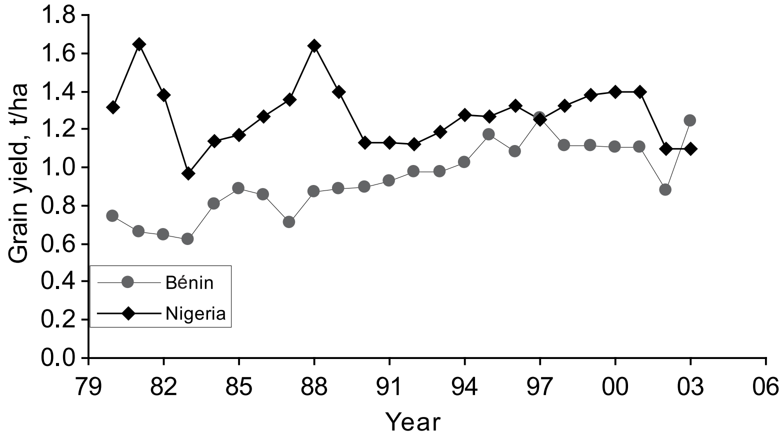

Figure 18. Grain yield/unit land area from 1980 to 2003 in two WECAMAN non- Lead Centers for maize breeding.

Productivity of the maize varieties in the subregion varied among individual member countries. Yield/unit land area increased in Lead Centers (Fig. 17) more than in non-lead Centers (Fig. 18) for plant breeding.

For example, while grain yield increased annually in Ghana at the rate of about 35 kg/ha (r^2=76%) and in Bénin at about 22 kg/ha (r^2=76%), (Fig. 17), the trend was less definite in Nigeria (r^2<2%, Fig. 18). Although the linear increase for Cameroon was quite large (55 kg/ha per annum, r^2=53%), the quadratic model showed positive quadratic b-value (Fig. 17). Increases in total annual grain production also varied among the countries, ranging from about 0.012 million t for Ghana to 0.276 million t for Nigeria (data not shown).

Production of improved technologies

Improved technologies developed by the network that have contributed immensely to its impact and some key activities have been summarized in Tables 2–4. The impact has resulted largely from the

Table 2. Capacity Building of NARS of WCA, 1994–2004.

Course Title	Year	Duration	Participants
Technicians' training course (4 courses)	1994–2001	5 months	52
Seed Production	1995	2 weeks	27
Striga control and technology transfer	1995	2 weeks	8
Preparation of extension materials	1996	1 week	15
Advanced Statistical Computing	1996	2 weeks	17
Farmer participatory methods for on-farm testing	1998	2 weeks	11
Impact assessment workshop	1998	2 weeks	6
Workshop on maize quality, processing and utilization	1998	2 weeks	13
Breeding for stress tolerance in maize	1999	1 week	13
Striga resistance breeding and marker assisted selection in cereals	1999	1 week	10
Advanced statistical computing for breeders and agronomists	2000	2 weeks	14
Impact assessment of maize stress management technologies	2000	2 weeks	9
Travel workshop	2001	1 week	15
Biotechnology workshop in maize	2002	1 week	11
Workshop on QPM development and seed delivery system	2003	2 weeks	32
Laboratory training workshop on Tryptophan analysis	2004	1 week	14
Total			267

Table 3. Participants of the WECAMAN Monitoring Tours, 1989–2000.

Year	Countries visited	Participants
1989	Ghana, Burkina Faso	7
1991	Nigeria, Cameroon	7
1994	Côte d'Ivoire, Mali	11
1996	Ghana, Burkina Faso	9
1998	Bénin, Togo	14
2000	Nigeria, Cameroon	15
Total		62

enhanced research capacity and capability of the 11 NARS through training courses and workshops (Table 2); scientific monitoring tours (Table 3) and several consultation visits which have served as fora for interaction among the participating national scientists with respect to maize research, extension, and production; Visiting Scientist Program; release of improved varieties and agronomic practices (Table 4); information and maize germplasm exchange among scientists (Table 4) and improved interpersonal, inter-institutional, and intercountry relationships, along with enhanced trust and confidence among the maize scientists of WCA.

Table 4. Maize varieties transferred across countries and research systems through networking, 1994–2005.

Improved varieties	Countries adopting varietites	Source of varieties
DMR-ESR-Y	Cameroon, Mali, Chad, Guinea, Togo	IITA
DMR-ESR-W	Bénin, Côte d'Ivoire, Cameroon	IITA
Pool 16 DT	Cameroon, Bénin, Togo, Ghana, Côte d'Ivoire, Senegal, Tchad, Burkina Faso	WECAMAN / IITA/ CIMMYT
EV DT 97 STRC$_1$	Bénin, Togo,and Chad	IITA-WECAMAN
ACR 94 TZE COMP 5-W	Nigeria, Côte d'Ivoire, Mali	IITA
Obantapa	Cameroon, Bénin, Togo, Ghana, Côte d'Ivoire, Senegal, Tchad, Burkina Faso, Nigeria, Mali, Guinea, Zimbabwe, Swaziland, Ethiopia, Mozambique.	Ghana
TZESR-W x Gua 314	Togo, Côte d'Ivoire, Nigeria	IITA-WECAMAN
DMR-ESR-W QPM	Côte d'Ivoire, Togo.	
95 TZEE-Y$_1$	Nigeria, Senegal, Togo, Tchad	IITA-WECAMAN
95 TZEE-W$_1$	Nigeria, Senegal, Togo	IITA-WECAMAN
99 TZEE-Y STR C$_0$	Nigeria, Bénin, Togo	IITA-WECAMAN
2000 Syn EE-W	Bénin, Nigeria	IITA-WECAMAN

Improved cultural practices exchanged among WECAMAN countries through networking, 1994–2005.

Cultural practice	Country adopting technology	Source of technology
1. Increased plant population for higher grain yield of early and extra-early varieties	Ghana, Bénin Togo, Cameroon, Burkina Faso, Nigeria, Mali, Côte d'Ivoire, Senegal.	Cameroon Nigeria Bénin
2. Earlier date of fertilizer application (top dressing) for increased yield of early and extra-early varieties	Bénin, Togo, Burkina Faso, Ghana, Cameroon, Senegal, Nigeria, Mali,	Cameroon Bénin
3. Use of maize–legume rotation for improved soil fertility and/or *Striga* control and maize grain yield	Bénin, Ghana, Cameroon, Mali, Burkina Faso, Nigeria, Togo	Bénin, Ghana Cameroon

Discussion

Results of the analyses carried out in this study clearly demonstrate that the network approach was effective in tackling the formidable constraints of maize production in the subregion of WCA. WECAMAN has three key partners: the donor agencies, the NARS collaborators, and the IARCs which served as the facilitators. One of the objectives of the present study was to evaluate the performance of each partner over the 20-year period of existence of the Network. Although the funds made available for network activities fluctuated over the years, they were released faithfully and promptly by the donors and distributed appropriately by the Steering Committee through the Network Coordinator. It is often said, "Who pays the piper dictates the tune." This does not seem applicable in the case of WECAMAN activities. The donors gave the Network a free hand to conduct research on the identified constraints of maize production in the subregion. This is highly commendable, and is perhaps one of the factors that contributed to the success of the Network.

The analyses presented herein also showed clearly that the NARS collaborators worked hard to make WECAMAN achieve much of the purpose for which it was put in place. Although initially, USAID was the only donor agency, UNDP and IFAD provided additional funding through the Africa Maize Stress (AMS) Project to combat some specific constraints to maize production in the subregion. Specifically, the project's goal was to develop resistance or tolerance to *Striga,* low soil N, drought, and stem borers. In addition, Nippon Foundation has been funding the Quality Protein Maize (QPM) Project in the subregion. With the addition of the AMS and QPM projects, WECAMAN expanded the coverage of its activities from 8 to 11 countries and from the Guinea savanna to all agroecologies in the countries.

As noted in earlier reports, the Network developed and transferred to farmers many technologies that have contributed greatly to the maize revolution in the subregion. Among these are early and extra-early maturing varieties that have made the cultivation of maize possible in ecologies traditionally thought to be unsuitable. Availability of these varieties has greatly facilitated the production of green maize throughout the year in most ecological zones of WCA countries. Earliness and extra-earliness are a drought-escaping mechanism that is effective only if terminal drought occurs towards the end of the season. Unfortunately, the recurrent droughts of WCA are unpredictable and are, therefore, best tackled with drought tolerant varieties. *Striga* is a major constraint in much of the savannas while low soil-N and stem borers are major constraints in most ecologies. The AMS project provided funds to develop screening sites for resistance or tolerance to all of these constraints, thus facilitating the creation of working groups to better solve breeding problems and generate new, improved technologies. The Network has developed several drought tolerant varieties for the savannas as well as the second season in the forest ecology. In many cases, the drought-tolerant varieties are also tolerant of *Striga* and low soil-N as well as resistant to most of the prevailing maize diseases in the subregion. In addition to developing low-N tolerant varieties, WECAMAN's collaborating scientists have approached the problem of non-availability/high cost of inorganic fertilizers in two other ways: incorporation of legume–maize rotation into the farming system and development of improved cultural practices that more efficiently utilize the native soil fertility. Maize–legume rotation has also been used to control *Striga,* improve soil fertility, and raise maize grain yield. Stem borer resistant varieties and complementary management practices have been developed and placed at the disposal of farmers in areas where the pest and soil acidity are prevalent, especially in Cameroon and southeast Nigeria.

Technology transfer has been of top priority to the Network. To facilitate this aspect of its mandate, WECAMAN funded community-based seed production of improved varieties. During the period covered by the analysis presented herein, a total of well over 2000 t of commercial seed was made available to maize farmers in WCA through the community seed production project. With the availability of high quality seed, it was possible to rapidly transfer the stress tolerant, early/extra-early, and QPM varieties to farmers in the savanna ecologies of the subregion (Gyasi *et al.* 2003; Onyibe *et al.* 2003; Sallah *et al.* 2003).

It is pertinent to note here that technologies developed by WECAMAN have been primarily demand-driven. The Network's member countries realized that, to stimulate production, there was an urgent need to diversify maize utilization and marketing. Therefore, the Network established appropriate linkages between NARS and producers, extension services, NGOs, and processors. Marketing constraints were identified and studies on the maize marketing network and utilization in the subregion were commissioned. Technologies for improved nutritional values of maize have been developed, and the availability of QPM varieties has led to the development of new food products. Consumers in Cameroon, Chad, Ghana, Mali, and Nigeria are finding new uses for maize (QPM and normal endosperm varieties). All of this together has stimulated maize production in the subregion, leading to an unprecedented rate of adoption of available production technologies.

The third objective of this study was to identify areas that need to be strengthened for further progress toward achieving the goals of the Network. One such area is the estimation of total grain production as well as grain yield per unit land area in the subregion. Results presented herein on these aspects would seem to suggest that the Lead Country Concept was not effective. For example, Cameroon and Ghana were lead countries in breeding while Nigeria was a lead country in technology transfer. Yield/ha clearly showed an improvement in Cameroon and Ghana, but not in Nigeria. On the contrary, annual gain in total production in Nigeria was outstandingly larger than in all other countries put together (0.276 vs 0.239 million tons). Whereas the annual rate of increase in land area under maize was 0.001 and 0.006 million ha in Cameroon and Ghana, it was 0.207 million ha in Nigeria (see Fakorede *et al.* 2003). These results would seem to give the misleading impression that technologies developed in the lead countries were adopted more in such countries than in others. It is common knowledge that the technologies developed in lead countries were tested on-farm in all other countries and many such technologies were widely adopted in the other countries (see Table 4). Closely related to this is the problem of the relatively low yield/ha reported for the subregion. Although the increasing trend in total grain production in the subregion is encouraging, the trend in yield/ha is discouragingly low. Data analyzed for these two factors are only estimates obtained by FAO in the subregion but these are the presently available estimates. However, the results presented herein for the relation between CV and grain yield suggest an urgent need for collaborators to refine their experimental techniques. Greater attention should be paid to land preparation, planting, weed control, fertilizer application, and data collection.

The IARCS and the donor agencies also derived some benefits from the activities of the Network. Duplication of research efforts, especially in the face of dwindling financial resrouces, has been greatly reducted through networking with NARES. WECAMAN member countries have collaborated very actively with both IITA and CIMMYT in conducting evaluation trials of promising varieties and breeding materials such as progeny trials from which experimental varieties are developed. Indeed, some of these varieties are named after the NARS site from which their parent materials were selected. Identification of fairly strong NARS, which have been designated lead centers, along with availability of screening sites for specific abiotic and biotic stresses has greatly facilitated IARCs' efforts for breeding for stress tolerance. *Striga*, low soil-N, and stem borers are endemic in certain locations so that escapes are hardly possible when screening maize germplasm for resistance to the stress factors in such locations. IARCs not only have access to these facilities but also have devolved some of the breeding activities on competent NARS partners to allow the international scientists to concentrate on some more basic research that requires relatively more advanced laboratories. In addition, IARCs have trained NARS partners to finalize specific technologies as most appropriate to their specific situations. For example, inbred lines are developed at IITA and made available to NARS partners who develop open-pollinated (synthetic) varieties or hybrids as best suited to their countries.

WECAMAN has provided an overall framework and greatly facilitated the implementation of projects targeted to West and Central Africa. Two examples are the AMS and NF projects which have been executed by member countries of WECMAN and administered in the same manner as the USAID-funded projects of WECAMAN.

The success of WECAMAN, including the AMS and NF projects, is not only in technology generation but also in technology transfer, which actually was given a high priority over the years. This has led to increased maize production, improved food security, and a positive move toward poverty alleviation in the subregion, thus achieving to a large extent, the goal of donors in funding the activities of the Network. Herein lies the benefit of the Network to the donors; that is, the assurance that the funds they have provided have been judiciously utilized to achieve the desired goal of food security and poverty alleviation in the countries of WCA.

To conclude, WECAMAN has been a good example of how collaboration among NARES, IARCs, and donor agencies can successfully overcome cross-cutting constraints in crop production in WCA. As reported by Badu-Apraku *et al.* (2005), for the collaboration among NARES, IARCs and donor agencies to have the desired impact, each stakeholder should focus on what it can do best. The IARCs should concentrate on research that NARES do not have the comparative advantage to implement, provide backstopping to NARES, and facilitate the exchange of germplasm and other technologies between NARES; participating NARES should focus on research in which they have capabilities as well as on the rapid transfer of proven new technologies; and donors and national governments should provide sustained funding support.

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Recent advances in breeding for *Striga* resistant extra-early maize for the savannas of West and Central Africa

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Abstract

Striga hermonthica is a major constraint to increased maize production and productivity in the savannas of West and Central Africa (WCA). The IITA-WECAMAN Maize Program has developed two extra-early source populations and several extra-early varieties, synthetics and inbred lines with resistance/tolerance to drought and/or *S. hermonthica*. Eleven extra-early maturing varieties were evaluated at Ferkessédougou, Abuja and Mokwa in 2002 and at Mokwa and Abuja in 2004 under artificial *Striga* infestation and *Striga*-free conditions. In another trial conducted at Mokwa and Abuja in 2004, 36 extra-early maturing inbred lines were evaluated under *Striga* infestation and *Striga*-free conditions. Significant differences occurred among the varieties for grain yield under both infested and *Striga*-free conditions. Several promising *Striga* resistant extra-early maturing varieties (2000 Syn EE-W, 99 Syn EE-W and Sine TZEE-W STR) were identified based on grain yield, *Striga* damage ratings and *Striga* emergence counts. Cluster analysis of the extra-early inbred lines, based on the similarity of quantitative characters, produced four and six major clusters under *Striga*-infested and *Striga*-free conditions, respectively. The extra-early inbred lines assigned to each cluster under *Striga* infestation were different from those of the corresponding clusters of the *Striga*-free conditions. Superior specific hybrid combinations could be obtained by crossing inbred lines of different clusters rather than matings within clusters and by selecting parents with high grain yield and low *Striga* damage symptoms. Several promising extra-early maturing inbred lines were identified as sources of *Striga* resistance for the development of synthetic varieties and populations.

Résumé

Striga hermonthica est une contrainte majeure à l'augmentation de la production et de la productivité du maïs dans les savanes d'Afrique de l'ouest et du Centre (AOC). Deux populations sources de maturité précoce et deux autres de maturité extra-précoce, des synthétiques et des lignées dotées de résistance/tolérance à la sécheresse et/ou à *S. hermonthica* ont été développées par le programme maïs IITA-WECAMAN. Onze variétés de maïs extra-précoces ont été chacune évaluée à Ferkessédougou, Abuja et à Mokwa en 2002 et à Mokwa et Abuja en 2004 sous infestation artificielle de *Striga* et sous condition de non-infestation de *Striga*. Dans deux autres essais conduits à Mokwa et à Abuja en 2004, 36 lignées extra-précoces ont été chacune évaluées sous infestation artificielle de *Striga* et sous conditions de non-infestation de *Striga*. Des différences significatives ont été obtenues entre les variétés pour le rendement grain sous les deux conditions d'infestation artificielle de *Striga* et de non-infestation de *Striga*. Plusieurs variétés prometteuses résistantes à *Striga*, extra-précoces (2000 Syn EE-W, 99 Syn EE-W et Sine TZEE-W STR) ont été identifiées sur la base du rendement grain, des évaluations des dommages dus à *Striga* et du nombre de plants de *Striga* émergés. L'analyse multivariée des lignées extra-précoces sur la base des similarités des caractères quantitatifs, a produit quatre groupes majeurs sous les conditions d'infestation artificielle et six groupes majeurs sous les conditions de non-infestation de *Striga*. Cependant, les lignées extra-précoces attribuées à chaque groupe sous infestation de *Striga*, étaient différentes de celles des conditions de non-infestation de *Striga*. Des combinaisons d'hybrides spécifiques de qualité supérieur pourraient être obtenus en croisant des lignées de groupes différents au lieu de croiser des individus du même groupe et en sélectionnant des parents avec un haut rendement grain et peu de dommage de *Striga*. Plusieurs lignées prometteuses extra-précoces ont été identifiées comme sources de résistance à *Striga* et pourraient être utilisées pour le développement de populations et de variétés synthétiques.

Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops in West and Central Africa (WCA). Maize production in WCA has increased from 2.7 t in 1980 to 10.5 million t in 2001 and is becoming increasingly important in the savanna ecology due to the high incident solar radiation, lower disease and pest incidence, and the availability of early and extra-early maize varieties. These have allowed production to expand into the northern fringes of the northern Guinea savanna and the Sudan savanna where low rainfall and recurrent drought had hitherto precluded maize cultivation. The early and extra-early maize can be harvested early in the season when sorghum and millet are not ready, and are thus used to fill the hunger gap in July in the savanna zone when all food reserves are depleted after the long dry period (IITA 1992).

Despite the high potential of maize in the savanna ecology, maize production and productivity in this zone are constrained by several major biotic and abiotic factors prominent among which are the parasitic weed, *Striga hermonthica* (Del.) Benth, drought, and declining fertility of the soils.

Striga hermonthica constitutes a major constraint to the rapid spread and hence to increased maize production and productivity in the savannas of WCA. The levels of infestation are often so high that maize can suffer 100% yield loss and farmers may be compelled to abandon their fields. Annual yield losses due to *Striga* species in the savanna ecology are estimated to be US $7 billion and threaten the livelihoods of over 100 million African people (M'Boob 1986).

Host plant resistance is considered the most practical and effective means for the control of damage caused by *Striga* (Parkinson *et al.* 1989; Kim, 1991; 1994). A *Striga* breeding program was therefore initiated in Côte d'Ivoire in 1994 through funding support of the International Institute of Tropical Agriculture (IITA) and West and Central Africa Collaborative Maize Research Network (WECAMAN) to combat the threat posed by *S. hermonthica* to the rapid spread of maize into the savannas. The objective of the program is to develop maize populations, varieties and inbred lines that combine earliness with resistance to *S. hermonthica.* Using inbreeding, backcrossing, hybridization and recurrent selection methods, two extra-early source populations and several extra-early varieties and inbred lines with resistance/tolerance to *Striga* and the major important diseases in WCA have been developed in the IITA-WECAMAN program. Badu-Apraku *et al.* (1999) reported earlier advances in the breeding program. However, information is lacking on the performance of the recently developed *Striga* resistant/tolerant varieties, synthetics and inbred lines, and on the advances made in the recurrent selection program involving the two extra-early source populations. Furthermore, there is a need to classify the extra-early *Striga* resistant/tolerant inbred lines in the breeding program into appropriate heterotic groups in order to maximize their use. The objectives of this paper were to (1) present an overview of the strategy and recent progress in developing *Striga* resistant extra-early maturing maize populations, varieties and inbred lines, (2) report on the performance of extra-early maturing maize varieties and inbred lines evaluated for *Striga* resistance, and (3) assess genetic diversity in the *Striga* resistant extra-early maturing inbred lines using UPGMA cluster analysis in an effort to select parental inbreds for the development of heterotic populations and for introgression of desirable genes from the inbred lines into elite populations.

Overview of the strategy for developing *Striga* resistant extra-early maturing maize

A major emphasis of the IITA-WECAMAN maize-breeding program has been on the development of extra-early drought and *Striga* resistant/tolerant populations using adapted and exotic germplasm identified through several years of extensive testing in WCA. In addition, *Striga* resistance/tolerance genes have been introgressed into extra-early maize populations and varieties using the STR inbred lines from IITA (9030 STR, 1368 STR, and 9450 STR) and CIMMYT (Pop 22 STR) as the resistance sources. Recurrent selection, backcrossing, inbreeding and hybridization methods have all been successfully used in the breeding program to increase the frequency of favorable alleles for resistance to *Striga*. In this paper, tolerance is defined as the ability of the host plant to withstand the effects of the parasitic plants that are already attached. On the other hand, resistance refers to the ability of the host plant to prevent the attachment of the parasite to its roots, or kill the attached parasite thus resulting in reduced *Striga* emergence (Kim 1994; Badu-Apraku *et al*. 2006). During the early stages of the breeding program, the emphasis was on the selection for tolerance, which allowed the pathogen to reproduce, thus increasing the buildup of the *Striga* seed bank in the soil. Since 1999, the emphasis has been on the selection for reduced *Striga* emergence and several inbred lines, which combine reduced *Striga* emergence counts and high grain yield, have been developed. Introgression of the sources of *Striga* resistance into existing extra-early maize populations and elite varieties, and the use of recurrent selection methods for improvement have led to the development of two extra-early *Striga* resistant populations. These are TZEE-W Pop STR (extra-early white endosperm) and TZEE-Y Pop STR (extra-early yellow endosperm). In addition, several extra-early maturing *Striga* resistant varieties with moderate levels of resistance/tolerance to *Striga* have been developed from the populations and crosses between various materials in the program.

The S_1 family selection scheme has mainly been used in the breeding program under artificial *Striga* infestation to concentrate favorable alleles for resistance to *Striga*. The S_1 family selection program was initiated in 1996 in each of the two source populations for *Striga* resistance. Since then each population has gone through four cycles of S_1 recurrent selection. S_1 progenies from each cycle of improvement were screened under artificial infestation with *S. hermonthica* and non-infested conditions at Ferkessédougou (hereafter called Ferké) in Côte d'Ivoire from 1996 to 2001 and at Abuja and Mokwa since 2002. Genotypes were evaluated using lattice designs with two replications. The number of progenies screened in each cycle ranged from 196 to 256, with a selection intensity of 25–30%. Based on the data across locations, 25–30% of the top ranking families of each population have been recombined to reconstitute the respective populations for new cycles of improvement. Furthermore, the top 10% families of each population have been intermated to form *Striga* tolerant/resistant varieties for each population.

One strategy of the maize breeding program is to extract extra-early maturing inbred lines from the source populations and other materials of diverse genetic backgrounds through pedigree inbreeding and selection to the S_4 or S_6/S_7 stages under *Striga* infestation in order to fix the favorable alleles for *Striga* resistance. The inbred lines are then used as sources of desirable traits for the improvement of breeding populations, and as parents of productive synthetic varieties. For this reason, inbred line development is an essential component of the *Striga* resistance/tolerance breeding program. Through this strategy, several extra-early *Striga* resistant inbred lines have been extracted from diverse germplasm sources in the breeding program. These have routinely been evaluated in Ferké in plots artificially infested with *S. hermonthica* for grain yield and other agronomic traits. Many of the new extra-early inbred lines possess high grain yield and good levels of resistance to *Striga*.

Evaluation of extra-early maturing maize varieties and inbred lines for reaction to *Striga*

The performance of the two extra-early maturing *Striga* resistant source populations (TZEE-W Pop STR and TZEE-Y Pop STR), synthetic varieties and inbred lines derived from the two source populations, as well as other germplasm sources were evaluated in two field trials conducted under *Striga*-infested and non-infested conditions at 2–3 locations since 2002. The first study involved the evaluation of eight extra-early maturing elite *Striga* resistant varieties (Table 1) in the Regional *Striga* Trial-Extra-early (RSVT-Extra-early), at Ferké (Latitude 9°30′ N, Longitude 5°10′ E; 325 m altitude), Côte d'Ivoire in 2002 and at Mokwa (Latitude 9°18'N, Longitude 5°04 E and elevation 457 m) and Abuja (Latitude 9°16′ N, Longitude 7°20′ E and elevation 300 m), Nigeria in 2002 and 2004. A randomized complete block design with four replications was used. There were 2 row plots, each 5 m long with the rows spaced 0.75 m and 0.4 m between hills. The *Striga* infestation method developed by IITA Maize Program was used that ensures uniform *Striga* infestation with no escapes (Kim 1991; Kim and Winslow 1991). *Striga hermonthica* seed collected from maize and sorghum fields and stored for at least six months was used for artificial field infestations. One row of each plot was artificially infested with 5000 germinable seed of *S. hermonthica* per planting hole made on the ridges. Apart from the *Striga* seed infestation, management practices for both

Table 1. Characteristics of extra-early maturing varieties evaluated under *Striga*-infested and *Striga*-free conditions at Ferké, Mokwa and Abuja in 2002 and 2004.

Varieties	Parentage	Grain type[1]	Reaction to *S. hermonthica*
2000 Syn EE-W	TZEE-W Pop STR S4 F2	W, F/D	Tolerant
99 TZEE-Y STR	TZEE-Y Pop STRS4F2	W,F	Tolerant
99 Syn EE-W	TZEE-W Pop × LDS4F2	W, F/D	Tolerant
98 TZEE-W STR	TZEE-W SR BC5 × 1368 STR S4F2	W, F/D	Tolerant
Ferke TZEE-W STR	TZEE-W SR BC5 × 1368 STR S6F2	W, F/D	Tolerant
Sine TZEE-W STR	TZEE-W SR BC5 × 1368 STR S6F2	W, F/D	Tolerant
TZEE-W SR BC5 (Local check)	Local and introduced germplasm, SR source	W,F	Susceptible
99 TZEF-Y STR CO	TZEF-Y SR BC1 × 9450 STR S4F2	Y,F	Tolerant

[1] W = White, F = Flint, D = Dent, Y = Yellow

Striga-infested and non-infested plots were the same. Three maize seeds were planted per hill. The maize plants were thinned to two per stand about two weeks after emergence to give a final population density of 66,000 plants ha^{-1}. About 30–50 kg N ha^{-1} was split-applied at planting and at about 30 days after planting. Weeds other than *Striga* were removed on a regular basis.

Observations were made for grain yield, number of ears and plants harvested, plant and ear heights, and days to 50% anthesis and silking in both infested and non-infested plots. In addition, host plant damage syndrome rating (Kim 1991) and emerged *Striga* counts were recorded at 8 and 10 weeks after planting (WAP) in the *Striga*–infested rows. Anthesis-silking interval (ASI) was determined as the difference between 50% silking and anthesis. Number of ears per plant (EPP) was determined by dividing the total number of ears per plot by the number of plants harvested. Grain yield adjusted to 15% moisture was calculated from the shelled kernel dry weight.

Combined analyses of variance were conducted for grain yield and other genotypic variables using the General Linear Model Procedure (GLM) of the statistical analysis systems (SAS) package (SAS 1990). The data on *Striga* count were subjected to logarithm transformation (y+1) before the analysis to remove the heterogeneity among the variances.

Results of the combined ANOVA across three locations for the RSVT-Extra-early showed significant differences among the varieties for most traits under *Striga*-infested and *Striga*–free conditions (Table 2). Similarly, the year × variety and location × variety interactions were significant for all traits under infested and non-infested conditions. Only ear aspect was not significant for location × variety interaction under infested conditions. The year × location × variety interaction was not significant for grain yield, plant height, and ear aspect under both environments. However, significant year × location × variety interactions were detected for days to silking, *Striga* damage rating at 10 WAP and EPP under artificial *Striga* infestation. 2000 Syn EE-W and 99 Syn EE-W were the outstanding varieties in terms of grain yield under both *Striga*-infested and non-infested conditions, as well as and *Striga* damage scores under *Striga* infestation.

The most promising variety, 2000 Syn EE-W outyielded the local check, TZEE-W SR BC5 by 63% under *Striga*-free conditions and 69% under *Striga* infestation. 98 TZEE-W STR had the lowest *Striga* damage score but this was not translated into high grain yield since it was among the lowest yielding varieties. The *Striga* emergence counts were generally high, ranging from 161 plants for Sine TZEE-W STR to 251 plants for 99 TZEE-Y STR. This indicates that the varieties studied have tolerance to *Striga*. It is encouraging to note that 2000 Syn EE-W has been released in Bénin following several years of testing both on-station and on-farm. The variety is also undergoing on-farm testing in northern Nigeria. There is, however, the need for national maize programs in the subregion to test 2000 Syn EE-W and other promising *Striga* resistant varieties more extensively in on-farm trials for promotion and adoption by farmers.

In the second study, 36 advanced extra-early maturing *Striga* resistant inbred lines were evaluated under *Striga*-infested and *Striga*-free conditions at Mokwa and Abuja in 2004 to determine the usefulness of the inbreds as parents of open-pollinated synthetic varieties, as well as sources of resistance for the national maize breeding programs. The 36 inbred lines were derived from the broad-based *Striga* and maize streak virus (MSV) resistant populations, TZEE-W Pop STR C_0 and the crosses, TZEE-W SR BC_5 × 1368 STR and TZEF-Y SR BC_1 × 9450 STR (Table 3). A 6 × 6 lattice design with two replications was used for the trial. There were two rows per plot and a row of each plot was infested artificially with about 5000 germinable *S. hermonthica* seeds/hole at planting following the protocol and statistical analyses described earlier for the RSVT-Extra-early. Data for five out of the 36 extra-early maturing inbred lines were not usable and were therefore not included in the results.

Results of the second study showed significant differences among the inbred lines in grain yield and all other traits except ASI under *Striga*-infested and *Striga*-free conditions (Table 3). However, the location × inbred interaction was not significant for the traits except

Table 2. Performance of extra-early maturing maize varieties under *Striga*-infested and non-infested conditions at Ferké, Mokwa and Abuja in 2002 and 2004.

Variety	Grain yield (kg/ha) Non-inf	Grain yield (kg/ha) Inf	Days to silking Non-inf	Days to silking Inf	Plant height (cm) Non-inf	Plant height (cm) Inf	*Striga* rating⁺ (10 wks)	*Striga* count (10 wks)	EPP Non-Inf	EPP Inf	Ear aspect Non-inf	Ear aspect Inf
2000 Syn EE-W	4288	1847	53	55	161	128	5	221	0.88	0.68	2.00	3.53
99 TZEE-Y STR	3372	1384	50	53	151	119	6	251	0.86	0.77	1.85	3.63
99 Syn EE-W	3001	1484	53	56	162	124	5	183	0.95	0.79	2.25	3.48
98 TZEE-W STR	2228	570	55	58	154	114	4	178	0.83	0.96	2.00	3.95
Ferke TZEE-W STR	1987	759	55	57	150	116	6	170	0.76	0.62	1.92	3.38
Sine TZEE-W STR	1828	892	53	55	135	110	5	161	0.85	0.58	1.97	3.78
TZEE-W SR BC5 (RE)	1573	573	50	53	139	111	6	193	0.91	0.71	2.16	3.89
99 TZEF-Y STR CO	1072	382	54	55	135	112	5	192	0.81	0.64	2.50	4.06
Mean	2509	1233	51	54	155	128	5.5	162	0.86	0.79	3.78	4.27
SE	226.00	122	0.6	0.5	5	4	0.4	18.68	0.67	0.11	0.25	0.21
Probability of F for variety	**	**	**	**	**	**	**	**	ns	ns	*	ns
Probability of F for year × variety	**	**	**	**	**	**	**	**	*	**	**	*
Probability of F for location × variety	**	**	**	**	**	**	**	**	*	**	*	ns
Probability of F for year × location × variety	ns	ns	ns	**	ns	ns	*	ns	ns	*	ns	ns

+=Rating for host plant damage syndrome where 1=little or no damage and 9= severe damage due to *S. hermonthica*
ns, Not significant, *, ** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 3. Grain yield and other agronomic characters of 31 extra-early maturing inbred lines evaluated under *Striga*-infested and *Striga*-free conditions at Abuja and Mokwa in 2004.

Inbred line	Parentage	Grain yield (kg/ha) Non-inf	Grain yield (kg/ha) Inf	Pollen shed Non-Inf	Pollen shed Inf	Days silk non-inf	Days silk inf	Plant height non-inf	Plant height inf	*Striga* count (10 wk)	*Striga* rating$^+$ (10 wk)	ASI non-inf	ASI inf	EPP Non-Inf	EPP Inf	EASP Non-Inf	EASP Inf
2	TZEE-W SR BC5 × 1368 STR S7 INB19	707	342	59	59	60	59	129	100	79	6	1	0.8	0.61	0.38	5.25	5.25
3	TZEE-W SR BC5 × 1368 STR S7 INB29	780	532	55	55	59	58	108	105	51	5	5.3	2.8	0.76	0.50	4.25	4.25
4	TZEE-W SR BC5 × 1368 STR S7 INB28	1253	433	52	52	55	56	91	75	42	6	3.3	3.8	0.91	0.46	4.75	5.75
5	TZEE-W SR BC5 × 1368 STR S7 INB35	1077	814	50	51	53	54	109	98	60	6	3.3	2.8	0.72	0.58	4.75	4.75
6	TZEE-W SR BC5 × 1368 STR S7 INB40	1753	1607	51	53	53	55	120	106	42	4	3.5	2.5	0.76	0.68	3.75	3.50
7	TZEE-W SR BC5 × 1368 STR S7 INB60	1427	1358	49	48	55	51	131	104	79	6	3.3	3	0.84	0.70	3.75	3.75
8	TZEE-W SR BC5 × 1368 STR S7 INB72	1029	765	52	53	52	56	114	91	108	6	2.8	3	0.69	0.50	4.75	4.75
9	TZEE-W SR BC5 × 1368 STR S7 INB76	1140	928	51	51	55	54	109	84	43	5	3.3	3.3	0.54	0.66	3.75	4.25
10	TZEE-W SR BC5 × 1368 STR S7 INB80	433	332	51	51	55	55	78	75	33	7	3.3	3.5	0.57	0.40	5.75	5.50
11	TZEE-W SR BC5 × 1368 STR S7 INB82	822	792	52	52	56	56	111	103	14	6	3.3	4	0.62	0.46	4.75	4.75
12	TZEE-W SR BC5 × 1368 STR S7 INB85	1373	1202	50	50	52	52	138	114	45	5	3	2.8	0.77	0.59	4.00	4.25
13	TZEE-W SR BC5 × 1368 STR S7 INB91	1109	544	48	48	50	50	118	93	41	7	2.3	2.3	0.84	0.55	4.50	5.25
14	TZEE-W SR BC5 × 1368 STR S7 INB92	377	358	51	50	54	54	91	74	21	7	3.3	3.8	0.79	0.59	5.75	5.75
15	TZEE-W SR BC5 × 1368 STR S7 INB98	1316	1259	48	49	52	52	128	119	29	5	3.3	3.5	0.59	0.66	4.25	3.75
16	TZEE-W SR BC5 × 1368 STR S7 INB100	1428	896	50	50	54	54	115	104	38	5	4.5	4	0.67	0.55	3.75	4.00
20	TZEE-W Pop C9 S6 INB 22 4/4	620	437	57	57	60	59	84	81	4	5	2.8	1.3	0.60	1.17	6.75	5.25

+=Rating for host plant damage syndrome where 1=little or no damage and 9= severe damage due to *S. hermonthica*.

Table 3. cont'd

Inbred line	Parentage	Grain yield (kg/ha) Non-inf	Grain yield (kg/ha) Inf	Pollen shed Non-Inf	Pollen shed Inf	Days silk non-inf	Days silk inf	Plant height non-inf	Plant height inf	*Striga* count (10 wk)	*Striga* rating (10 wk)	ASI non-inf	ASI inf	EPP Non-Inf	EPP Inf	EASP Non-Inf	EASP Inf
21	TZEE-W Pop C9 S6 INB 96 2/2	325	337	57	57	61	59	84	85	12	6	3.8	2.8	0.62	0.51	6.50	6.00
22	TZEE-W SR BC5 × 1368 STR S6 INB331/2	747	735	54	54	56	57	109	100	49	5	2.8	2.8	0.70	0.63	4.75	4.00
23	TZEE-W SR BC5×1368 STR S6 INB55A 1/2	1359	1183	54	54	56	57	125	113	55	4	2	2.8	0.81	0.84	4.25	4.25
24	TZEE-W SR BC5×1368 STR S6 INB55B 1/2	1537	1444	53	54	55	56	116	111	56	4	2	3.3	0.78	0.66	3.75	3.50
26	TZEE-W SR BC5 × 1368 STR S6 INB106 1/3	1117	1019	53	54	57	57	119	109	72	6	3.5	2.3	0.83	0.60	3.50	4.00
27	TZEE-W SR BC5 × 1368 STR S6 INB106 2/3	763	691	56	55	57	57	89	81	20	5	2.3	3.3	0.73	0.49	4.75	4.50
28	TZEE-W SR BC5 × 1368 STR S6 INB106 3/3	1144	940	51	50	55	53	115	104	77	6	3.8	5.5	0.71	0.70	4.25	4.75
29	TZEE-W SR BC5 × 1368 STR S6 INB229B	2011	705	49	49	54	55	120	101	78	5	4.3	4	0.86	0.49	3.50	5.00
30	TZEE-W SR BC5 × 1368 STR S6 INB333	860	517	52	52	56	56	100	85	21	6	3.8	4.3	0.91	0.64	4.25	4.50
31	TZEE-Y SR BC1 × 9450 STR S6 INB1A	631	433	50	50	54	54	118	110	50	6	3.8	3.8	0.61	0.42	5.75	6.00
32	TZEE-Y SR BC1 × 9450 STR S6 INB1A	820	553	52	51	55	55	116	101	54	6	2.8	4	0.54	0.36	5.25	5.25
33	TZEE-Y SR BC1 × 9450 STR S6 INB3A	795	571	53	52	55	56	124	121	59	6	2.3	3.8	0.81	0.46	5.00	5.25
34	TZEE-Y SR BC1 × 9450 STR S6 INB8A	686	433	49	49	52	53	99	101	61	6	3	3.8	0.69	0.59	5.25	5.25
35	TZEE-Y SR BC1 × 9450 STR S6 INB9A	695	374	55	55	58	58	108	101	34	7	3.3	3	0.82	0.58	5.50	6.00
	Means	975	767	52	52	55	55	112	99	50	5.5	3.1	3.2	0.72	0.57	4.69	4.75
	SE	240	228	0.7	0.8	0.8	1.06	7.2	7.8	11.3	0.44	0.7	0.7	0.09	0.09	0.43	0.46
	Probability of F for inbred	**	**	**	**	**	**	**	**	**	**	ns	ns	*	**	**	**
	Probability of F for location × inbred	ns	ns	ns	ns	*	ns	ns	ns	**	ns	ns	ns	ns	ns	*	ns

+=Rating for host plant damage syndrome where 1=little or no damage and 9= severe damage due to *S. hermonthica*

NS, Not significant *, ** Significant at the 0.05 and 0.01 levels of probability, respectively.

Data obtained for lines 1, 17, 18, 19 and 25 were not usable and were, therefore, excluded from this analysis.

days to silking and ear aspect under non-infested conditions, and *Striga* emergence counts under *Striga* infestation. Six inbred lines (TZEE-W SR BC$_5$ × 1368 STR S$_7$ INB 40, TZEE-W SR BC$_5$ × 1368 STR S$_7$ INB 98, TZEE-W SR BC$_5$ × 1368 STR S$_6$ INB 55A-1-2, TZEE-W SR BC$_5$ × 1368 STR S$_6$ INB 55 B-1-2, TZEE-W SR BC$_5$ × 1368 STR S$_6$ INB 55 B-2-2, TZEE-W SR BC$_5$ × 1368 STR S7 INB 85) were outstanding in terms of grain yield under *Striga*-infested and non-infested conditions and for *Striga* damage scores.

The *Striga* emergence counts were generally high but a few lines such as TZEE-W Pop C0 S$_6$ INB 22- 4-4, TZEE-W SR BC$_5$ × 1368 STR S$_7$ INB 82, TZEE-W SR BC$_5$ × 1368 STR S$_6$ Inbred 106-2-3 and TZEE-W SR BC$_5$ × 1368 STR S$_7$ INB 10 had low *Striga* emergence counts and sustained low *Striga* damage. However, they recorded low grain yield under both *Striga*-infested and non-infested conditions. The inbred llines with high *Striga* emergence counts may be classified as tolerant to *Striga*.

The problem with the available *Striga* tolerant varieties and inbred lines is that they allow the reproduction of the parasite thereby increasing the *Striga* soil seed bank after each season. The results of the two studies reported here indicate that some superior *Striga* tolerant populations, synthetic varieties and inbred lines are now available in WCA. These inbred lines are serving as invaluable sources of *Striga* resistance for the development of synthetic varieties and populations. In addition to the available moderate level of *Striga* resistance, there is a need for intensified search for unique sources of *Striga* resistance, which will not allow reproduction of the parasite so that the *Striga* seed bank in the soils of the *Striga* endemic areas of the savanna ecology could be depleted or brought down to low levels. A potential unique source of resistance is *Zea diploperennis*, which is presently under extensive evaluation in WCA.

Assessment of genetic diversity in extra-early maturing inbred lines using UPGMA cluster analysis

Knowledge and understanding of genetic relationships among the extra-early maturing inbred lines in the maize breeding program would be very useful in designing mating schemes for field testing of the heterotic patterns of the inbred lines, in assigning them to specific heterotic groups, and for precise identification with respect to plant varietal protection (Hallauer and Miranda 1988). Furthermore, the phenotypic classification of inbred lines would be helpful in the selection of parental inbreds for the development of heterotic populations and the introgression of desirable genes from diverse germplasm sources into the available genetic base (Thompson *et al.* 1998). The most commonly used approach for elucidating genetic differences between different germplasm and for placing inbred lines into heterotic groups is the pedigree method. However, several approaches other than the pedigree method are available. For example, multivariate analyses could be used to identify closely related lines and determine the variation in genetic similarity among genotypes that show no variation for parentage, and to plan crosses between genetically divergent parents to maximize the genetic variation in segregating generations. Among the multivariate analytical methods, cluster analysis, principal component analyses (PCA), principal coordinate analyses (PCoA), and multi-dimensional scaling (MDS) are the most commonly employed and probably particularly useful (Melchinger 1993; Johns *et al.* 1997; Thompson *et al.* 1998; Brown-Guidera *et al.* 2000). The clustering technique is very useful for the study of effects of pedigree and the origin of genotypes on their phenotypic behavior in various environments (Shorter *et al*. 1977). Badu-Apraku *et al.* (2006b) used the phenotypic similarity (PS) based cluster analysis to study the genetic diversity in 47 *Striga* resistant tropical early maize inbreds from WCA. Based on the results of that study, it was predicted that heterosis could be best maximized through matings between phenotypic-based clusters and by selecting parents which combine high grain yield, low *Striga* emergence and damage symptoms.

A study was initiated in 2004 to assess the genetic diversity in 36 extra-early maturing maize inbred lines developed in the breeding program using UPGMA cluster analysis. The data collected on 31 out of 36 extra-early maturing *Striga* resistant inbred lines (26 with white endosperm color and 5 yellow endosperm color) at the S_6 or S_7 stage of inbreeding evaluated at Mokwa and Abuja under *Striga*-infested and non-infested conditions in 2004 were used for the study. The details of the field evaluation of the inbred lines have been described elsewhere in this paper. Data for five of the inbred lines used in the study were not usable and were therefore not included in the cluster analysis.

Using the PRINCOMP procedure of the SAS package, principal component analysis (PCA) was performed on the average values for each trait to identify a group of traits that accounted for most of the variance in the set of data and could be used to rank the inbred lines for their performance. The contribution of each trait to the principal component axis was determined by performing simple correlation analysis between the PC scores and each trait. Only traits that had significant correlation with PC scores were considered as important and were selected for the cluster analysis. The cluster analyses were computed using the CLUSTER procedure of the SAS statistical package.

In the second study, combined analyses of variance of the data across locations showed large genotypic variation in the phenotypic traits of the 31 inbred lines under *Striga*-infested and non-infested conditions

(Table 3). This prompted the use of multivariate analysis to identify the major genotypic patterns. The first three principal components with eigenvalues ≥0.3 under both *Striga*-infested and *Striga*-free conditions summarized 72% of the multivariate variation in inbred means (data not shown) and were the most important. The traits loaded on the three axes were used for the grouping of the inbred lines. The inbred lines evaluated under *Striga* infestation were clustered using grain yield, days to 50% silking, plant height, EPP, ASI, *Striga* emergence counts and damage rating (Fig. 1). On the other hand, the inbred lines evaluated under *Striga*-free conditions were grouped based on grain yield, days to 50% silking, plant height, EPP and ASI (Fig. 2). The resulting dendrograms generated four main groups for the inbred lines under *Striga* infestation and six main groups under *Striga*-free conditions. Under *Striga* infestation, group 1 was represented by 17 inbred lines; group 2 by 11 inbred lines; group 3 by one inbred line (inbred 6) and group 4 by six inbred lines. Ten of the inbreds in group 1 had white endosperm color and were derived from TZEE-W SR BC_5 × 1368 STR; two had white endosperm color and were extracted from TZEE-W Pop while the remaining five lines had yellow endosperm and were derived from TZEE-Y SR BC_1 × 9450 STR. Group 2 contained inbred lines derived from two germplasm sources, TZEE-W SR BC_5 × 1368 STR and TZEE-Y SR BC_1 × 9450. The extra-early inbreds were grouped into six major clusters under *Striga*-free conditions (Fig. 2). The number and type of inbred lines in the different clusters under *Striga*-free conditions were different from those in the corresponding clusters generated under *Striga* infestation. As under *Striga* infestation, the inbred lines in clusters 1, 2 and 4 were derived from different source populations. It is interesting to note that in some cases some inbred lines derived from the same germplasm sources were placed in different clusters while in others they were grouped together. For example, inbreds derived from TZEE-W SR BC_5 × 1368 STR were found in all groups under both environments. On the contrary, all the yellow endosperm inbred lines derived from TZEE-Y SR BC_1 × 9450 STR (31, 32, 33 and 34) were placed in group 1 under both *Striga*-infested and non-infested conditions. Furthermore, inbreds 20 and 21 derived from TZEE-W Pop were both placed in group 1 under *Striga* infestation while inbred 20 was placed in group 1 and inbred 21 in group 5 under *Striga*-free conditions.

The results of this study indicate that the clustering of the inbred lines under *Striga* infestation was in some cases dependent on the germplasm source from which they were derived while in some cases the grouping was independent of the genetic background. Furthermore, the yellow endosperm inbred lines were classified into one group suggesting that probably there is no genetic diversity among

Figure 1. Clustering of 35 extra-early inbreds evaluated under *Striga* infestation at Mokwa and Abuja in 2004.

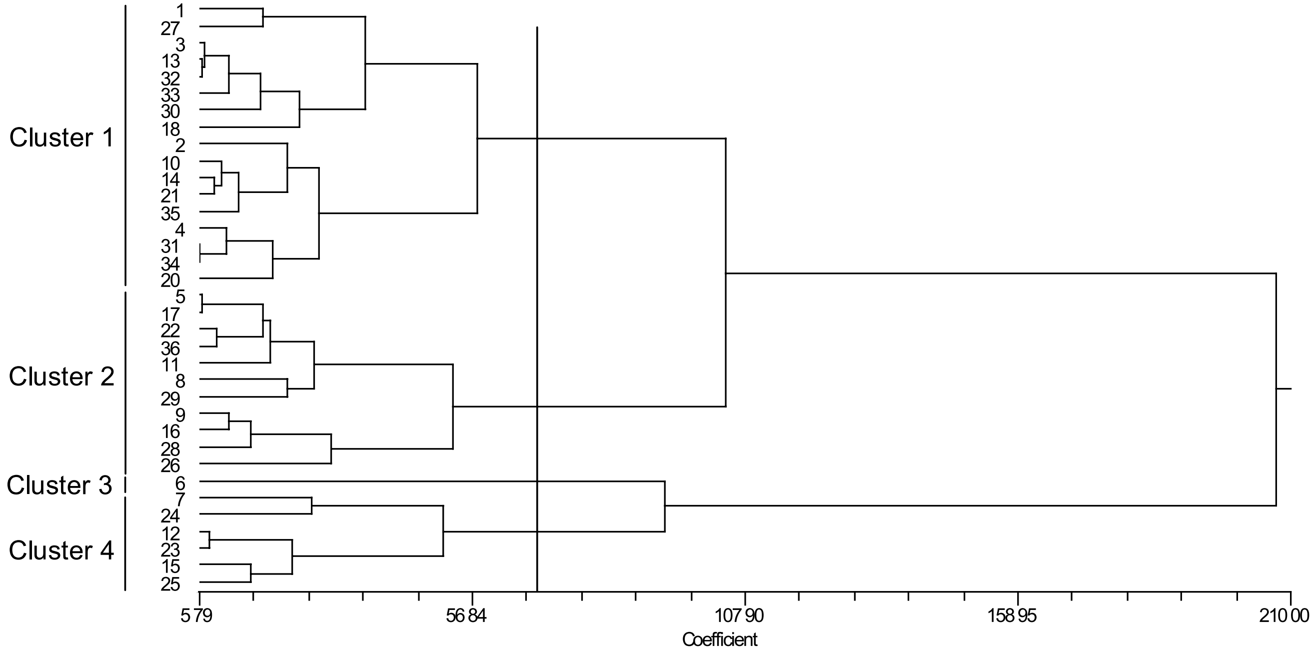

Figure 2. Clustering of 35 extra-early inbreds evaluated under *Striga*-free conditions at Mokwa and Abuja in 2004.

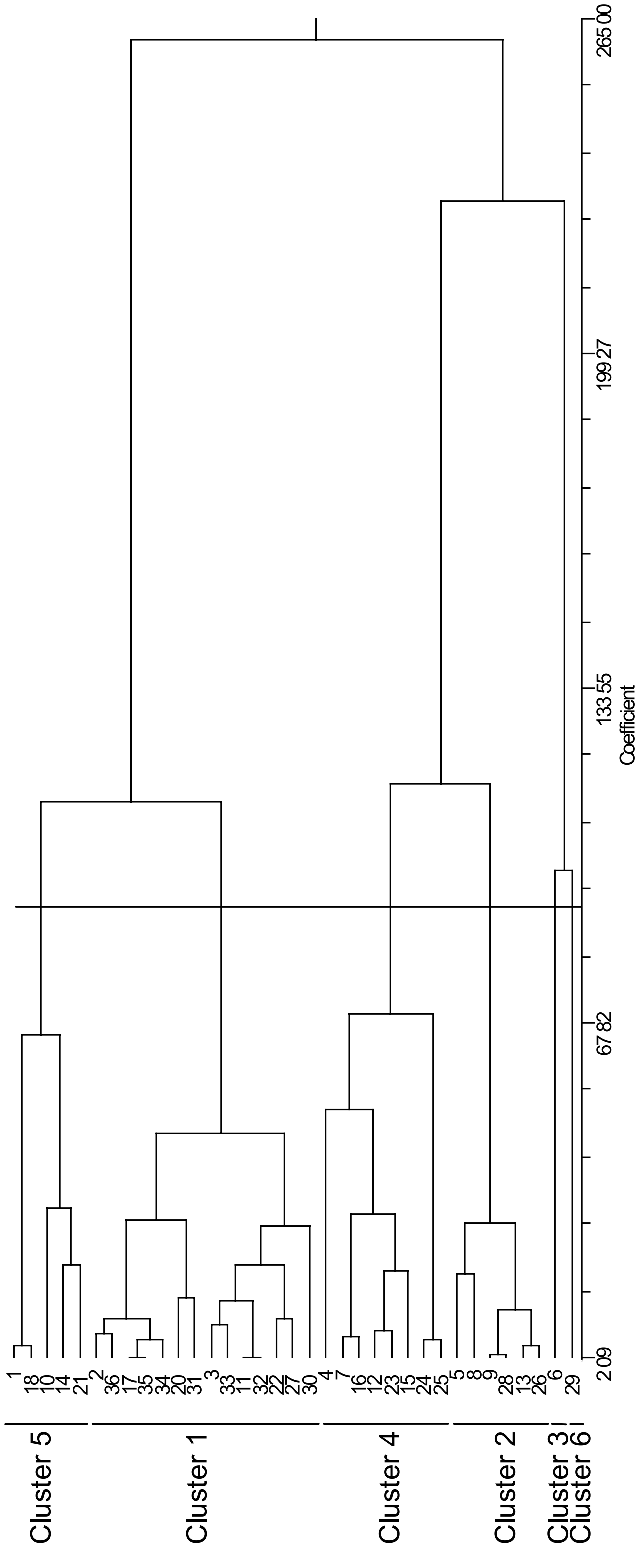

Table 4. Number of inbred lines in each cluster and lines common in the clusters.

	Cluster number					
	1	2	3	4	5	6
No. of inbreds grouped under infested conditions	17	11	1	6	0	0
No. of inbreds grouped under non-infested conditions	14	6	1	8	5	1
No. of inbreds common in each group	7	5	1	6	0	0

them. The implication is that some inbred lines derived from the three germplasm sources have diverse genetic diversity and could be used to develop broad-based *Striga* resistant pools and populations.

A close examination of the inbred lines in the different clusters showed that while 17, 11, and 6 inbreds were classified into groups 1, 2 and 4 respectively, under *Striga*-infested conditions, 14, 6, and 8 inbreds were placed in groups 1, 2, and 4 respectively, under non-infested conditions (Table 4). Seven of the inbred lines assigned to group 1 were common, while 5 and 6 were common in groups 2 and 4, respectively under both *Striga*-infested and non-infested conditions. Inbred 6 was classified into group 3 under both environments. It may therefore be concluded that the environment in which the inbred lines were evaluated significantly influenced the clustering. This implies that there is a need for the evaluation of the extra-early inbred lines under both *Striga*-infested and non-infested conditions in order to place them in appropriate heterotic groups. The results of this study indicate that superior specific hybrid combinations could be obtained by crossing inbred lines of different clusters rather than matings within clusters and by selecting parents with high grain yield and low *Striga* damage.

An important objective of this study was to use multivariate analysis for preliminary grouping of the 31 extra-early maturing inbred lines and to use the results to design mating schemes for field testing of the heterotic patterns of the inbred lines. Based on the results of this study, diallel crosses will be made between representative samples of inbred lines from each of the four clusters for evaluation under artificial *Striga* infestation in the field in an effort to confirm the heterotic groupings.

Conclusions

The results of this study have shown that high yielding, *Striga* resistant extra-early maturing maize varieties (2000 Syn EE-W, 99 Syn EE-W and Sine TZEE-W STR) and inbred lines (TZEE-W SR BC5 × 1368 STR S7 INB 40, TZEE-W SR BC5 × 1368 STR S7 INB 98, TZEE-W SR BC5 × 1368 STR S6 INB 55A-1-2, TZEE-W SR BC5 × 1368

STR S6 INB 55 B-1-2, TZEE-W SR BC5 × 1368 STR S6 INB 55 B-2-2, TZEE-W SR BC5 × 1368 STR S7 INB 85) have been developed in the IITA-WECAMAN maize breeding program. There is a need for extensive testing of the varieties on-farm to ensure wide adoption by farmers, and hence the desired impact on maize production and productivity in the savanna ecology of WCA. An advantage should be taken of the promising *Striga* resistant inbred lines identified in this study for introgression into the breeding pools and populations of the national maize breeding programs in order to improve the *Striga* resistance levels of their germplasm. The results of this study indicate that superior specific hybrid combinations could be obtained by crossing inbred lines of different clusters rather than matings within clusters, and by selecting parents with high grain yield and low *Striga* damage.

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Genetic analysis of drought tolerance in maize inbred lines: preliminary results

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Abstract

Drought stress causes significant yield reduction in maize (*Zea mays* L) grown in sub-Saharan Africa (SSA). An understanding of the inheritance of drought tolerance would be useful in developing drought tolerant hybrids. The objectives of this study were to determine (i) the effects of the level of drought tolerance in parental inbred lines on the performance of their hybrids, (ii) mode of inheritance of drought tolerance in inbred lines selected for contrasting responses to drought, and (iii) relationship between *per se* performance of the parental lines and their hybrids. A Design II mating scheme was used to produce 96 single-cross hybrids from 24 inbred lines. The parental lines and F_1 hybrids were evaluated in separate trials laid out side by side at Ikenne, Nigeria in 2002. Both general (GCA) and specific (SCA) combining abilities were significant ($P < 0.01$), with GCA accounting for >50% of total variation for all traits except ears per plant under well-watered conditions. These results indicated that additive genetic effects largely influenced grain yield and other traits of the hybrids when evaluated under water stress. Most of the crosses with at least one tolerant parent produced tolerant hybrids, whereas most of the crosses involving two susceptible lines produced susceptible hybrids. Mid-parent values of inbred lines *per se* were useful predictors of hybrid performance for all traits except ear aspect scores. Inbred lines KU1409, 1824, 9006, 4001, POP10, and (TZI501xKU1414x501) could be used as parents for developing drought tolerant maize hybrids. Results of this study led to the conclusion that yield improvement in drought tolerant maize is associated with the level of drought tolerance in parental lines.

Résumé

La sécheresse est un stress qui cause une réduction significative de rendement chez le maïs (*Zea mays* L) en Afrique sub-Saharienne (ASS). La compréhension du mode de transmission de la tolérance à la sécheresse serait utile pour la création d'hybrides tolérants à la sécheresse. Les objectifs de cette étude étaient de déterminer (i) les effets du niveau de la tolérance à la sécheresse des lignées parentales sur la performance de leurs hybrides, (ii) mode de transmission de la tolérence à la sécheresse dans les lignées sélectionnées pour des réponses contrastées à la sécheresse. et (iii) les rapports entre la performance intrinsèque des parents et leurs hybrides. Un schéma de croisements dénommé 'Design II' a été utilisé pour produire 96 hybrides à partir de 24 lignées. Les lignées parentales et les hybrides F1 ont été évalués dans des essais séparés mis en place côte à côte à Ikenne, au Nigéria en 2002. Les aptitudes générales à la combinaison (AGC) et spécifiques à la combinaison (ASC) étaient significatives ($p < 0.01$), avec AGC comptant pour plus que 50% de la variation totale pour tous les caractères, à l'exception des épis par plant en conditions d'arrosage. Les effets génétiques additifs ont largement influencés le rendement grain et les autres caractères chez les hybrides de maïs sous le stress de la sécheresse. La plupart des croisements avec au moins un parent tolérant, a produit des hybrides tolérants, tandis que la plupart des croisements entre des lignées susceptibles ont généré des hybrides susceptibles. Les valeurs moyennes parentales des lignées étaient utiles pour la prédiction de la performance de leurs hybrides pour tous les caractères, à l'exception du score de l'aspect des épis. Les lignées KU1409, 1824, 9006, 4001, POP10 et (TZI501xKU1414x501) pourraient être utilisés comme parents pour créer des hybrides tolérants à la sécheresse. Les résultats de cette étude revèlent que l'amélioration du rendement grain dans le maïs tolérant à la sécheresse est associée au niveau de tolérance à la sécheresse dans les lignées parentales.

Introduction

The majority of farmers in the developing world, including sub-Saharan Africa (SSA), depend on maize (*Zea mays* L.) for their daily caloric intake. However, an estimated 80% of the maize crop suffers periodic yield reduction due to drought stress (Bolanos and Edmeades 1993). Drought may occur at any stage of maize growth, but when it coincides with the flowering and grain filling periods it causes yield losses of 40-90% (NeSmith and Ritchie 1992; Menkir and Akintunde 2001). An understanding of the genetic basis of drought tolerance in source materials would be useful in developing maize genotypes for drought-prone areas.

Duvick (1992) and Tollenaar and Lee (2002) associated yield improvement in maize with stress tolerance. However, few studies have been conducted to determine the effect of the level of drought tolerance in parents on the productivity of their hybrid progenies. Kirkham *et al.* (1984) found that hybrids with one or two drought tolerant parents produced higher grain yield than hybrids with both parents susceptible to drought stress. Betran *et al.* (2003) reported similar results for a set of diallel crosses involving 17 parental lines, and proposed the need for using at least one drought tolerant inbred line in hybrid combinations to increase grain yield under drought conditions. However, these studies were conducted either under naturally occurring drought (Kirkham *et al.* 1984) or managed drought stress imposed only at flowering stage (Betran *et al.* 2003). Unfortunately, the inbred lines used in these studies were either too few or not fully characterised for responses to drought stress. The objectives of our study were to determine (i) the effects of level of drought tolerance in parents (both susceptible, one parent susceptible the other tolerant, or both tolerant) on the performance of their hybrids, (ii) the mode of inheritance of drought tolerance in inbred lines selected for contrasting responses to drought, and (iii) the relationship between *per se* performance of the parents and their hybrids.

Materials and Methods

Twenty-four maize inbred lines developed at the International Institute of Tropical Agriculture (IITA) were crossed in a Design II mating scheme (Comstock and Robinson 1948; Hallauer and Miranda 1988) to produce 96 single-cross hybids evaluated in this study. The inbred lines were classified using a base index involving anthesis-silking interval (ASI), number of ears per plant, grain yield, ear aspect and leaf death scores, all of which are sensitive to drought stress. Twelve of the inbred lines were classified as tolerant to drought (T) while the other twelve were susceptible (S) (Table 1). The 24 parental lines were divided into six sets each of four inbred lines. Each inbred line was used as female parent in one set and as male parent in a second set. A total of 96 hybrids were produced from this mating scheme. The 96 hybrids, along with four checks were arranged in a 10 × 10 triple lattice design and were evaluated under both water stressed and well-watered conditions at Ikenne (6° 53′ N, 3° 42′ E, altitude 60 mas) during the dry season of 2002. The parental lines were arranged in a randomized complete block design with three replications and evaluated in plots adjacent to the hybrid trial.

The soil at Ikenne is characterised as eutric nitsol (FAO classification) and the experimental fields are flat and fairly uniform. The experiment was conducted in two blocks with two irrigation treatments. Block 1 was well watered (WW) while Block 2 was moisture stressed (WS). Apart from the targeted stress, the management of the trials was the same in the two blocks. A sprinkler irrigation system was used to apply sufficient water weekly to both blocks during the first 5 weeks (35 days) after germination. Block 1 continued to receive irrigation each week until physiological maturity.

Table 1. **Mean grain yield (Mg ha^{-1}) of parental lines used in Design II crosses tested under water stressed (WS) and well-watered (WW) conditions at Ikenne in 2002.**

Inbred line	WSR[†]	Grain yield (Mg ha^{-1}) WS	Grain yield (Mg ha^{-1}) WW	Yield reduction (%)[††]	Index[‡]
KU1409	T	0.75	1.94	61	15.89
4058	T	0.76	2.83	73	10.26
(TZMI501xKU1414x501)	T	1.10	1.85	41	8.72
1824	T	0.76	2.34	68	8.11
(POOL 26 Sequia)C3F2	T	0.68	1.58	60	7.41
4001	T	0.68	1.64	60	6.37
9006	T	0.82	1.95	58	5.69
POP 10	T	0.42	1.58	73	5.31
9613	T	0.55	2.17	75	4.64
9450	T	0.89	1.59	44	4.39
161	T	1.04	1.94	46	2.57
(KU1403x1368)STR	T	0.38	1.30	70	0.71
4008	S	0.55	1.35	59	-0.08
Fun.47-3	S	0.60	1.18	49	-1.79
(KU1403x1368)	S	0.25	1.10	77	-2.67
9071	S	0.68	1.26	46	-3.40
9485	S	0.18	1.19	85	-4.13
GH 24	S	0.31	1.06	71	-4.21
(KU1403x1368)BC2	S	0.24	0.95	75	-4.45
5012	S	0.41	0.94	56	-6.51
1808	S	0.29	0.79	63	-7.90
5057	S	0.52	0.60	13	-10.18
9432	S	0.38	0.58	71	-10.18
Mok Pion-Y-S4	S	0.25	0.31	19	-14.64
Mean		0.55	1.42		
S.E±		0.05	0.12		

[†] WSR=Water-stress response; T=tolerant and S=susceptible.

[††] WS relative to WW.

[‡] Index = positive and negative numbers indicate tolerance and susceptibility to drought, respectively.

In Block 2, moisture stress was imposed by withdrawing irrigation water as from 5 weeks after planting (WAP) (15 to 23 days before 50% anthesis) until the end of the growing season, to ensure drought stress at flowering and grain filling stages. The crop was allowed to mature only on stored soil moisture.

Each hybrid or parental line was planted in a 3 m row plot spaced 0.75 m apart with 0.25 m spacing between plants within each row. Within a row, two seeds were planted in a hill and thinned to one plant after emergence to obtain a population density of approximately 53,333 plants ha^{-1}. A compound fertilizer was applied at the rates of

60 kg N, 60 kg P and 60 kg K ha^{-1} at the time of sowing. An additional 60 kg N ha^{-1} was topdressed 4 weeks later. In all the trials, gramoxone was applied as foliar contact herbicide at 5 L ha^{-1} of paraquat (1,1′-dimethyl-4,4′-bipyridinium). Subsequent manual weeding was done as necessary to keep the trials weed-free.

Days to anthesis and silking were recorded as the number of days from planting to when 50% of the plants in a row reached anthesis and had emerged silks, respectively. Anthesis-silking interval (ASI) was computed as the interval in days between silking and anthesis. Plant and ear heights were measured as the distance from the base of the plant to the height of the first tassel branch and the node bearing the upper ear, respectively. Ear aspect was scored on a 1 to 5 scale, where 1 = clean, uniform, large, and well-filled ears and 5 = rotten, variable, small, and partially or poorly filled ears. Leaf death was scored only in Block 2 at 70 (score 1) and 82 (score 2) days after planting on a scale of 1 to 9, where 1 = less than 10% dead leaf area and 9 = more than 80% dead leaf area. Number of ears/plant^{-1} was computed as the total number of ears divided by the number of plants harvested. All ears harvested from each plot were shelled and used to determine percentage grain moisture and grain weight. Grain yield, adjusted to 15% moisture, was computed from the shelled grain weight.

To test the effect of irrigation treatments and the significance of genotypes x irrigation interactions, data from the two blocks were subjected to ANOVA using a mixed model as described in SAS package (SAS Institute 1999). The ANOVA for both inbred and hybrid trials were performed with PROC GLM in SAS, using a RANDOM statement with the TEST option. For the hybrid trials, ANOVA was computed for each irrigation block to generate entry means adjusted for block effects, according to the lattice design (Cochran and Cox 1960). The hybrids within sets component of the variation was divided into variation due to male within sets, female within sets, and the female x male within sets interaction.

The main effects of males within sets and females within sets represented the general combing ability (GCA), and the female x male (sets) interaction represented the specific combing ability (SCA) (Hallauer and Miranda Fo 1988). Line x Tester analysis was performed for grain yield using adjusted means after the check entries had been omitted, following the procedure of Singh and Chaudhary (1985).

For each trait, mid-parent value for a cross was computed as the mean of the two parental lines for each irrigation treatment separately. The relationship between parental lines and *per se* performance of their hybrids was estimated using simple correlation. Average heterosis for each trait was computed as the difference between F_1 value and the mid-parent value.

Table 2. Means for grain yield and other traits for four groups of hybrid combinations evaluated under water stress and well-watered conditions at Ikenne in 2002.

	Inbred line combinations[†]					
Trait	T x T (20)	T x S (28)	S x T (28)	S x S (20)	Check (4)	±S.E.
	Water stress environment					
Silking date (days)	55.30	56.10	56.60	57.10	56.10	1.13
ASI (days)	1.90	2.60	2.10	3.30	2.30	0.99
Plant ht (cm)	185.40	179.60	173.60	165.00	169.10	2.61
Ear ht (cm)	96.50	96.40	93.80	86.20	88.40	2.41
Ear plant^{-1} (no.)	0.89	0.87	0.89	0.79	0.86	0.52
Ear aspect (1–5)[a]	3.20	3.40	3.40	3.70	3.60	0.58
Leaf death1 (1–9)[b]	5.50	5.50	5.80	6.00	5.80	0.63
Leaf death2 (1–9)[b]	7.00	7.20	7.50	7.70	7.50	0.63
Grain yield (Mg ha^{-1})	1.99	1.88	1.85	1.48	1.72	0.56
	Well-watered environment					
Silking date (days)	53.70	54.30	54.30	54.60	54.50	0.82
ASI (days)	0.30	0.90	0.90	0.90	0.50	0.73
Plant ht (cm)	212.30	208.60	206.80	198.10	197.50	2.60
Ear ht (cm)	107.70	106.50	105.20	101.20	99.00	2.56
Ear plant^{-1} (no.)	1.03	1.06	1.06	1.03	1.03	0.28
Ear aspect (1–5)[a]	3.10	3.20	3.10	3.30	2.50	0.58
Grain yield (Mg ha^{-1})	6.85	6.46	6.80	6.22	6.94	0.85
No. of hybrids	20	28	28	20	4	

[†] T = tolerant, S = susceptible; No. of hybrids in each group is in parenthesis.

[a] Ear aspect on a scale of 1 to 5, where 1 = clean, uniform and well-filled ears and 5 = ears with undesirable features.

[b] Leaf death score, a scale of 1 to 9, where 1 = less than 10% leaf death area and 9 = more than 80% leaf death area.

Results and Discussion

Significant differences for grain yield among inbred lines were observed under both WS and WW conditions (Table 1). Water stress affected yield performance of susceptible (63% yield reduction) more than tolerant inbred lines (53%). The intensity of drought observed in this study falls within the range of stress levels applied during selection of inbred lines for tolerance to drought by other workers (Bolanos and Edmeades 1993; Betran *et al.* 2003). Tolerant lines including KU1409, 161, (TZMI501xKU1414x501), 9006, 4058 and 1824 had consistently high grain yields under both WS and WW conditions (Table 1). Our results indicate that yield improvement in inbred lines is associated with tolerance to drought, a conclusion that is consistent with earlier studies (Duvick 1992; Tollenaar and Lee 2002).

There were no significant differences among hybrid groups for grain yield and other traits under WW conditions (Table 2). Under WS conditions, however, hybrids differed significantly for grain yield,

Table 3. Percentages of the sums of squares for crosses attributable to general (GCA) and specific (SCA) combining ability for grain yield and other agronomic traits tested under water stress and well-watered conditions at Ikenne in 2002.

	Water stress environment			Well-watered environment		
Trait	GCA-male	GCA-female	SCA	GCA-male	GCA-female	SCA
Silking date (days)	34	22	44	34	23	43
ASI (days)	39	22	40	44	22	34
Plant ht (cm)	35	34	32	42	33	25
Ear ht (cm)	26	31	42	32	22	46
Ears plant $^{-1}$ (no.)	44	21	35	25	22	52
Ear aspect (1–5)[a]	33	22	45	34	23	43
Grain yield (Mg ha^{-1})	34	21	45	33	20	48
Leaf death1 (1–9)[b]	40	36	25	–	–	–
Leaf death2 (1–9)[b]	28	52	20	–	–	–

[a] Ear aspect, on a scale of 1 to 5, where 1 = clean, uniform and well-filled ears and 5 = ears with undesirable features.

[b] Leaf death score, on a scale of 1 to 9, where 1 = less than 10% leaf death area and 9 = more than 80% leaf death area.

plant height, ASI, ear aspect and the second leaf death scores. Hybrids of tolerant x tolerant (T x T), tolerant x susceptible (T x S) and S x T crosses had higher grain yields, taller plants and larger stay green scores compared to S x S crosses (Table 2). The T x T crosses had the shortest ASI (about 2 days) compared with the other hybrid groups. Hybrids of T x T crosses had the highest mean grain yield (1.99 Mg ha^{-1}) followed by T x S (1.88 Mg ha^{-1}) and S x T (1.85 Mg ha^{-1}), while S x S crosses had the lowest (1.48 Mg ha^{-1}). Grain yields obtained in our study support the original hypothesis that hybrids with at least one drought tolerant parental line would give higher yields than crosses formed from two susceptible lines (Kirkham *et al.* 1984; Betran *et al.* 2003).

Days to silking were similar for all hybrid groups indicating that maturity was not a factor for yield differences among hybrid groups. The difference in yields was largely due to the level of drought tolerance in inbred lines.

In the combining ability analysis, mean squares for both males within sets and females within sets were significant for all traits except number of ears plant^{-1} under WS. Similarly, the female x male within sets interaction was significant for all traits except number of ears plant^{-1} under WS (Table not presented).

Partitioning of hybrid sums of squares showed that GCA accounted for > 50% of the total variation among hybrids for most of the traits under both WS and WW conditions (Table 3). SCA was slightly higher than GCA only for number of ears plant^{-1} under WW. The relative

Table 4. Estimates of GCA effects for grain yield of 24 maize inbred lines evaluated under water stress and well-watered condition at Ikenne in 2002.

		Water stress		Well-watered	
Inbred	Category[†]	GCA-male	GCA-female	GCA-male	GCA-female
9613	T	0.05	-0.02	0.17	0.12
9006	T	0.16*	0.39**	1.06**	0.71**
4058	T	0.10	-0.12	0.03	-0.21*
POP 10	T	0.20*	-0.05	0.38**	0.86**
1824	T	-0.12	0.42**	0.11	0.56**
4001	T	0.20*	-0.05	0.18	-0.54**
KU1409	T	0.34**	0.08	0.24*	0.03
(POOL 26 Sequia)C3F2	T	-0.12	-0.16*	0.38**	0.45**
9450	T	-0.40**	0.11	-0.80**	0.06
161	T	0.12	-0.03	0.69**	0.37**
(KU1403x1368)STR	T	0.04	-0.21**	-0.57**	-0.76**
(TZMI501xKU1414x501)	T	0.08	0.10	-0.09	0.78**
5012	S	-0.26*	0.26**	-0.03	-0.36**
5057	S	-0.06	-0.62**	-0.37**	-0.79**
Fun.47-3	S	0.11	0.10	-0.25*	0.50**
9432	S	-0.13	0.39**	0.17	-0.13
GH 24	S	0.10	0.13	0.47**	0.43**
(KU1403x1368)	S	0.20*	0.08	-0.95**	-0.16
1808	S	-0.35**	-0.39**	-0.61**	-0.89**
9071	S	-0.01	-0.09	0.50**	0.34**
9485	S	-0.30**	0.01	-0.26*	0.12
4008	S	0.13	-0.05	0.48**	-0.54**
Mok Pion-Y-S4	S	0.10	0.07	-0.38**	0.31**
(KU1403x1368)BC2	S	-0.08	-0.25**	-0.51**	-1.21**
SED		0.04	0.05	0.10	0.12

[†] T = tolerant and S = susceptible.
*, ** Significant at 0.05 and 0.01 levels of probability, respectively.
SED = standard error of the difference between estimates of two GCA estimates.

importance of GCA effects was greater than SCA effects, indicating the importance of additive gene effect in the inheritance of yield and other traits under drought stress. The significant SCA mean square suggests that hybrid development could be employed to exploit non-additive gene action to improve drought tolerance in this set of maize lines. Menkir and Akintunde (2001) had earlier noted the superiority of hybrids over other genotypes under WS conditions.

Most tolerant parental lines had positive GCA effects for grain yield, while most susceptible lines showed consistently negative GCA effects for grain yield under both WS and WW conditions. Inbred lines KU1409 and 9006 had the highest positive GCA-male effects under WS and WW, while 1824 and POP10 had the highest positive GCA-female effects under WS and WW (Table 4). The estimates of SCA effects were positive for 56% of T x T, 52% of T x S and 50% of the S x T crosses, while more than 50% of S x S crosses had consistently negative SCA effects for both irrigation treatments (Table not presented).

Table 5. **Phenotypic correlation coefficients between inbred traits and their hybrid counterparts, and estimates of average heterosis for 24 maize inbred lines evaluated *per se* and in hybrid combinations under water stressed and well-watered conditions in Ikenne, 2002.**

	Correlation coefficient (r-value)		Average heterosis (%)	
Inbred	Water stressed	Well watered	Water stressed	Well watered
Silking date (days)	0.37**	0.63***	-10.79**	-6.84*
ASI (days)	0.28**	0.49***	-62.20	7.38
Plant ht (cm)	0.63***	0.66***	33.10**	27.22**
Ear ht (cm)	0.57**	0.64***	38.96**	32.16**
Ear No. plant^{-1} (no.)	0.26*	0.39***	26.74	13.46
Ear aspect (1–5)[a]	0.10	0.50***	-22.72	-1.54
Grain yield (Mg ha^{-1})	0.34**	0.36**	68.89**	72.49**
Leaf death1 (1–9)[b]	0.60***	-	-6.66	-
Leaf death2 (1–9)[b]	0.54***	-	-7.02	-

*, **, *** Significant at 0.05, 0.01 and 0.001 levels of probability, respectively.

[a] Ear aspect on a scale of 1 to 5, where 1 = clean, uniform, large, and well-filled ears and 5 = ears with undesirable features.

[b] Leaf death score on a scale of 1 to 9, where 1 = less than 10% dead leaf area and 9 = more than 80% dead leaf area.

The potential of a parental line in hybridisation may be assessed by its *per se* performance, F_1 performance, the GCA and SCA effects (Verma and Srivastava 2004). Our results showed that KU1409, 9006, 1824, POP10, (TZMI501x KU1414x501) and 4001 could be used as potential parents in developing hybrids for drought-prone as well as optimal growing conditions.

Hybrids expressed superiority over their parental lines for grain yield, number of ears plant^{-1}, and plant and ear heights at both irrigation levels (Table 5). Phenotypic correlation of parental inbred traits and their hybrid counterparts differed significantly from zero, with the exception of ear aspect under WS. These results indicated that drought tolerant inbred lines generally produced drought tolerant hybrids.

Conclusions

From the results of this study we conclude that, in maize, the level of drought tolerance in parental inbreds affects the expression of drought tolerance in their hybrid progenies. Most hybrids with at least one drought tolerant parent produced higher yields under drought than hybrids with both parents susceptible to drought stress.

Furthermore, GCA effects accounted for > 50% of the variation among hybrids, indicating the importance of additive gene effect in the inheritance of yield and other traits under drought. Significant SCA effects, however, suggested that hybrid development could be employed to exploit non-additive gene action to improve drought tolerance. The significant correlations of hybrid means and mid-parent values also indicated that drought tolerant inbred lines generally produced drought tolerant hybrids.

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Contribution of introduced inbred lines to maize varietal improvement for acid soil tolerance

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Abstract

One hundred and five F1 hybrids from a diallel cross among 15 inbred lines of maize (*Zea mays* L.) were evaluated for two years in Nkoemvone acid-soil. The 15 inbred parents consisted of five IRAD lines (87036, 91105,Cam-Inb gp 1, NCRE gp 8 and ATP-S4-25w), one IITA line (9450), six introduced lines from CIMMYT-Cali-Colombia (Cml 365, Cml 358, CLA 17, CLA 18, Cml 361,Entrada 3), two lines from CIMMYT-Mexico (Cml 247, Cml 254) and one other line. The evaluation trials were conducted under two soil treatments, O and T. The treatment coded O consisted of acid soil with low pH and high Al saturation while the T treatment consisted of acid soil corrected with 2 tons/ha of dolomitic lime and 4 tons/ha of poultry manure. The objectives of the study were to (i) evaluate the genetic potential of introduced inbred lines for the improvement of acid tolerance in varieties adapted to West and Central Africa (WCA) and (ii) identify high yielding crosses under acid soil conditions. Results indicated that the highest-yielding 20 hybrids on acid-soil involved 60% introduced inbreds from CIMMYT and only 40% locally adapted inbred lines. The six inbreds with positive general combining ability (GCA) included four introductions and only two IRAD lines. Soil acidity tolerance was predominantly under non-additive gene action, suggesting that two heterotic pools could be developed; one from CIMMYT lines and the other from IRAD and IITA lines.

Résumé

Cent cinq hybrides F1 d'un croisement diallèle entre 15 lignées de maïs (*Zea mays* L.) ont été évalués pendant deux ans dans les sols acide de Nkoemvone. Les 15 lignées parentales comprenaient 5 lignées de l'IRAD (87036, 91105, Cam-Inb gp 1, NCRE gp et ATP –S4-25w), une lignée de l'IITA (9450), six lignées introduites du CIMMYT-Cali-Colombia (Cml 365, Cml 358, CLA 17, CLA 18, Cml 361 Entrada 3), deux lignées de CIMMYT-Mexico (Cml 247, Cml 254) et une autre lignée. Les hybrides ont été évalués sur des sols acides avec deux traitements de sol (O, T). Le traitement O désignait le sol acide ayant un pH faible et une saturation élevée en Al3+. Le traitement T désignait un sol acide corrigé avec 2 tonnes ha-1 de chaux dolomitique et 4 tonnes ha-1 de fiente de volaille. Les objectifs de l'étude étaient de (i) évaluer le potentiel génétique des lignées introduites dans l'amélioration de la tolérance au sols acides dans le germplasme adapté à l'Afrique de l'ouest et du centre (AOC), et (ii) identifier des croisements à hauts rendements dans des conditions de sols acides. Les résultats ont indiqué que les 20 hybrides les plus productifs dans les sols acides impliquaient 60% des lignées introduites du CIMMYT - Colombie et seulement 40% des lignées locales adaptées. Les six lignées ayant une aptitude générale à la combinaison (AGC) positive, comprenaient 4 introductions et 2 lignées de l'IRAD. La tolérance à l'acidité des sols était essentiellement conditionnée par une action de gènes non – additifs, suggérant que 2 pools hétérotiques pourraient être formés, l'une sur la base des lignées du CIMMYT, et l'autre à partir des lignées de l'IRAD et de l'IITA.

Introduction

Acid soils cover approximately 3950 million ha, which is about 30% of the total icefree land area on the earth (Von Uexkull and Mutert 1995; Salazar *et al.* 1997). In the tropics, more than 8 million ha of acid soils are planted with maize, and 17% of tropical Africa is covered by acid soil (Von Uexkull and Mutert 1995). In Cameroon, acid soil covers 75% of the soil, and this is mainly in the humid forest zones.

Acid soils are characterized by low pH, deficiency in Ca, Mg, P, K and Mo contents and toxic levels of Al and Mn (Granados *et al.* 1993). These characteristics limit the fertility of the soil and inhibit root development, thus leading to low water and nutrient uptake and low maize yields (Duque-Vargas *et al.* 1994).

Soil amendment with lime, phosphorus and organic matter has been suggested to bring unproductive acid soil under acceptable agricultural production. However, such solutions are temporary and expensive for the resource-poor farmers (Thé *et al.* 2003). A more permanent solution affordable by resource-poor farmers is the development of maize varieties that are tolerant of acid soils. Such varieties have the added advantage of being inexpensive, environmentally friendly, and a sustainable solution to crop production on acid soils.

Significant genetic variation for tolerance to soil acidity has been reported. Early studies demonstrated qualitative inheritance (Rhue *et al.* 1978; Miranda Filho *et al.* 1984). Quantitative inheritance to Al resistance was later demonstrated (Lima *et al.* 1992; Duque-Vargas *et al.* 1994; Pandey *et al.* 1994; Borrero *et al.* 1995; Salazar *et al.* 1997;

Eticha *et al.* 2005). Considerable progress has been made in breeding maize for acid soil tolerance through recurrent selection (Lima *et al.* 1992; Granados *et al.* 1993; Ceballos *et al.* 1995). However, most of the materials used exhibited significant additive genetic variance x environment interaction, suggesting that the materials had specific adaptation (Borrero *et al.* 1995). Therefore, to identify and improve varieties that would perform well under acid soil and non-acid soil environments, selections would have to be based on performance across a range of environments. This would lead to germplasm with broader adaptation. One way to obtain such germplasm is by introgression of exotic germplasm to locally adapted cultivars.

Heterosis has been reported for grain yield of maize under acid soil conditions (Lima *et al.* 1992; Pandey *et al.* 1994; Ceballos et al. 1998). This information led to extensive selection of inbred lines for hybrid development under soil acid conditions (Narro *et al.* 2000; Thé *et al.* 2002). In the present study, 15 such inbreds were used in a diallel cross and the resulting 105 single-cross hybrids were used to (i) evaluate the genetic potential of introduced inbred lines for the improvement of acid tolerance in varieties adapted to WCA and (ii) identify high yielding crosses under acid soil conditions. The information obtained on the mode of gene action would assist the breeder to classify the lines into heterotic pools for better exploitation of heterosis under acid soil conditions.

Materials and Methods

Fifteen maize inbred lines with different genetic backgrounds were crossed in a diallel scheme to produce 105 F1 hybrids. The inbred parents included 4 lines introduced from CIMMYT-Colombia (Cml 365, Cml 358, Cla 17, Cla 18), 2 inbred lines from CIMMYT-Mexico (Cml 247 and Cml 254), 1 inbred line from IITA-Ibadan (9450), 2 lines from IRAD-Cameroon with mid-altitude adaptation (87036, 91105) and 3 lines from IRAD-Cameroon with lowland adaptation (Cam inb gp117, NCRE gp28, and ATP S4-25W). The characteristics of the parental lines are presented in Table 1.

The 105 F1 hybrids were evaluated for 2 years at Nkoemvone (Ebolowa, 2° 43′N, 12° 15′E, 637 mas, oxisol, typical Kandidious) in 2003 and 2004. The hybrids were tested under two soil treatments: native acid soil with toxic level of Al and non-acid soil, which were limed plots of native soil. The experimental design was a split-plot with soil treatment as main plot and hybrids as sub-plot. The hybrids were arranged in a randomized complete block design with 3 replicates. Each experimental unit consisted of a single 5m row, with 0.75m between-row spacing. The spacing between maize hills in the same row was 0.5 m.

Table 1. **Characteristic of 15 parental inbred lines crossed in a diallel scheme to produce 105 single-cross hybrids evaluated under acid soil and non-acid soil conditions in Cameroon, 2003 and 2004.**

Parent	Origin	Adaptation	Color	Remarks
87036	IRAD	Mid-altitude	White	Good general combiner
91105	IRAD	„	„	-
ATP-S4-25W	IRAD	Lowland	„	Tolerant to acid soil
NCRE gp28	IRAD	„	„	Sensitive to acid soil
Cam Inb gp117	IRAD	„	Yellow	Tolerant and P efficient
9450	IITA	„	„	Moderately tolerant
Cml 247	CIMMYT-Mexico	„	White	Heterotic to Cml 254
Cml 257	CIMMYT-Mexico	„	„	Heterotic to Cml 247
Cml 358	CIMMYT-Mexico	„	„	Tolerant to acid soil
Cml 361	CIMMYT-CALI	„	Yellow	Eto background
Cml 365	CIMMYT-CALI	„	White	SA8, Tuxpeno
Lin P	CIMMYT-CALI	„	Yellow	P efficient
Cla 17	CIMMYT-CALI	„	“	Heterotic to CLA 18
Cla 18	CIMMYT-CALI	„	“	Heterotic to CLA 17
Entrada	CIMMYT-CALI	„	White	SA 7

C M CIMMYT Mexico CC CIMMYT Cali

Two maize seeds were planted per hill with no thinning. Plant density at planting was approximately 53,333 plants /ha. Weeds and insects were chemically controlled. Rainfall in Ebolowa averaged 1800 mm. The field trials received the recommended fertilizer rate in split application, which consisted of a basal dose of 37 N, 24 P_2O_5 and 14 K_2O kg/ha applied 7 days after planting and the remaining 63 kg N/ha was applied 30 days after planting as urea.

Data were recorded on the number of days from planting to 50% anthesis (DTA) and silking (DTS), ear and plant heights (from the soil surface to the node of the top ear and the flag leaf, respectively). All plants in a plot were hand harvested. Grain yield (Mg ha^{-1}) was determined, assuming 80% shelling percentage and adjusting grain weight to a standard 155 kg^{-1} grain moisture.

Analysis of variance was performed using the GLM procedure of SAS (SAS Institute, 1989). Year, replicates within year, and soil treatments were considered as random effects and pooled as environmental effects. Hybrids were considered as fixed effects. Diallel analysis was carried out using Griffing's (1956) method model 1 (excluding parents and reciprocal F1s), to determine the general combining ability (GCA) and the specific combining ability (SCA) effects.

Table 2. **Soil characteristics of Nkoemvone, Cameroon, at the beginning of the field trials, 2003.**

Characteristic	0-20 cm	20-40 cm	Means
PH (water)	4.33	4.52	4.43
Ca cmol(+) /kg	0.43	0.25	0.34
Mg cmol(+) /kg	0.22	0.09	0.15
K cmol(+) /kg	0.11	0.07	0.09
Na cmol(+) /kg	0.21	0.25	0.23
Al cmol(+) /kg	2.09	0.04	2.06
Mn cmol(+) /kg	0.04	0.02	0.03
H^+ cmol(+) /kg	0.45	0.35	0.40
CEC cmol(+) /kg	4.31	3.99	4.15
T/S	22.22	16.69	18.45
P (olsen)	95.00	38.00	66.50

Table 3. **Mean values for grain yield, number of days to silking (DTS), anthesis-silking interval (ASI) and plant height for 105 F1 hybrids evaluated under acid soil (O) and non-acid soil (T) conditions in Cameroon, 2003 and 2004.**

Year	Grain yield (t/ha)			DTS (days)		ASI (days)		Plant ht (cm)	
	O	T	% R[+]	O	T	O	T	O	T
2003	1.44	4.17	65.5	69	63	4	3	132	192
2004	1.30	3.07	57.7	71	64	5	2	129	184
Mean	1.37	3.62	62.2	70	64	5	3	131	188

[+] %R = Percent reduction of O relative to T.

Results and Discussion

Results of Nkoemvone soil analysis at the beginning of the trials are presented in Table 2. The pH of the soil was less than 5.0 (pH = 4.43) and Al^{3+} was at toxic level. Therefore, the soil acidity was mainly due to aluminium.

Means for measured traits presented in Table 3 revealed that, relative to the non-acid soil, grain yield of the hybrids on acid soil was reduced by about 62%, DTS was lengthened by 6 days, ASI increased by 2 days and plant height decreased by 31%. These results confirm earlier reports that soil acidity is a major constraint to maize production (Borrero et al. 1995; Duque Vargas *et al.* 1994).

Under both soil conditions, but particularly under the non-acid soil condition, grain yield was lower in 2004 than 2003. A dry spell of about 10 days that occurred during the 2004 cropping season

Table 4. Diallel analysis of variance for grain yield (t/ha) of 105 F_1 hybrids evaluated under acid soil (O) and non-acid soil (T) conditions in Cameroon, 2003 and 2004.

Source of variation	D.F.	Mean squares	
		O	T
Years	1	13.27**	161.90**
Hybrids	104	3.12**	3.84**
GCA	14	3.38**	4.31**
SCA	90	2.60*	2.40
Hybrid × Year	104	1.09**	1.84**
Error	208	0.55	

may have been the cause of the lower hybrid performance that year. The reduction in grain yield, however, did not translate into greater grain yield reduction due to soil acidity. In other words, 2003 that was apparently more favorable suffered larger grain yield reduction than 2004 that had a dry spell.

Analysis of variance for grain yield indicated highly significant year, hybrid, hybrid × year interaction and GCA effects under both acid soil (O) and non-acid soil (T) conditions (Table 4). SCA effects were also statistically significant under acid soil but not under non-acid soil conditions.

Significant hybrid × year interaction effects obtained in our study, to some extent, provide experimental evidence in support of the suggestion made by Borrero *et al.* (1995) that selection on acid soil would be more effective if it is based on performance across a range of environments, including acid soil, non-acid soil, moisture stress and non-stress conditions.

Hybrid performance

Significant differences were detected among the hybrids on both acid soil and non-acid soil. On acid soils, grain yield of the hybrids ranged from 0.7 to 2.9 t/ha while on non-acid soil, the yields ranged from 1.5 to 6.6 t/ha.

Mean grain yields of the top 20 hybrids selected under acid soil conditions ranged from 2.08 to 2.88 t/ha on acid soil and from 2.57 to 5.96 t/ha on non-acid soil, with overall means of 2.39 and 3.89 t/ha, respectively (Table 5). This represented 74% and 7% selection progress for grain yield over the means of the trial on acid and non-acid soil, respectively. The means of the selected hybrids were not significantly different under soil acid conditions but the differences under non-acid soil conditions were highly significant. Therefore, the

Table 5. **Mean grain yield (t/ha) and type of cross of the top 20 hybrids selected from 105 F1 hybrids evaluated under acid soil (O) and non-acid soil (T) conditions in Cameroon, 2003 and 2004.**

Hybrids	Grain yield (t/ha)			Type of cross^{++}
	O	T	%R^{+}	
Cm/ 365×Cam Inb gp 17	2.88	3.34	13.7	I×A
87036 × 91105	2.87	4.68	38.6	A×A
C/A 18 × 91105	2.75	4.13	33.4	I×A
87036× Cml 365	2.66	2.91	8.4	A×I
ATPSU-25w × Cml 358	2.61	4.08	36.0	A×I
Cml 247× ATPSU-25w	2.49	5.34	53.4	I×A
Cam Inb gp 17× 91105	2.48	5.96	58.4	A×A
Cml 254 × Cml 361	2.35	2.92	19.5	I×I
C/A 18 × 9450	2.35	4.05	41.9	I×A
C/A 18 × Cml 361	2.34	3.66	36.1	I×I
Cml 247 × NCRE gp 8	2.33	3.82	39.0	I×A
Cml 254 × C/A 18	2.30	5.63	59.1	I×I
Cml 254 × 9450	2.30	2.57	10.5	I×A
Cml 365 × 9450	2.30	4.33	46.9	I×A
ATPSU-25w × NCRE gp 8	2.21	3.87	42.9	A×A
Entrada 3 × Cml 361	2.20	3.20	31.3	I×I
Cml 254 × NCRE gp 8	2.15	3.70	41.9	I×A
Cml 254 × C/A 17	2.10	3.30	36.4	I×I
Cml 365 × 91105	2.09	2.72	23.2	I×A
Cml 247 × Cam Inb gp 17	2.08	3.49	40.4	I×A
Mean of selected hybrids	2.39	3.89	41.8	
Mean trial	1.37	3.62	62.2	
C.V (%)	45.50	26.90	–	
S.E	1.10	0.50	–	

$^{+}$ %R = Percent reduction of O relative to T.

$^{++}$I = Introduced inbred line, A = Adapted inbred line.

hybrids were compared with emphasis on the yield reduction caused by soil acidity.

The selected top 20 hybrids exhibited 41.8% grain yield loss under acid soil relative to non-acid soil conditions. This was about 20% lower than the overall grain-yield reduction in the trial.

Grain yield loss exhibited by selected hybrids ranged from 8.4% for 86036 x Cml 365 to 59.1% for Cml 245 x Cla 18. Five hybrids exhibited 25% or less grain yield loss due to soil acidity. The hybrids, 87036 x Cml 365 (8.4%), Cml 254 x 9450 (10.5%), Cml 365 x Cam Inb gp117 (13.7%), Cml 254 x Cml 251 (19.5%) and Cml 365 x 91105 (23.2%) could be considered tolerant of soil acidity. Each of the five hybrids had at least one parent introduced from CIMMYT, and they produced grain yield of 2.61 t/ha or more on acid soil.

Five hybrids had relatively high grain yield on acid soil but were not necessarily tolerant of acid soil. Three of the hybrids had yield

Table 6. **Number of adapted x adapted (A x A), introduced x adapted (I x A) and intoduced x introduced crosses, their mean grain yield and percent yield reduction due to soil acidity for the top 20 hybrids selected from 105 F1 hybrids evaluated under acid soil (O) and non-acid soil (T) conditions in Cameroon, 2003 and 2004.**

Hybrid type	Number	% Top 20	Grain yield O	Grain yield T	% RGY
A x A	3	15	2.52	4.84	47.9
I x A	12	60	2.42	3.71	34.8
I x I	5	25	2.26	3.74	39.6

reductions larger than 25% due to soil acidity. The hybrids, which included Cml 365 x Cam Inb gp117 (2.88 t/ha), 87036 x 91195 (2.87 t/ha), Cla 18 x 91105 (2.75 t/ha), 87036 x Cml 365 (2.66 t/ha) and ATP-S4-25W x Cml 358 (2.61 t/ha), were considered efficient on acid soil. Again, all of the hybrids, except for 87036 x 91105, had at least one parental line introduced from CIMMYT. Two of the hybrids, Cml 365 x Cam Inb gp117 and 87036 x Cml 365, with yield reductions of only 13.7 and 8.4%, respectively were both efficient and tolerant of acid soil.

Among the top 20 hybrids, three (15%) originated from locally adapted x locally adapted (A x A) lines; 12 (60%) were developed from crosses between introductions from CIMMYT x locally adapted lines (I x A), and five (25%) were crosses between 2 introduced inbred lines (I x I) (Table 6). On average, the A x A crosses exhibited the best performance on acid soil (2.52 t/ha) as well as on non-acid acid soil (4.84 t/ha); however, they also showed the largest grain yield loss due to soil acidity. The I x A hybrids showed an average of 2.42 t/ha on acid soil and exhibited the smallest grain yield loss due to soil acidity. They were, therefore, more tolerant than crosses between locally adapted germplasm.

Gene effect and breeding values

Significant GCA and SCA mean squares (Table 4) suggested that, tolerance to soil acidity was controlled by additive as well as non-additive gene effects, with the preponderance of additive effects. These results corroborate those of earlier workers (Lima *et al.* 1992; Duque-Vargas *et al.* 1994; Borrero *et al.* 1995; Salazar *et al.* 1997). Progress could be achieved by subjecting the parental populations from which the inbred lines were developed to recurrent selection for improved performance. In addition, the presence of non-additive gene action suggested that high yielding hybrids on acid soil may be obtained by classifying the inbred lines into different heterotic groups

Table 7. General combining ability (GCA) effects for grain yield of 15 parental inbred lines used in a diallel cross to produce 105 F1 hybrids evaluated under acid soil (O) and non-acid soil (T) conditions in Cameroon, 2003 and 2004.

Parental inbred line	GCA (t/ha)	
	O	T
87036	–0.05	0.96
Cml 365	0.22	0.12
Cml 247	–0.20	–0.12
Cml 254	0.90	–0.41
Cml 358	0.23	–0.09
Cml 361	–0.50	–0.64
Lin P	–0.10	–0.13
Entrada 3	–0.11	–0.15
ATP-S_4-25W	0.42	–0.09
NCRE $gp_2$8	–0.27	0.48
Cla 17	0.10	–0.02
Cla 18	–0.30	–0.40
Cam Inb $gp_1$17	0.26	1.16
91105	–0.10	–0.02
9450	–0.50	–0.64

and crossing lines from the different groups to produce hybrids. This study showed that 60% of the top 20 hybrids originated from crosses between lines from Cali-Colombia and lines that originated from IITA-Ibadan, Nigeria and IRAD Cameroon. Therefore, two heterotic pools could be developed on the basis of CIMMYT-Colombia and IRAD-IITA inbred lines, respectively.

The GCA effects of the parental inbred lines on both acid and non-acid soils are presented in Table 7. On acid soil, Cml 365, Cml 254, Cml 358, ATP-S4-25W, Cla 17, and Cam Inb gp117 exhibited positive GCA effects. Four (66%) of these lines originated from CIMMYT. On non-acid soil, only four inbred lines—87036, Cml 365, NCRE gp28, and Cam Inb gp117–had positive GCA effects. All CIMMYT lines, except Cml 365, exhibited negative GCA effects on non-acid soil. Only Cml 365 and Cam Inb gp117 had positive GCA on both acid and non-acid soils. Crosses between these two lines gave the best hybrid on acid soil with only 13.7% grain yield loss relative to non-acid soil. These two inbreds could be used as donor parents in breeding programs for Al tolerance.

Conclusion

The results of this study showed that maize cultivation on acid soils could lead to grain yield reduction of 60% or more in tropical environments. Grain yield loss due to soil acidity could be minimized by the development of hybrids from crosses between locally adapted inbred lines and those introduced from CIMMYT Cali, Colombia acid soil program.

Al tolerance is under both additive and non-additive gene action. Therefore, two heterotic pools could be developed and used as source populations from which second generation inbred lines could be extracted to improve hybrid performance on acid soils. Inbred lines from IITA, Ibadan, Nigeria, and IRAD, Cameroon, could be screened for Al tolerance and recombined to form one of the pools. The second pool could be developed by intermating selected lines from the numerous CIMMYT lines extracted from SA_3, SA_4, SA_6 and SA_7 populations.

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Combining ability of diverse maize inbred lines under *Striga* infestation in Nigeria and Bénin

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Abstract

Striga hermonthica (Del.) Benth. is a parasitic weed that seriously constrains maize (*Zea mays* L) production in sub-Saharan Africa. Yield losses from the infestation of *S. hermonthica* on maize can reach up to 100%. Host plant resistance is the most effective means of control of the weed, but the level of resistance in the presently available sources is not high enough to completely control the weed. Higher levels of resistance have been found in *Zea diploperennis* Iltis, Doebley & Guzman, a wild relative of maize. The objective of this study was to determine the mode of inheritance of resistance to *S. hermonthica* in five inbred lines derived from *Z. mays x Z. diploperennis* crosses (Zd lines), one inbred line form TZL Composite 1, and four standard inbred lines. The ten lines were crossed in a diallel fashion and the resulting 45 single-cross hybrids were evaluated under artificial *Striga* infestation at two locations each in Nigeria and Republic of Benin for two years. The results showed that general combining ability (GCA) mean squares were much larger than those for specific combining ability (SCA) for grain yield under *Striga* infestation, *Striga* damage symptom score, and numbers of emerged *Striga* plants, indicating that, for these traits, additive genetic effects were more important than non-additive effects. Interactions of hybrids with environments (years and locations) were significant for the three traits. The Zd inbred lines had positive GCA values for grain yield and negative values for *Striga* damage symptom score, and numbers of emerged *Striga* plants. On the other hand the standard inbred lines, which were susceptible, had negative GCA values for grain yield and positive values for *Striga* damage symptom score and number of emerged *Striga* plants. Inbred Zd 551 was the most *Striga*-resistant line in the study. This line as well as other Zd lines may represent better sources of resistance to *Striga* than the standard inbred lines.

Résumé

Striga hermonthica (Del.) Benth., est une herbe parasite limitant la production du maïs (*Zea mays* L.) en Afrique sub-Saharienne. Les pertes en rendement du maïs dues à *S. hermonthica* peuvent atteindre 100 %. La résistance génétique est la méthode la plus efficace pour lutter contre cette plante parasite, mais le niveau de résistance dans le germplasme actuel n'est pas suffisant pour lutter contre le *Striga*. Des niveaux élevés de résistance ont été découvertes dans *Zea diploperennis*, Iltis, Doebley et Guzman, une une espèce sauvage voisine du maïs. L'objectif de cette étude était de déterminer le mode de transmission de la résistance à *Striga* chez de 5 nouvelles lignées derivées du croisement *Zea mays* x *Z. diploperennis*, une lignée autogame derivée de TZL composite 1, et quatre lignées standard. Les 10 lignées ont été croisées dans un schéma diallèle et les 45 hybrides simples résultants ont été évalués sous infestation artificielle de *Striga* dans deux localités chacune au Nigéria et en République du Bénin pendant deux années. Les carrés moyens de l'aptitude générale à la combinaison étaient plus élevés que ceux de l'aptitude spécifique à la combinaison pour le rendement grain sous infestation de *Striga,* les scores des dommages et le nombre de plants de *Striga* émergés, indiquant que les effets génétiques additifs étaient plus importants que les effets non-additifs qui contrôlent ces caractères. Les interactions entre hybrides et années d'une part et entre hybrides et localités d'autre part, étaient significatifs pour tous les 3 caractères. Les nouvelles lignées Zd ont eu des effets positifs d'aptitude générale à la combinaison pour le rendement grain et des effets négatifs d'aptitude générale à la combinaison pour les scores dûs aux dommages de *Striga* et le nombre de plants de *Striga* émergés. Par contre, les lignées susceptibles ont eu des effets négatifs d'aptitude générale à la combinaison pour le rendement grain et des effets positifs d'aptitude générale à la combinaison pour les scores dûs aux dommages de *Striga* et le nombre de plants de *Striga* émergés. La lignée Zd 551 était la lignée la plus résistante au *Striga* de toute l'étude. Les nouvelles lignées Zd peuvent représenter de meilleurs sources de résistance au *Striga* que l'ensemble des vieilles lignées.

Introduction

Parasitic witchweed (*Striga* spp.) infestation is a major constraint to crop production in the savanna ecologies across most countries of sub-Saharan Africa. *Striga* is an obligate hemiparasite that threatens crop production since most of its damage occurs underground before it emerges and is, therefore, out of reach of most control measures. Depending on the species and the environmental conditions, a *Striga* plant may produce 40,000 to 90,000 seeds (Ejeta *et al.* 1997). In sub-Saharan Africa, maize (*Zea mays* L.) is highly susceptible to two species, *S. hermonthica* and *S. asiatica*. Yield losses of *Striga*-infested crops can range from 50% to more than 90% (Lagoke *et al*. 1991; Ransom *et al.* 1990; Kim 1991; Kim *et al.* 1997). Control of the parasitic weed is very complex and difficult. Host plant resistance has been found to be effective and relatively cheap from the viewpoint of resource-poor farmers in the West and Central Africa (WCA) sub-region. It has, therefore, been recommended that any effective *Striga* control strategy must include host plant resistance (Robinson and Dowler 1990; Kim 1991; Kim and Winslow 1991; Kim and Adetimirin 1995; Adetimirin *et al*. 2000a, b).

Some maize varieties have demonstrated partial resistance to *Striga* under field conditions. The varieties supported fewer fully developed *Striga* plants (Ransom and Odhiambo 1995) while other varieties have demonstrated *Striga* tolerance by supporting growth of many plants of the parasite with little or no reduction in grain yield (Kim 1991; Kim and Adetimirin 1995). However, maize varieties that completely prevent successful development of *S. hermonthica* are presently not available. Lane *et al*. (1997) reported that such resistance exists in *Zea diploperennis* Iltis, Doebley and Guzman (Iltis *et al.* 1979).

The present study involved inbred lines derived from *Z. mays* x *Z. diploperennis* crosses. The objective of the study was to determine the mode of inheritance of resistance to *S. hermonthica* among the new maize inbred lines, using diallel analysis.

Materials and Methods

A 10 x 10 diallel cross involving ten inbred lines was made and the resulting 45 single-cross hybrids were evaluated at Abuja (4°25′ N, 7°33′ E) and Mokwa (9°30′ N, 5°07′ E) in Nigeria, Ina (9°30′ N, 2°62′ E) and Angaradébou (11°33′ N, 2°13′ E) in the Republic of Benin. Field evaluations were carried out in the two countries during the major rainy season in 2001 and 2002.

Five of the inbred lines were derived from crosses between *Z. mays* x *Z. diploperennis,* one line was derived from TZL Comp.1 and four were standard inbred checks (Table 1).

The F_1 hybrids were evaluated in infested and non-infested plots, which were adjacent and separated by a 1.5 m alley. Alpha lattice design with three replicates was used. A pair of infested and non-infested plots was planted with each F_1 hybrid. Proximity of the infested and non-infested plots provided the basis for a valid estimate of yield loss due to *Striga* infestation. *Striga* seeds used for the trials were collected in the previous year from each of the locations. Plots consisted of single rows, each 5 m long spaced 0.75 m apart. Maize seeds were planted at 0.25 m interval within each infested and non-infested row. Artificial *Striga* infestation was achieved by applying a

Table 1. Names and origin of the inbred lines evaluated in 10 x 10 diallel crosses in Nigeria and the Republic of Benin, 2001 and 2002.

No.	Inbred code	Pedigree	Reaction to *Striga hermonthica*
1	Zd 282	Z.diplo. BC4-282-5-2-2-1	Very high stimulation ability
2	Zd 290	Z. diplo BC4-290-4-2-1-1	Very low stimulation ability
3	Zd 467	Z.diplo. BC4-467-4-1-2-1	Low stimulation ability
4	Zd 472	Z.diplo. BC4-472-2-2-2-3	Very low stimulation ability
5	Zd 551	Z.diplo. BC4-551-2-1-#-2	Moderate stimulation ability
6	TZL TC87	TZL Comp.1 (TC87)-2-#-4	Very low stimulation ability
7	1393	Guna Caste 7729 × TZSR	High *Striga* emergence
8	5057	Tlatt 7844 × TZSR	Very high *Striga* emergence
9	9006	Mo 17 × TZSR	Moderate *Striga* emergence
10	9450	B 73 BC 3 × RppSR	Low *Striga* emergence

Striga seed-sand mixture in holes about 5 cm deep. The estimated number of germinable *Striga* seeds per hill was 3,000. In infested rows, two maize seeds were planted in holes already infested with *Striga* seeds and lightly covered with sand. Maize planting was carried out on the same day that *Striga* seed was applied.

Plots were thinned to one plant per hill two weeks after planting to give a population density of 53,333 plants/ha. A total of 60 kg N was applied in two equal splits, first at planting and 3 weeks later. Also at planting, 60 kg/ha each of P_2O_5 and K_2O was applied. Weeds other than *Striga* were removed by hand throughout the cropping season. Analysis of variance (ANOVA) for hybrid trials was performed with SAS program (SAS Institute 2001). This was followed by diallel analysis to obtain general (GCA) and specific (SCA) combining ability effects using Griffing's (1956) method 4, Model I for fixed effects.

Results and Discussion

In the across-site ANOVA for grain yield, GCA mean squares were 23 and 2 times larger than the SCA mean squares for infested and non-infested plots (Table 2). GCA x Env interaction mean squares for grain yield was significant for both *Striga*-infested and *Striga*-free treatments while the SCA x Env interaction mean squares were not significant for grain yield under *Striga*-free condition. Similarly, GCA and GCA x Env interaction mean squares were highly significant for ear number, host damage score and number of emerged *Striga* plants per plot, although GCA mean squares were 38, 26 and 18 times larger than SCA mean squares for the three traits. SCA and SCA x Env mean squares for these traits were not significant. The trends observed in the combined ANOVA were generally maintained in the individual countries, with very few deviations (Tables 3 and 4).

Table 2. **Mean squares of grain yield, number of ears/plant, host damage score, and number of emerged *Striga* plants at 10 weeks after planting from a combined analysis of variance for diallel crosses of 10 inbred lines tested at Abuja, Mokwa, Ina and Angaradébou in 2001 and 2002.**

Source of variation	DF	Grain yield/ infested plot	Grain yield/ non-infested plot	Number of ears/plant	Host damage score/plot	Number of emerged *Striga* plants/plot
Source	7	137090531.8**	255214430.0**	0.90**	232.18**	1034544.67**
Env	16	3558375.0**	5068637.0**	0.11**	7.75**	12927.87**
Rep (Env)	9	20996695.2**	3400218.9*	0.74**	37.99**	101286.14**
GCA	35	929089.4*	1663138.7**	0.03 ^{ns}	1.48 ^{ns}	2651.60 ^{ns}
SCA	63	2556932.9**	1090068.3**	0.10***	4.91**	18895.94**
GCA × Env	245	481902.0 ^{ns}	566159.1ns	0.02 ^{ns}	1.00 ^{ns}	2376.63 ^{ns}
SCA × Env	704	334502.0	639735.0	0.02	0.71	3354.27

Env= Environment; Rep= Replicate; GCA= General combining ability; SCA= Specific combining ability.

*, **, Significant at the 0.05 and 0.01 probability levels, respectively; ns = not significant.

Table 3. Mean squares of grain yield, number of ears/plant, host damage score, and number of emerged *Striga* plants at 10 weeks after planting from a combined ANOVA for diallel crosses of ten inbred lines tested at Abuja and Mokwa (Nigeria) from 2001 to 2002.

Source of variation	DF	Grain yield/ infested plot	Grain yield/ non-infested plot	Number of ears/plant	Host damage score/plot	Number of emerged *Striga* plants/plot
Env	3	48884428.5**	233554927.2**	038**	64.70**	283773.83**
Rep (Env)	8	5074519.3**	5858086.6**	0.13**	10.05**	10084.47**
GCA	9	22601742.1**	3002618.8**	0.72**	43.01**	46175.48**
SCA	35	1155360.9*	1653445.9*	0.04*	1.76 ns	1905.38 ^{ns}
GCA × Env	27	2181696.8**	1332177.7*	0.07*	5.17**	5006.82*
SCA × Env	105	606019.4 ^{ns}	831048.7 ^{ns}	0.02 ^{ns}	1.33ns	1774.35 ^{ns}
Pooled error	352	507519.6	915553.0	0.02	0.91	2150.98

Env= Environment; Rep= Replicate; GCA= General combining ability; SCA= Specific combining ability.
*, **, Significant at the 0.05 and 0.01 probability levels, respectively; ns = not significant.

Table 4. **Mean squares of grain yield, number of ears/plant, host damage score, and number of emerged *Striga* plants at 10 weeks after planting from a combined analysis of variance for diallel crosses of 10 inbred lines tested at Ina and Angaradébou (Republic of Benin) in 2001 and 2002.**

Source of variation	DF	Grain yield/ infested plot	Grain yield/ non-infested plot	Number of ears/plant	Host damage score/plot	Number of emerged *Striga* plants/plot
Env	3	24260859.2**	299340949.4**	1.72**	236.95**	2115875.32**
Rep (Env)	8	2042230.7**	429188.2**	0.08**	5.44**	15771.26**
GCA	9	4676284.88**	1272245.8 ns	0.22**	8.06**	85192.08**
SCA	35	438746.3 ns	586372.6 ns	0.02*	1.00 ns	4145.36 ns
GCA × Env	27	1690702.8**	919766.4**	0.10**	1.91**	29056.58**
SCA × Env	105	296746.0 ns	302429.2 ns	0.01 ns	0.58 ns	2638.07 ns
Pooled error	352	161484.1	363916.0	0.02	0.51	4557.57

Env= Environment; Rep= Replicate; GCA= General combining ability; SCA= Specific combining ability.
*, **, Significant at the 0.05 and 0.01 probability levels, respectively; ns = not significant.

The larger GCA than SCA mean squares implies that, although non-additive gene action, especially dominance, plays an important part in the inheritance of the traits evaluated in this study, additive gene action is by far more important. However, estimates of additive effects would be greatly influenced by the environmental conditions of the evaluation trials. Therefore, recurrent selection could be used to improve the performance of the population developed from the lines while the lines *per se* or their derivatives could be used to develop *Striga*-resistant single-cross hybrids that would be released to farmers.

In the present study, greater attention was focused on *Striga* host damage score and number of emerged *Striga* plants 10 weeks after planting because of the use of *Z. diploperennis* as the donor parent for *Striga* resistance genes. The grain-yield performance of the lines in hybrid combinations was also considered to be important. Estimates of the GCA effect for each line, which is the average performance of the line in hybrid combination with other lines in the study, are presented for the three traits in Tables 5, 6 and 7. For *Striga* host damage score and number of emerged *Striga* plants at 10 weeks after planting, significant negative GCA effect indicates tolerance/resistance while for grain yield, significant positive GCA value is desirable. Judging by the reaction of the lines to *S. hermonthica* as presented in Table 1, all the Zd lines and TZL TC87 were expected to have negative GCA values for *Striga* host damage score and number of emerged *Striga* plants, and positive values for grain yield. On the other hand, the standard inbreds would have positive values for the first two traits and negative values for grain yield.

Proportions of significant positive and negative GCA values for the three traits are summarized in Table 8 for the three groups of lines in the study (that is, Zd lines, TZL TC87 and the standard inbreds) and in Table 9 for the individual lines. Of the 40 possible values for the Zd lines, 17 and 18 (42.5 and 45%) were negative for emerged *Striga* plants and *Striga* host damage score. Corresponding values for TZL TC87 were 3 and 2 (37.5 and 25%) for the two traits. The two groups of inbreds had few or no positive values for the two traits. On the contrary, 53% of the values for the four standard inbreds were positive for *Striga* host damage score and 12.5% for emerged *Striga* plants.

For grain yield, 55 and 50% of the GCA values for Zd lines and TZL TC87 were positive (Table 8). The four standard inbreds had only 6.3% positive values compared with 50% negative values. These results indicated that, indeed, the Zd lines and TZL TC87 were tolerant/resistant to *S. hermonthica* while the standard inbreds were susceptible.

In this study as in previous ones (Efron 1993; Efron *et al.* 1989; Kim 1991; 1994; 1996; Kim *et al.* 1997; Kim and Adetimirin 1997),

Table 5. Estimates of general combining ability (GCA) effects for number of emerged *Striga* plants at 10 weeks after planting of 10 inbred lines evaluated in diallel crosses at Abuja, Mokwa, Ina, and Angaradébou in 2001 and 2002.

Inbred Lines	Abuja 2001	Mokwa 2001	Ina 2001	Angar 2001	Abuja 2002	Mokwa 2002	Ina 2002	Angar 2002
Zd 282	-21.09***	-36.94***	-8.94***	-25.13*	-29.42*	-23.29^{ns}	24.23***	13.10^{ns}
Zd 290	13.31*	6.01^{ns}	-2.89^{ns}	-3.34^{ns}	11.75^{ns}	-6.05^{ns}	-21.40**	-192.61***
Zd 467	-3.60^{ns}	8.28^{ns}	-9.26***	6.87^{ns}	0.62^{ns}	-27.83^{ns}	-2.92^{ns}	-26.63^{ns}
Zd 472	0.02^{ns}	-13.66^{ns}	-2.51^{ns}	-21.94^{ns}	-27.39*	0.90^{ns}	-8.41^{ns}	-42.39^{ns}
Zd 551	-22.73***	-31.33***	-4.09*	-41.01**	-22.79^{ns}	-27.90^{ns}	-8.70^{ns}	-111.25**
TZL TC 87	-10.35^{ns}	-17.71^{ns}	0.01^{ns}	-29.33*	5.36^{ns}	-31.78*	-13.88*	-58.16^{ns}
9450	-5.10^{ns}	-7.57^{ns}	-0.73^{ns}	-11.31^{ns}	-8.54^{ns}	-19.90^{ns}	-4.75^{ns}	-6.12^{ns}
9006	8.00^{ns}	20.52^{ns}	7.71^{ns}	42.09^{ns}	16.15^{ns}	47.91^{ns}	11.09^{ns}	140.86^{ns}
1393	15.03^{ns}	21.02^{ns}	9.39*	17.20^{ns}	43.00^{ns}	32.83^{ns}	6.14^{ns}	132.16^{ns}
5057	26.52^{ns}	51.37*	11.30*	65.89*	11.27^{ns}	55.11^{ns}	18.60^{ns}	151.05^{ns}
LSD	13.4	16.0	4.5	26.4	28.4	31.7	12.3	77.6

LSD= Least significant difference between effects of two crosses having no parents in common, Angar= Angaradébou.

*, **, *** Significantly different from zero at the 0.05, 0.01 and 0.001 probability levels, respectively. ns = not significant.

Table 6. Estimates of general combining ability (GCA) effects for *Striga* host damage score at 10 weeks after planting of ten inbred lines evaluated in diallel crosses in *Striga*-infested plots at Abuja, Mokwa, Ina, and Angaradébou in 2001 and 2002.

Inbred Lines	Abuja 2001	Mokwa 2001	Ina 2001	Angar 2001	Abuja 2002	Mokwa 2002	Ina 2002	Angar 2002
Zd 282	-2.46***	-1.23***	0.20 ^{ns}	-0.42*	-2.25***	0.10 ^{ns}	0.33 ^{ns}	0.12 ^{ns}
Zd 290	-2.06***	0.19 ^{ns}	-0.35 ^{ns}	-0.58**	-1.08***	-0.40*	0.20 ^{ns}	-0.66***
Zd 467	-0.27 ^{ns}	-0.46 ^{ns}	-0.07 ^{ns}	-0.18 ^{ns}	-0.10 ^{ns}	-0.45*	-0.92***	-0.70***
Zd 472	-0.20 ^{ns}	-0.54 ^{ns}	-0.14 ^{ns}	-0.33*	-0.46*	-0.41*	-0.33 ^{ns}	-0.34 ^{ns}
Zd 551	-1.52***	-0.28 ^{ns}	-0.26 ^{ns}	-0.13 ^{ns}	-0.71**	-0.70**	-0.16 ^{ns}	-0.57*
TZL TC 87	-0.47 ^{ns}	-0.45 ^{ns}	-0.03 ^{ns}	-0.03 ^{ns}	-0.38ns	-0.46*	-0.37*	-0.03 ^{ns}
9450	0.81*	0.14 ^{ns}	0.28 ^{ns}	0.50**	0.003 ^{ns}	0.07 ^{ns}	0.21 ^{ns}	0.31 ^{ns}
9006	1.90***	0.19 ^{ns}	0.12 ^{ns}	0.17 ^{ns}	1.98***	0.30 ^{ns}	0.56**	-0.03 ^{ns}
1393	1.14***	0.52 ^{ns}	-0.52*	0.16 ^{ns}	0.84***	0.43*	-0.20 ^{ns}	0.53*
5057	3.14***	1.91***	0.77**	0.85***	2.16***	1.52***	0.68***	1.38***
LSD (0.05)	0.61	0.66	0.52	0.34	0.48	0.38	0.38	0.50

LSD= Least significant difference between effects of two crosses having no parents in common, Angar= Angaradébou.

*, **, *** Significantly different from zero at the 0.05, 0.01 and 0.001 probability levels, respectively. ns = not significant.

Table 7. **Estimates of general combining ability (GCA) effects for grain yield (kg/ha) of 10 inbred lines evaluated in diallel crosses in *Striga*-infested plots at Abuja, Mokwa, Ina, and Angaradébou in 2001 and 2002.**

Inbred Lines	Abuja 2001	Mokwa 2001	Ina 2001	Angar 2001	Abuja 2002	Mokwa 2002	Ina 2002	Angar 2002
Zd 282	574.0***	556.4***	-70.8^{ns}	254.3**	936.4***	412.8^{ns}	-670.6***	-272.4*
Zd 290	815.7***	-197.2^{ns}	4.0^{ns}	-169.0*	785.9***	632.4*	-120.6^{ns}	358.5*
Zd 467	443.1**	306.6*	39.3^{ns}	108.3^{ns}	-156.0^{ns}	552.6*	583.2**	505.4**
Zd 472	228.7^{ns}	150.8^{ns}	112.7*	71.7^{ns}	611.8**	869.4**	249.3ns	236.7^{ns}
Zd 551	507.2**	156.3^{ns}	186.7***	20.3^{ns}	679.5**	834.9**	344.4*	679.2***
TZL TC 87	273.8*	188.3^{ns}	-127.5**	96.6^{ns}	365.0^{ns}	757.5**	441.6**	358.3*
9450	-259.5^{ns}	-84.2^{ns}	175.3***	-161.4^{ns}	-289.4^{ns}	-194.8^{ns}	57.8^{ns}	55.5^{ns}
9006	-754.5***	-93.3^{ns}	-147.0**	15.8^{ns}	-1020.4***	-610.9*	-628.8***	-226.4^{ns}
1393	-378.9**	-169.9^{ns}	-4.4^{ns}	136.3^{ns}	-359.9^{ns}	-857.6**	318.5*	-518.7***
5057	-1449.5***	-813.9***	-168.4***	-372.9***	-1553.1***	-2396.2***	-574.7**	-1176.1***
L.S.D (0.05)	299.7	292.3	90.9	187.7	426.6	572.1	335.9	297.0

LSD= Least significant difference between effects of two crosses having no parents in common, Angar= Angaradébou.

*, **, *** Significantly different from zero at the 0.05, 0.01 and 0.001 probability levels, respectively. ns = not significant.

Table 8. Percentage of significant positive and negative GCA values for number of emerged *Striga* plants 10 weeks after planting, *Striga* host damage score and grain yield for three groups of inbred lines used in a 10 × 10 diallel cross evaluated in four locations in 2001 and 2002.

Inbred group	No of lines	Total No of values[+]	Emerged *Striga* plants -ve	+ve	*Striga* host damage score -ve	+ve	Grain yield +ve	-ve
Zd lines	5	40	42.5	2.5	45.0	0.0	55.0	7.5
TZL TC87	1	8	37.5	0.0	25.0	0.0	50.0	0.0
Std inbreds	4	32	0.0	12.5	0.0	53.0	6.3	50.0

[+] Total No of values = 4 loc. × 2 yrs. × No. of lines

Table 9. Percentage of significant positive and negative GCA values[+] for number of emerged *Striga* plants 10 weeks after planting, *Striga* host damage score and grain yield for 10 inbred lines used in a diallel cross evaluated in four locations in 2001 and 2002.

Inbred code	Emerged *Striga* plants -ve	+ve	*Striga* host damage score -ve	+ve	Grain yield -ve	+ve
Zd 282	62.5	12.5	37.5	0.0	25.0	50.0
Zd 290	25.0	12.5	50.0	0.0	12.5	50.0
Zd 467	12.5	0.0	37.5	0.0	0.0	65.5
Zd 472	12.5	0.0	37.5	0.0	0.0	37.5
Zd 551	62.5	0.0	50.0	0.0	0.0	75.0
TZL TC87	37.5	0.0	25.0	0.0	12.5	50.0
1393	0.0	0.0	0.0	25.0	0.0	12.5
5057	0.0	0.0	0.0	37.5	50.0	0.0
9006	0.0	12.5	12.5	50.0	37.5	12.5
9450	0.0	37.5	0.0	100.0	100.0	0.0

[+] Total No of values = 4 loc. x 2 yrs. = 8.

rating of host plant damage symptoms was the most important trait for assessment of crop response under *Striga* infestation. Using this criterion, Inbred 9450 was the most susceptible to *S. hermonthica* among the set of lines in the study (Table 9). This line had negative GCA values for host damage score and grain yield in all eight environments thus indicating that its susceptibility was not subject to location and years in the study. None of the Zd lines had any positive GCA value for host damage score; rather, about 40–50% of the lines had negative GCA values for the trait, and about 40–75% had positive values for grain yield.

Inbred Zd 551 was the most resistant/tolerant to *S. hermonthica* among the lines. The line combined low number of emerged *Striga* plants with low *Striga* host damage score to produce relatively high grain yield under *Striga* infestation. The implication of the large proportion of significant positive GCA values for grain yield and negative values for the other traits obtained for this line is that its resistance/tolerance is easily transmitted to the progeny of its crosses with other lines. The remaining Zd lines also demonstrated satisfactory GCA values and would, therefore, be useful in breeding for improved *Striga* resistance/ tolerance in this and perhaps other sets of inbred lines.

Summary and Conclusions

Striga hermonthica is the greatest constraint to maize production in the sub-Saharan savanna. To improve the level of resistance in maize to this parasitic weed, resistance genes were introgressed from *Zea diploperennis*. Forty-five F1 hybrids of a half-diallel cross obtained from 10 inbred lines, including five lines derived from *Z. diploperennis,* were evaluated in field locations at Abuja and Mokwa in Nigeria and at Ina and Angaradébou in the Republic of Benin in 2001 and 2002.

The results led to the following conclusions:

i. There was preponderance of additive genetic effects among the lines evaluated in the study, although non-additive effects were also not negligible. Therefore, breeding methods that capitalize on both additive and non-additive gene actions, such as recurrent selection and hybridization, may be used to improve the lines *per se* as well as other lines or populations derived from them.
ii. The lines derived from *Z. mays* x *Z. diploperennis* generally showed high levels of resistance/tolerance to *S. hermonthica* as well as good GCA for grain yield.
iii. Inbred line Zd 551, a *Z. mays* x *Z. diploperennis* line, was the most *Striga*-resistant line and the best general combiner for grain yield. Inbred 9450 was the most susceptible to *S. hermonthica* and the line had the worst GCA for grain yield.
iv. The additive effects of the lines were greatly influenced by the evaluation environments (locations and years). Therefore, testing in more than one environment would be required to detect favorable genetic effects for rapid breeding progress.

Based on these findings, it was concluded that multilocation trials of hybrids derived from *Z. mays* x *Z. diploperennis* lines would permit the selection of good and stable *Striga* resistant/tolerant hybrids or inbred lines.

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Evaluation of divergence of agronomic and nutritional traits in quality protein maize

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Abstract

In a three-year study (2000 to 2002), genetic diversity for 12 traits among 63 Quality Protein Maize (QPM) lines was evaluated using multivariate analysis (D^2 statistic). The QPM lines were grouped into 11 clusters. Inter-cluster D^2 values ranged from 61.2 (between clusters I and VI) to 511.7 (between clusters V and IX). Plant height, days to physiological maturity, grain yield, days to silk and protein content together accounted for over 70% of the genetic diversity among the QPM lines. Ten QPM lines were identified from three clusters for improvement and hybridization.

Résumé

La diversité génétique a été évaluée entre 63 génotypes de maïs riches en protéines de qualité pour 12 caractères pendant trois années (2000 2001 et 2002) en utilisant l'analyse multivariée (D^2 statistique). Les lignées QPM ont été regroupées en 11 groupes. Les valeur inter-groupe D^2 variaient entre 61,2 (entre groupe I et IV) et 511,7 (entre groupe V et IX). La hauteur des plants, le nombre de jours à la maturité physiologique, le nombre de jours à la floraison femelle, la teneur en protéines et le rendement grain sont intervenus pour plus de 70% dans la diversité génétique entre les génotypes riche en protéines de qualité. Dix lignées QPM ont été identifiées à partir de trois groupes pour l'amélioration et l'hybridization.

Introduction

Maize (*Zea mays* L) is an important staple crop in Africa, especially in the countries of West and Central Africa (WCA) where its importance in the food basket has been on the increase during the last two decades. About 26 million t of maize is produced annually in Africa on about 20 million ha of land (Byerlee and Eicher 1997). In Nigeria, maize is grown in all the agro-ecological zones except in the swamp and mangrove forests. In the northern parts of the country where the rainy season is relatively short, it is cultivated under both rainfed and irrigated conditions.

Maize accounts for between 30 and 60% of food calories and dietary proteins in developing countries, especially in foods used for weaning infants. The grain is processed into several local dishes and drinks and consumed by both young and old. The protein in normal maize is, however, of poor nutritional value due to the limited concentrations of two essential amino acids, lysine and tryptophan. Maize varieties into which relatively high concentrations of these two amino acids have been incorporated through breeding are referred to as Quality Protein Maize (QPM). Introduction of QPM into human diet will help in alleviating the imbalance in maize protein, insufficient calories, malnutrition, diseases and death among low income, maize-consuming populations of WCA.

Results of studies of genetic diversity, character association, heterosis and combining ability have been reported extensively in the literature for various crops, including normal maize (Muppidathi *et al.* 1995; Choudhary 1997). However, QPM has received little attention in these areas of study. Divergence studies are important in gaining an understanding of the trend of evolutionary patterns, assessing the relative contribution of different components of yield to total divergence and in determining the nature of associations operating at inter- and intra-cluster levels (Anand and Rawat 1984; Thakur and Zarger 1989). The objective of the present study was to assess the genetic divergence among introduced QPM lines, using genetic distance (D^2) analysis, with the goal of isolating divergent lines to be used in breeding programs.

Materials and Methods

The experimental plant materials were 63 QPM lines introduced into the Institute for Agricultural Research (IAR), Samaru, Nigeria from Mexico, Ghana and Zimbabwe. The lines were sown on 20 June 2000, 15 June 2001, and 18 June 2002, at IAR Research Farm (11 ^{0}11′N; 7 ^{0}38′E, 686m above sea level). Each plot consisted of two 5m rows spaced 0.75m apart with a spacing of 0.5m between plants (plot size = 7.5m^2). In each year, the experiment was laid out as a randomized complete block design with three replications. All agronomic practices recommended for maize production in the savanna ecology were followed (IAR 1993). The lines were evaluated for 12 agronomic and nutritional traits in the three years of study. The traits were: days to tassel (DT), days to silk (DS), days to physiological maturity (DPM), plant height (PH), ear height (EH), grain yield (GY), percentage protein (PRO), moisture content (MOI), carbohydrate content (CHO), ash content (ASH), fibre content (FIB) and fat content (FAT).

Data obtained for the 12 traits were subjected to the analysis of variance (ANOVA). The genetic divergence of the 63 QPM lines was

Table 1. Mean squares from the combined analysis of variance, means and coefficients of variation (CV %) for different agronomic and nutritional traits of 63 QPM inbred lines evaluated in Samaru, 2000–2002.

	Mean squares					
Traits†	Year DF = 2	Lines DF = 62	Year × Line DF = 124	Error DF = 270	Mean	CV %
DT	76.44**	52.05**	29.63**	5.46	60.2	10.1
DS	102.11**	91.23**	52.13**	10.31	65.4	9.7
DPM	69.41**	48.36**	26.02**	5.55	95.5	12.8
PH	33.02**	29.11**	10.93**	2.26	178.8	5.1
EH	15.46**	12.55**	5.35**	1.79	70.5	6.3
GY	8.71**	7.34**	3.41**	0.65	3.6	17.5
PRO	2.45**	1.79**	0.69**	0.13	9.5	3.9
MOI	2.07**	1.93**	0.72**	0.14	6.4	4.8
CHO	1.18**	0.88**	0.61**	0.12	78.1	10.7
ASH	6.21**	5.37**	3.71**	0.75	1.4	11.9
FIB	4.33**	3.18**	1.81**	0.34	2.1	4.0
FAT	5.68**	4.77**	2.15**	0.41	2.7	2.2

† See text for name.
**Significant F-test at 0.01 level of probability.

analyzed using Mahalanobis D^2 statistic (Mahalanobis 1936). Tocher's method described by Rao (1952) was used in grouping the lines into clusters. The D^2 values for 'k' traits between the ith and jth genotypes were computed as:

$$D^2 = (Y_{it}-Y_{jt})^2$$

Statistical significance of D^2 was tested using chi-square (χ^2) values at 't' degrees of freedom and 0.05 level of significance, where 't' is the number of traits evaluated. Each trait was ranked on the basis of $d_i = y_{ik}-y_{ki.}$ Rank-1 was given to the highest mean difference. Percentage contribution (X) of each trait was computed as: X = (Nx/Pc)100; where Nx = number of line combinations which were ranked first for a trait and Pc is the number of all possible combinations, which was obtained as n(n-1)/2 =1953; (n = 63).

Results

Highly significant mean squares for years, lines and line × year interactions were observed for all traits (Table 1). Means and coefficients of variation (CV) for the traits are also presented in Table 1. The clusters, their mean values for the 12 traits and their percentage contribution to divergence are presented in Table 2. Cluster VIII had the highest number of lines (11), followed by cluster II with 10 lines, while clusters VII, V, X and IV had 8, 7, 6 and 5 lines. The superior clusters with respect to grain yield were VIII (4.8 t/ha), III (4.7 t/ha), and

VII, XI and V that had grain yield of 4.0 t/ha or higher. Clusters VI, XI, I, IV, XI, III, VII and V had mean protein content of 8% or more.

The QPM lines in cluster VIII, although high yielding, exhibited some undesirable traits such as high fibre (2.8%), moisture (6.5%) and fat (2.4%) contents. Lines in cluster V showed lower grain yield than those in cluster VIII but they had some desirable traits such as acceptable plant height (190cm), high percentage protein (12.1%) and low moisture, ash, fibre and fat contents (4.8%, 1.0%, 1.8% and 1.9%, respectively).

The contribution of each trait to the expression of genetic divergence measured by D^2 values revealed that the highest contributor was plant height (35.2%) followed by days to physiological maturity (14.9%), grain yield (8.1%), days to silk (7.8%), protein content (7.2%) and ear height (7.1%). The least contributors were carbohydrate (0.6%), fat (0.7%) and fibre (2.1%) contents (Table 2).

Inter- and intra-cluster genetic distances (D^2) of the 63 lines are presented in Table 3. High values of inter-cluster D^2 statistic ranged from 61.2 (between cluster I and VI) to 511.7 (between cluster V and IX). Over 80% of the inter-cluster variability among these lines was explained by the analysis. The intra-cluster distance of 0 was obtained for clusters II, III, VI, VII, VIII, IX and XI, followed by 4.3 for cluster V, 8.6 for cluster I, 13.2 for cluster IV and 39.5 for cluster X.

Table 4 contains the number of clusters and their corresponding QPM lines. PMG007M, PMG019M, PMG029M, PMG023L and PMG028L in cluster VIII, PMG019E, PMG007E and PMG003L members of cluster V, and PMG009E and PMG028E of cluster III were high yielding. They exhibited other desirable traits such as high protein and carbohydrate contents, low ash, fibre and fat contents.

Discussion

The highly significant mean square obtained in this study revealed appreciable variations among the 63 lines evaluated for 3 years. Thus, the possibilities exist for selection and further improvement of these QPM lines. The results obtained in this study indicated that intercrossing lines from clusters V and VIII and other lines, especially from clusters III, VII and XI, could produce high-yielding transgressive segregants for population improvement programs.

Contributions of each trait to genetic diversity in this study could be used as selection criteria for further improvement and choice of parents for hybridization and generate of wider variability. The present study clearly indicated that progenies expected from crossing diverse parents would reveal greater diversity for crop improvement. These results are in agreement with the findings of Thakur and Zarger (1989) and Alagarswamy and Chandra (1998).

Table 2. Cluster mean values for 12 agronomic and nutritional traits and their percent contribution to divergence among 63 QPM lines evaluated in Samaru, 2000-2002.

Cluster no.		DT	DS	DPM	PH	EH	GY	PRO	MOI	CHO	ASH	FIB	FAT
I	(4)*	55	60	87	143	58	2.9	9.4	6.2	78.3	1.3	2.2	3.2
II	(10)	60	63	94	180	67	3.6	7.5	1.5	81.0	1.1	2.0	2.9
III	(3)	62	70	99	201	80	4.7	10.7	7.0	76.2	1.1	1.9	2.0
IV	(5)	60	64	96	181	69	3.4	9.4	5.5	75.1	1.6	2.0	2.8
V	(7)	64	69	100	190	79	4.0	12.1	4.8	80.6	1.0	1.8	1.7
VI	(2)	52	62	90	148	58	2.2	8.0	8.4	79.2	1.4	1.7	3.5
VII	(8)	67	70	100	201	83	4.2	11.6	6.1	78.1	1.6	2.2	2.0
VIII	(11)	60	69	99	200	80	4.8	10.4	6.5	78.2	1.4	2.8	2.2
IX	(3)	61	65	96	179	65	3.3	7.8	9.1	80.6	1.7	1.9	3.4
X	(6)	56	59	87	146	56	2.5	8.1	9.3	75.2	1.7	2.1	2.7
XI	(4)	65	68	102	198	82	4.1	9.1	6.5	76.2	1.6	2.1	2.8
Contribution (%)		5.1	7.8	14.9	35.2	7.1	8.1	7.2	6.0	0.6	5.2	2.1	0.7

* Number of genotypes in each cluster in parenthesis.

Table 3. Inter- and intra-cluster (bold) D^2 values among 11 clusters formed by 63 QPM lines evaluated in Samaru, 2000-2002.

Cluster no.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
I	**8.6**	78.8	121.4	119.8	68.5	61.4	206.7	413.2	90.6	79.7	282.3
II		**0.0**	116.8	95.0	78.3	111.0	200.3	326.1	190.8	85.8	343.8
III			**0.0**	7109	63.9	100.2	96.5	229.8	214.7	69.4	140.5
IV				**13.2**	100.0	85.5	115.4	106.6	315.6	100.9	302.7
V					**4.3**	73.6	88.5	120.3	511.7	84.3	115.9
VI						**0.0**	95.7	81.7	120.6	91.9	107.5
VII							**0.0**	118.3	160.5	85.6	213.3
VIII								**0.0**	136.2	116.2	340.1
IX									**0.0**	99.6	248.3
X										**39.5**	174.5
XI											**0.0**

Table 4. **Number and names of genotypes of eleven clusters formed from 63 QPM lines evaluated in Samaru, 2000–2002.**

Cluster no.	No. of Genotypes	QPM Genotypes
I	4	PMG012E, 014E, 015E and 021M
II	10	PMG001L, 002L, 003L, 005L, 008L, 009L, 016E, 017E, 018E, and 023M
III	3	PMG009E, 028E and 029E
IV	5	PMG001M, 002M, 005M, 008M, and 012M
V	7	PMG005E, 007E, 008E, 019E, 001M, 002M and 003L
VI	2	PMG004L and 008L
VII	8	PMG009E, 010E, 011E, 020E, 009M, 022M, 017E and 018M
VIII	11	PMG006M, 007M, 019M, 026M, 029M, 007L, 010L, 023L, 024L, 025L and 028L
IX	3	PMG014M, 015M and 002E
X	6	PMG021E, 022E, 023E, 027E, 012M and 013M
XI	4	PMG019L, 020L, 020M and 023L

The wide range of D^2 values obtained implied that enormous diversity could be generated through hybridization, especially between lines in cluster V and IX. The minimum inter-cluster proximity between clusters I and VI indicated that they are closely related and similar; therefore, minimum opportunity for further improvement exists between these clusters. These results corroborate those reported in chickpea (Anilkumar *et al.* 1993), sunflower (Muppidathi *et al.* 1995; Chungui *et al.* 1996) and African pearl millet (Quendeba *et al.* 1995).

High *per se* performance along with maximum inter-cluster distance among the genotypes with high D^2 values should be considered while choosing genotypes as parents for hybridization. On the other hand, crosses involving genotypes with low *per se* performance and low genetic divergence are not likely to produce a high-yield or high protein or any exceptionally high heterotic effect of any practical value. Based on the results of D^2 analysis carried out in this study, some lines with high yielding ability along with desired traits and moderate to high D^2 values could be selected as potentially good parental materials. Examples of such lines are PMG007M, PMG019M, PMG029M, PMG023L and PMG028L in cluster VIII, PMG019E, PMG007E and PMG003L members of cluster V, and PMG009E and PMG028E of cluster III. These genotypes possess divergent traits of agronomic interest, including early, medium and late maturity, and desirable plant height. These genotypes could, therefore, be crossed *inter se* or with other QPM genotypes to develop new varieties for specific purposes.

Conclusion

Plant height, days to physiological maturity, grain yield, days to mid-silk, and protein content made the largest contribution to the genetic divergence among the 63 QPM lines evaluated in this study. On the basis of the clustering of the lines for these traits, ten lines were selected from three clusters for further improvement.

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Inadequately generated index improves on AMMI analysis

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Abstract

Among the methods proposed for partitioning interaction in a two-way table is the Additive Main Effect and Multiplicative Interaction (AMMI) model. Though the AMMI model has been found to give precise estimates through validation studies (Gauch 1988), results of the studies reported herein indicated some biasness in fitting the sums of squares of the model. Relating the sums of squares contributed by the different genotypes to the genotype by environment interaction matrix (GE) and the GE correlation matrix showed that the sum of squares from the AMMI model is optimistic. Results from using different sizes of GE matrix showed that the environmental index (of the AMMI model) is dependent on the size of the correlations between the terms of the GE matrix, which explains the causes of the increased sums of squares in AMMI models. The use of transfer of indices from different sets of the GE matrix to eliminate the optimism associated with AMMI models is proposed in the paper.

Résumé

Le modèle d'effet additif principal et d'interaction multiplicative (AMMI) est une des méthodes proposées pour la partition de l'interaction dans un tableau à deux voies. Quoique le modèle AMMI ait été identifié pour donner des estimations précises à travers des études de validation (Gauch, 1988), les résultats dans ce travail indiquent quelques biais dans les carrés moyens appropriés du modèle. Les résultats relatifs aux liens entre les carrés moyens, auxquels ont contribué les différents génotypes issus de la matrice d'interaction génotype par environnement (GE), et la matrice de corrélation GE, ont montré que les sommes des carrés du modèle AMMI étaient optimistes. Les résultats de l'utilisation des différentes tailles de la matrice GE, ont montré que l'index d'environnement (du modèle AMMI) est très dépendant de la taille des corrélations entre les termes de la matrice GE, ce qui explique les causes de l'augmentation des sommes des carrés des modèles AMMI. Cette communication propose l'utilisation du transfert d'indices de différents ensembles de la matrice GE afin d'éliminer l'optimisme associé aux modèles AMMI.

Introduction

The multi-environment trial in which a number of genotypes are evaluated over a range of environmental conditions is a standard experiment in plant breeding programs. Such multi-environment testing of varieties often shows genotype x environment interaction (GEI) due to differential response of genotypes to diverse growing conditions. Useful statistical models for the analysis of multi-environment trials, with emphasis on the analysis of GEI, can be found in the classes of linear and bilinear models. In recent years, Additive Main Effects and Multiplicative Interaction (AMMI) model, originally proposed by Gollob (1968), has become more popular in scientific journals. Gauch (1988) looks at methods for assessing how many multiplicative terms are needed. Gauch's methodology is based on the approach originally described by Gabriel (1978) and Bradu and Gabriel (1978) for approximating matrices and using biplot approximate displays. Other related GEI models in the literature include those by Digby (1979) in which a single multiplicative term is used to summarise interaction, and Kempton (1984), which shows how biplots displaying genotype and environmental effects can provide useful interpretation. Gauch (1992) has advocated the use of AMMI model for the analysis of multilocation trial data. The model is given as

$$y_{ij} = \mu + g_i + e_j + \sum_{k=1}^{k=n} q_k u_{ik} v_{jk} + \varepsilon_{ij} \qquad (1)$$

where i = 1, 2, …, b for genotypes; j = 1, 2, …, t for environments; y_{ij} is the mean yield of the ith genotype in the jth environment, g_i and e_j are the main effects of ith genotype and jth environment, k the number of multiplicative terms and ε_{ij} is a random component. g_i and e_j are estimated from the additive model.

If Z is the residual interaction matrix, where

$$z_{ij} = y_{ij} - y_{i.} - y_{.j} + y_{.}$$

then $\hat{u}_{ik}$ and $\hat{v}_{jk}$ are elements of the eigenvectors of ZZ' and $Z'Z$ respectively, and $\hat{q}_k$ is the square root of the eigenvalues of the PCA axis k. The presence of interaction corresponds to $\hat{q}_k$ being non-zero. The multiplicative interaction terms $q_k u_{ik} v_{jk}$ satisfy the constraints

$$q_1 > q_2 > q_3 > \ldots > q_t > 0 \qquad (2)$$

$$\sum_i^b g_i = \sum_j^t e_j = \sum_t^b u_{ik} = \sum_j^t v_{jk} = 0 \qquad (3)$$

$$\sum_t^b u_{ik}^2 = \sum_j^t v_{jk}^2 = 1 \qquad (4)$$

The number of axes retained gives the name of the model. For instance, if no axis is retained we have AMMI0 while the full model AMMIF is used when all the SVD axes are considered. The performance of the model, however, has attracted some concerns. Crossa *et al.* (1991) noted that relying solely on AMMI model to describe GEI might lead to important interactions from a single environment with a unique stress being overlooked. Romagosa and Fox (1993) reported an analysis of a homogeneous subset of data indicating a more complex pattern than the complete data. Piepho (1994), working with faba bean (*Vicia faba* L.) data sets from 1985 to 1989, found the full model as the best AMMI model contrary to many other usual cases where AMMI0, AMMI1 or AMMI2 were identified as the most accurate models.

A problem that may be less obvious and so often overlooked by users of AMMI models is that the procedure for fitting the multiplicative terms is strongly "optimistic". The nature of the residuals after fitting the additive main effects inevitably produces the appearance of multiplicative effects with the structure of the matrix of interaction residuals (Z) exhibiting high correlations between the genotype vectors over the environments. Consequently, the first eigenvector from ZZ' which is used as an environment index, will tend to be correlated with the highly correlated terms of the residual interaction matrix. This will result in the sums of squares for fitting the multiplicative term(s), which may be read directly from the latent root proportions of explained variation and which has a formal $(g+e-1-2k)$ df, being much larger than expected based on $\sigma 2\chi 2(g+e-1-2k)$ df. Simulation results for R^2 values from completely null cases have been produced on which to base the formal tests for the first multiplicative term (Mandel 1971). The objectives of this paper are (i) to illustrate the optimism associated with AMMI models, and (ii) to develop a new approach using transfer of indices that would lead to the calculation of a complement index vector. The complement index vector proposed is described in the context of a real data set.

Effect of correlations on AMMI models

To illustrate the optimism associated with AMMI models, it is necessary to consider real data that have some well-known structure. The soybean [*Glycine max* (L.) Merill.] data (Gauch 1992) are just such a standard benchmark set, and have frequently been used for illustrating the potential of the AMMI model. The data consist of yields from seven soybean genotypes planted in ten environments in the State of New York with four replications. Gauch (1992) has described the details of the full AMMI analysis of the data. Using the residual interaction matrix, correlation between the terms of the genotype vectors were calculated as well as the sums of squares contributed by each of the seven genotype vectors. Table 1 shows the sums of squares explained by regressing each genotype's vector of the residual interaction matrix on the environment index (1st eigenvector). If we sum up the sums

Table 1: Sums of squares (SS) explained by seven genotype vectors of the residual interaction matrix of the yield data consisting of 10 environments and 7 genotypes (Gauch, 1992).

Genotype	G1	G2	G3	G4	G5	G6	G7
Sum of Squares (SS)	0.2524	1.0433	0.0020	0.0005	0.4926	0.1593	0.1991

Table 2: Correlations among genotype vectors of the residual interaction matrix, and with the first eigenvector from the residual interaction matrix of the yield data consisting of 10 environments and 7 genotypes (Gauch, 1992).

	G1	G2	G3	G4	G5	G6	G7
G2	0.91						
G3	0.24	0.01					
G4	-0.06	-0.24	0.50				
G5	-0.90	-0.88	-0.43	-0.03			
G6	-0.97	-0.86	-0.31	-0.01	0.84		
G7	-0.90	-0.95	-0.04	0.03	0.82	0.88	
First Eigenvector	-0.96	-0.98	-0.18	0.12	0.94	0.92	0.95

of squares for the seven genotypes, we obtain the sum of squares due to the first multiplicative term (AMMI1 model). From Table 1, genotype 2 has the highest sum of squares. Four other genotypes showing relatively high sums of squares are genotypes 5, 1, 7 and 6. The high sums of squares explained by the five genotypes are less surprising if the correlations (Table 2) between the terms of the matrix are compared, and correlations between the terms of the matrix and the first eigenvector are compared. Apparently, the first eigenvector (later on referred to as AMMI index vector) bears a closer resemblance to the terms of the residual interaction matrix which are highly intercorrelated than to the terms which are uncorrelated resulting in relatively large sums of squares for genotypes 5, 1, 7 and 6. The overall proportion of variation explained is 88.8% (Gauch 1992). In this instance the GEI data will be considered as best described by AMMI model with one multiplicative term while predictions from the analysis may be less reliable due to the terms of the residual interaction matrix being correlated. The characteristic of the first eigenvector being dependent on the size of correlations between the terms of the residual interaction matrix (**Z**) may explain the causes of the increased sum of squares in AMMI models. These results therefore suggest that the environment index vector from the AMMI may not be a useful predictive index vector.

Method for estimating Complement index vector

Since there are almost always strong indications that the nature of the residuals after fitting the additive terms inevitably produces a matrix, which tends to be correlated, sums of squares from AMMI models will tend to be optimistic. In this section, we therefore propose an alternative index vector unrelated to the genotype vectors of the residual interaction matrix. Using analysis of variance notation, it is customary to write a non-additive model as

$$y_{ij} = \mu + g_i + e_j + w_{ij} + \varepsilon_{ij} \qquad (5)$$

where w_{ij} the genotype by environment interaction term is a function of two factors. Given that we have an environment index which represents the environment variation (θ_j), we can calculate the regression dependence of the genotype-environment interaction terms by regressing w_{ij} on θ_j for each genotype, obtaining regression coefficient β_i. Effectively, we are fitting the model

$$w_{ij} = \beta_i \theta_j + \delta_{ij} \qquad (6)$$

where δ_{ij} represents the random component. By combining equation (5) and (6) the full model can be rewritten as an additive multiplicative mixture.

$$y_{ij} = \mu + g_i + e_j + \beta_i \theta_j + \delta_{ij} \qquad (7)$$

Many other models are special cases of this general model and the model is also equivalent to the AMMI models of Gauch (1988). The environment index of the AMMI model (θ_j) shall be referred to as Self index vector. The Self index vector (θ_s) is the first eigenvector of the matrix **ZZ′**. The regression of the terms of **Z** on θ_s is the AMMI1 model. Since Self index vector is correlated with highly correlated terms of the matrix **Z**, we propose an alternative index vector referred to as the Complement index vector (θ_c).

The Complement index vector is defined as a vector of values estimated by splitting the total number of genotypes into two subgroups (target set). One subgroup constitutes the main data being analysed and the environment index θ_c is estimated as the first eigenvector from the remaining number of genotypes. By this approach we estimate an environment index completely unrelated to the genotypes whose GEI are analysed.

Comparison between Self index vector and Complement index vector

The performance of the two index vectors discussed above was assessed using a model with a single multiplicative interaction term (7). The data used for the assessment were grain yields from a set of spring

Table 3: Average proportion of the interaction variation explained ($\hat{R}^2$) when two environment index vectors are used in AMMI model for the analysis data set consisting of 40 genotypes and 9 environments (subset of the CIMMYT ISWYN data for 1967–1968).

Target Set	Self Index	Complement Index	Mandel's Simulation
1–4	69	38	61
1–5	58	36	54
1–8	52	34	41
1–10	49	33	39
1–20	43	24	30
Mean	54	33	45

wheat nursery yield trials (ISWYN) conducted by the International Maize and Wheat Improvement Centre, Mexico (CIMMYT) in 1967–1968. The cultivars represented the principal types of spring wheat grown throughout the world. Their parentage, origin and aspects of their agronomic characters, disease resistance and quality have been described by Mackenzie *et al.* (1971). The trials, which consisted of 40 genotypes, were conducted in 45 environments (9 out of the 45 environments were analysed in this section) using a randomised complete block design with three replications. The set of 40 genotypes by 9 environments by 3 replications was randomly split into 10 target sets of 4 genotypes by 9 environments by 3 replications each (4 x 9 x 3 data matrix), and the two index vectors were estimated for each of the ten target sets as explained in the previous section. Thus, for the analysis based on the complement index vector, a target set of four genotypes was analysed using an index vector estimated from 36 genotypes x 9 environments x 3 replications. For each target set, the proportion of the interaction variation explained from regressing each genotype's vector of the residual interaction matrix on each of the corresponding environment index vector was calculated and the average $\hat{R}^2$ value was computed for the set of ten target sets. The analysis was repeated for different target sets of sizes 5, 8, 10 and 20 genotypes. The performance data of the two index vectors in terms of $\hat{R}^2$ values are presented in Table 3. The last column of Table 3 lists expected $\hat{R}^2$ values for corresponding target set sizes for Mandel's simulation (Mandel, 1971), which may be read directly from Mandel's tables. If we compare average $\hat{R}^2$ values based on the Self-index vector with corresponding values from Mandel's simulated values for the five different target set sizes, then there is invariably good evidence that the interaction is not zero. This evidence points to the conclusion that there are almost always strong indications of genotype × environment interactions.

Table 4. The mean, median and the variance (s_b^2) of the proportion of variation explained by 19 target sets from the analysis of a dataset with 40 genotypes by 9 environments (subset of the CIMMYT ISWYN data for 1967–1968).

Target set	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38
Mean	30.2	29.0	31.8	32.4	32.5	32.3	34.5	31.6	31.6	30.7	30.6	27.8	27.4	31.1	28.5	26.6	23.1	19.8	14.4
Median	30.4	31.4	28.7	31.1	31.3	30.6	37.4	30.3	33.4	31.0	31.2	28.5	28.0	32.3	29.5	26.2	26.5	20.0	15.9
s_b^2	559	255	160	89	121	66	81	50	18	14	39	19	18	27	38	20	48	51	30

On average, regressing the target sets on Complement index vector accounted for 33%. This indicates a dramatic reduction in the sums of squares compared to values obtained from using the Self index vector. The apparent differences between the Self index vector and the Complement index vector in terms of $\hat{R}^2$ values illustrate the effect of correlations and optimism in the sums of squares of AMMI models. If we compare the $\hat{R}^2$ values based on the Complement index vector with "expected" $\hat{R}^2$ value expressed as ratio of the degrees of freedom of the fitting sum of squares with (g - 1) df to the degrees of freedom of interaction sum of squares ((t - 1)(b - 1)) df then the Complement index vector can be described as a useful index vector.

Optimum target set

We can identify the size of the target set which gives the best prediction. This is achieved by varying the sizes of the target sets and estimating the $\hat{R}^2$ for each target set. Once again, using a subset of the CIMMYT dataset (40 genotypes by 9 environments by 3 replications), target set sizes were chosen so that complement set sizes ranged from 2 to 38 genotypes. For example, a target set of size 2 genotypes involved the use of two randomly selected genotypes to calculate the residual interaction matrix and the Complement index vector estimated from the remaining 38 genotypes. Using the 40 genotypes, 19 target sets consisting of 2, 4, ..., 38 genotypes were created. For each target set, 10 random samples of different combinations of genotypes were generated. The mean, median and variance of $\hat{R}^2$ (s_b^2) values for each target set was estimated and the results presented in Table 4.

The results show that the proportion of the variation explained is very variable for target sets of sizes less than eight genotypes as it is indicated by high s_b^2 values. For target sets of such few genotypes the regression fits were unduly influenced by influential or dominant genotypes within the target sets. There were few genotypes classified as dominant whose presence in the target set improved the proportion of the variation explained in every case. The $\hat{R}^2$ value can therefore be very high or low depending mainly on the number of dominant genotypes in the target set. This is also indicated by the median $\hat{R}^2$ values being in most cases lower than the mean $\hat{R}^2$ values for the small target set sizes. Although parameter estimates from Complement index vectors are unbiased estimates, unreliable estimates can be obtained when the target set is based on too few genotypes.

The behaviour of the dominant genotypes was also observed when target sets included more genotypes (target set > complement set) than the number of genotypes used for estimating the Complement index vectors. This is indicated by lower $\hat{R}^2$ values for target sets of sizes greater than twenty genotypes. As far as the optimum is concerned, the distribution of the mean $\hat{R}^2$ values over nearly optimal target set sizes is generally flat with slight peaks occurring between target sets from 8 to 18 genotypes. It is reasonable to use a half of the number of genotypes as the target set and the other half for estimating the Complement index vector.

Average Complement index vector

The Complement index vector was proposed for analysing subset of the GE data matrix. If the full dataset is to be analysed it is not possible to estimate its Complement index vector in the same framework as described in the previous sections because it has no Complement set. The objective of this section is to extend the method for estimating the Complement index vector in order to estimate an index vector for analysing the full dataset. To analyse the full dataset, the dataset is randomly split into two target sets and the Complement index vector estimated for each target set. Simulation studies (not reported here) have shown that correlations between the different Complement index vectors from the same set of environments are relatively high (>|0.9|). This suggests that we can obtain a single index vector by averaging sets of Complement index vectors from the same set of environments which can be used for analysing complete datasets. We refer to this vector as the average Complement index vector. The averaging of the sets of Complement index vectors is based on the assumption that the vectors have the same direction.

The procedure for obtaining an average Complement index vector is as follows :

1. Randomly split the data into subsets (target sets)
2. Calculate the Complement index vector (θ_c) for each subset
3. Ensure that the Complement index vectors have the same direction
4. Calculate the average (arithmetic) Complement index vector (θ_a) from the Complement index vectors.

Table 5. Proportion of interaction variation ($\hat{R}^2$) explained when Self, Complement and average Complement index vectors are used in AMMI model for the analysis of data set consisting of 40 genotypes by 9 environments (subset of the CIMMYT ISWYN data for 1967-1968).

Set	Self Index	Complement Index	Average Complement Index
1	43.64	28.05	32.82
2	41.42	28.64	33.41

Performance of the average Complement index vector

The question of the suitability of the average Complement index vector as an effective index vector is an important one. To investigate the performance of the average Complement index vector (θ_a) we analysed the CIMMYT dataset of 40 genotypes in 9 environments with 3 replications. Again, the data matrix was randomly split into 2 subsets (each subset of size 20 genotypes x 9 environments x 3 replications data matrix) and the Self index vector was estimated from each subset. For each subset of 20 x 9 x 3 data matrix, the Complement index vector was estimated from the corresponding Complement set of 20 x 9 x 3 data matrix. The average Complement index vector was then estimated as the average of the two Complement index vectors. Table 5 shows $\hat{R}^2$ values from regressing the genotype vectors of the residual interaction matrix on the Self index vector, Complement index vector and average Complement index vector.

It can be seen that $\hat{R}^2$ values from using the average Complement index vector and Complement index vector are relatively close compared to the $\hat{R}^2$ values from the Self index vector. This suggests that the average Complement index vector and Complement index vector are closely related. Essentially, the pattern of response for the two Complement vectors appear to be similar across the two target sets suggesting that average Complement index has a useful predictive value. The differences in the $\hat{R}^2$ values indicate the amount of bias introduced into the estimation of the average Complement index vector. Future work will need to use an appropriate scaling factor to scale down $\hat{R}^2$ values arising from the use of average Complement index vectors in order to achieve the same level of accuracy as the Complement index vector.

Conclusion

AMMI model is a powerful tool for partitioning GEI data. However, the structure of the residual interaction matrix after fitting the additive terms exhibit high correlations between the genotype vectors over the environments. Ignoring the correlations between the terms of the residual interaction matrix has been shown to lead to optimism in fitting the sums of squares. The optimism is dependent on the size of the correlations between the terms of the GEI matrix. Certainly, with GEI studies designed with large numbers of genotypes and environments the correlations between the terms of the matrix will usually be small and the bias will be small. However, for models with relatively small numbers of genotypes and environments the problem cannot be ignored. The optimism is dealt with by using the Complement index vector proposed in this study. Essentially, this is a form of cross-validation technique whereby one set of the data is used for the model while the remaining sets are reserved for estimating index vectors. It is expected that if an environment index θ_c has a good predictive value, it will be an effective index even when applied to a different set of genotypes in the same environment. By using the Complement index vector we eliminate the optimism in the estimation of the index. The technique is similar to the technique proposed by Mather and Caligari (1974) to overcome the problem of non-independence in the joint regression analysis. They regressed the yield of each genotype on the mean yield of the rest. However, this does not supply only one estimate of θ_c, and therefore the procedure was rather less attractive. The recommendation given in this paper is that half of the number of genotypes in a trial should be used to estimate the Complement index vector and the average Complement index vector estimated by averaging the set of Complement index vectors.

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Effects of farmers' seed source on maize seed quality and crop productivity in Ghana

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Abstract

Although farmer-saved seed constitutes about 90% of maize seed planted annually in Ghana, its effects on crop performance is not fully known. A study was conducted to determine the seed quality and field performance of farmer-saved seed of the most popular quality protein maize (QPM) variety, *Obatanpa,* compared to the certified seed of the same variety. Certified seed samples collected from four locations (Wenchi, Nkoranza, Ejura and Kwadaso) in Ghana showed higher percentage complete vital staining of embryos using 2,3,5 triphenyl tetrazolium chloride (TTC), as well as higher 1000 seed weight, indicating high vigour and complete seed development. Whereas germinating seedlings of the certified seeds did not show any fungal growth, farmer-saved seeds showed profuse fungal development and stunting. Reduction in seedling counts was 9% in certified seeds and 24% in farmer-saved seeds, whereas reduction in plant counts prior to harvest was 12% in certified seeds and 23% in farmer-saved seeds. Plants originating from certified seeds flowered at the predetermined date of 55 days, whereas the farmer-saved seeds flowered about a day or two later due to reduced vigour. Less lodging occurred in plants originating from certified seeds, particularly in the trial planted at Ejura (Transition zone) than in Kwadao (Forest zone). The use of certified seeds increased grain yield by 47% over the farmer-saved seeds. The study therefore demonstrates the importance of certified seeds in increasing maize productivity and farmers' incomes.

Résumé

Bien que les semences conservées par les agriculteurs constituent près de 90% des semences de maïs cultivées annuellement au Ghana, leurs effets sur la performance de la culture ne sont pas pleinement connus. Une étude a été conduite pour déterminer la qualité et la performance des semences conservées par les agriculteurs de la variété de maïs riche en protéines de qualité la plus populaire (QPM), *Obatanpa*, en comparaison avec les semences certifiées de la même variété. Les échantillons de semences certifiées recueillis dans quatre localités (Wenchi, Nkoranza, Ejura et Kwadaso) au Ghana, ont montré un pourcentage plus élevé d'embryons complets vitaux teintés en utilisant 2,3,5 Triphenyl Tetrazolium Chlorure (TTC), ainsi qu'un poids de 1000 semences plus lourd pour les semences certifiées, indiquant une vigueur élevée et un développement complet de ces semences. Les semences certifiées en germination n'ont pas été affectées par le développement de champignons, tandis que les semences conservées par les agriculteurs avaient de multiples champignons et une croissance retardée. Le comptage des plantules germées a montré 9% de réduction pour les semences certifiées et 24% de réduction pour les semences conservées par les agriculteurs, alors que le comptage du nombre de plants antérieurement à la récolte pour les semences certifiées et les semences conservées par les agriculteurs avaient 12% et 23% de réductions respectivement. Les plants originaires des semences certifiées ont fleuri à 55 jours après semis, tandis que les semences conservées par les agriculteurs ont fleuri près d'un jour ou deux ultérieurement à cause de la réduction de vigueur. Il y a eu moins de verse chez les plants originaires de semences certifiés particulièrement à Ejura dans la zone de transition comparé à Kwodao dans la zone forestière. L'utilisation de semences certifiées a contribué à accroître de 47% le rendement grain par rapport aux semences conservées par les agriculteurs. L'étude a démontré l'importance des semences certifiées dans l'augmentation de la productivité du maïs et des revenus paysans.

Introduction

In Ghana, total annual maize (*Zea mays* L.) producion is about 1,008,000 tonnes on a total land area of about 665,000 ha (PPMED-MOFA, 2000). This gives an average yield of 1.5 t/ha, which is much lower than the potential yield of 5.0-7.3 t/ha of the most popular open-pollinated quality protein maize (QPM) variety, *Obatanpa* and the QPM hybrid, *Mamaba* (Twumasi-Afriyie *et al.* 1997). Among the factors contributing to the relatively low grain yield in the farmers' fields are low plant population, low soil fertility, poor weed control, late harvesting, post-harvest losses and the use of poor quality farmer-saved seeds.

The total amount of certified seed produced annually in Ghana is low. For example in 2003, a total of 1,300 t of maize seeds were produced, which, at a planting rate of 20 kg/ha, could plant 65,000 ha representing only 10% of total land area planted to maize in 2004. Thus, 90% of maize seed planted annually is from farmer-saved seeds, which may be of poor quality due to the poor conditions under which the seeds are produced, processed and stored. The effect of such seeds on crop performance and productivity is, however, not fully known. The objective of this study was, therefore, to determine the quality, field performance and yield of farmer-saved seeds compared to certified seed of the QPM variety, *Obatanpa*.

Materials and Methods

Samples of certified and farmer-saved seeds retained for planting during the major season of 2003 were collected from four important maize growing districts in Ghana; namely, Wenchi and Nkoranza, both in the Forest-Savanna Transition Zone of the Brong Ahafo Region and Ejura and the Kumasi Metropolitan Area (Kwadaso) in the Transition and Forest Zones of the Ashanti Region. Four seed samples, comprising two farmer-saved open-pollinated varieties and two certified seeds of *Obatanpa*, were collected from each district. From each seed source, a 500 g sample was drawn for quality determination in the laboratory, followed by a field trial. Weight per 1000 seeds was determined in four replicates for each seed source. Germination test was conducted by setting four replicates of 50 seeds in moist sand, sterilized by heating at 105ºC for 24h, in 30 cm diameter trays, kept in polythene bags at 27-32ºC. First germination count was made on the fourth day and the second on the seventh day after seeds had been set for germination. Only normal seedlings, as described by AOSA (2002), were counted.

The living tissues of the embryos of the seeds were stained with 2,3,5 triphenyl tetrazolium chloride (TTC). Twenty seeds per replicate were soaked in water for 2 h at room temperature (27 ºC) after which each seed was dissected through the embryo side. One hundred ml of 1% (w/v) TTC solution in distilled water was added to each set of dissected seeds in a petri dish. The seeds were then kept in the dark for 3 h at room temperature. In living tissues, the TTC reacts with the dehydrogenase enzymes in the cotyledons to produce a red stain called fromazan (Cottrell 1948; Roberts 1951; Powell and Mathews 1979; Asiedu *et al.* 2000b). Weak and dead tissues of the cotyledons damaged during imbibition remain unstained. In the study, the cotyledons of treated seeds were rated for staining on a 1 to 4 scale as follows: (1) 100% stained, (2) 100% to 50%, (3) 50% to 1%, and (4) 0% stained.

Field trials were conducted at Ejura and Kwadaso to determine the effect of seed source on agronomic performance. There were four entries (two farmer-saved seed sources and two certified seed sources) from each District, a total of 16 entries laid out in a randomized complete block design with four replications in each trial. An experimental plot consisted of four rows, each 5 m long, spaced 0.75 m apart, with hill spacing of 0.40 m and three seeds per hill. Seedlings were thinned to two plants/hill two weeks after planting (WAP), giving a population density of 62,500 plants/ha. Fertilizer was split-applied at 2 and 4 WAP at the rate of 90:60:30 NPK/ha and standard weed control measures were applied to clean weeds. Agronomic traits measured included number of days to flower, percentage lodging and grain yield.

Results and Discussion

In the laboratory, slight increases in complete staining of the embryonic tissues were observed in the certified seeds over the farmer-saved seeds (Fig. 1). Visual observation during germination showed the development of healthy seedlings in the certified seeds, whereas the farmer-saved seed showed fungal infection and stunting (Fig. 2). The certified seeds had higher 1000 seed weight, ranging between 330 and 350 g (Fig. 3), which is comparable to the characteristic 1000 seed weight (350 g) of the variety *Obatanpa* determined earlier by Asiedu *et al.* (2000a). The farmer-saved seeds were lower in seed weight, ranging between 206 and 310 g, possibly due to sub-optimum field conditions, including drought stress, low soil fertility and poor weed control during seed production. In addition, farmers' seeds were stored under unfavorable natural conditions, including high temperature and high relative humidity, resulting in enhanced physiological aging, fungal infection and consequently reduced seed weight. Such seeds would normally exhibit low nutrient content and seedling vigour (Asiedu *et al.* 2000a).

The number of seedlings counted 2 WAP at the two locations ranged between 56,000 and 57,000 plants per hectare for the certified seeds and 47,500 to 51,000 for farmer-saved seed (Fig. 4a). Plant count prior to harvest ranged from 52,500 to 57,000 per hectare for certified seeds and 46,000 to 50,000 plants per hectare for farmer-saved seeds (Fig. 4b). The low seedling count of the farmer-saved seeds could result from poor seed quality. For both seedlots planted at Kwadaso, a significant decrease occurred from seedling to harvest, whereas at Ejura such a decrease was not observed. The decrease in seedling counts against the target 62,500 plants per hectare might have been the result of the effects of field conditions, including soil properties, pathogens and pests, whereas the subsequent decrease prior to harvest at Kwadaso resulted from pre-maturity lodging.

Plants produced from both the certified and the farmer-saved seeds flowered around 55 days (Fig. 5), which is the characteristic flowering date for *Obatanpa* (Asiedu *et al.* 2000a). This indicated that the seeds collected from both sources were indeed of the same maturity rating. Farmer-saved seed was slightly late for the seed samples collected at Ejura, Nkoranza and Wenchi, which may be the result of slow growth rate due to reduced seed vigour as observed with poor TTC staining (Fig. 1), low germination test (Fig. 2) and low 1000 seed weight (Fig. 3).

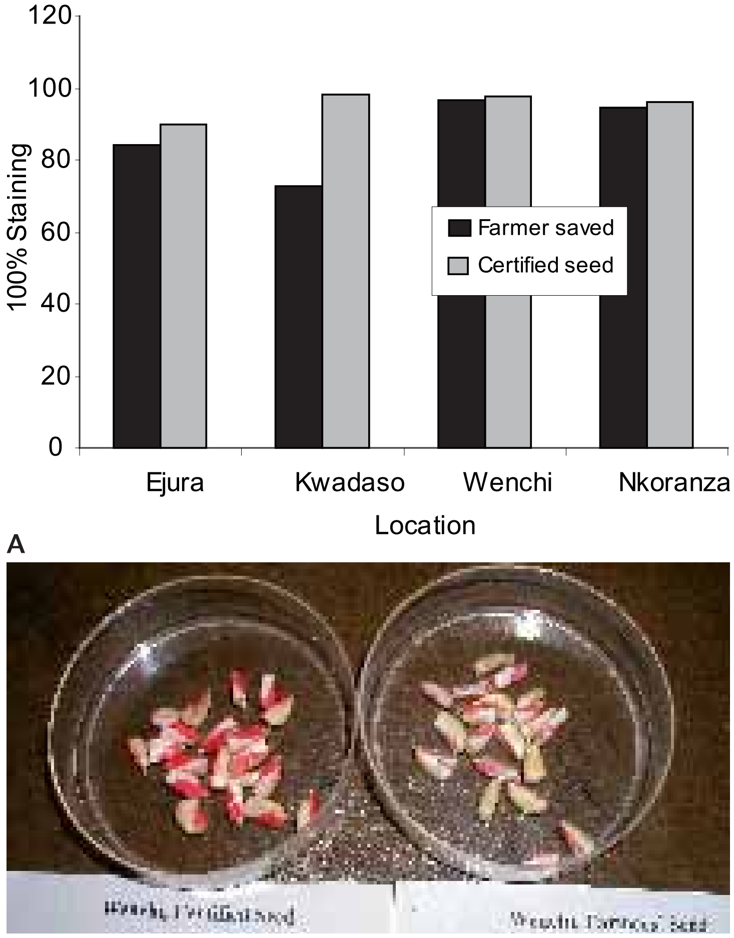

Figure 1. (A) Percentage seeds with complete vital staining of embryos of farmer-saved and certified seeds sampled from four major maize producing districts of Ghana; (B) Farmer-saved seed showing poor level of vital staining; (C) Certified seed showing good level of vital staining.

Figure 2. Germinating (a) farmer-saved and (b) certified seeds showing differences in fungal infection and seedling vigour.

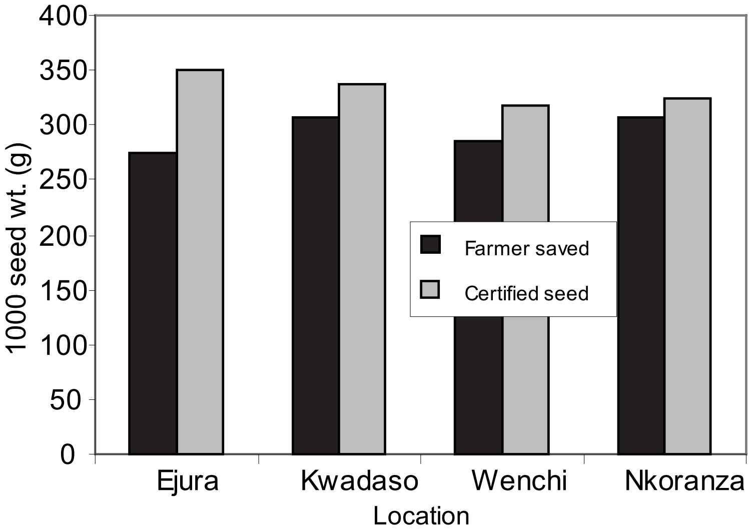

Figure 3. Thousand seed weight of farmer-saved and certified seeds collected from four major maize producing areas in Ghana.

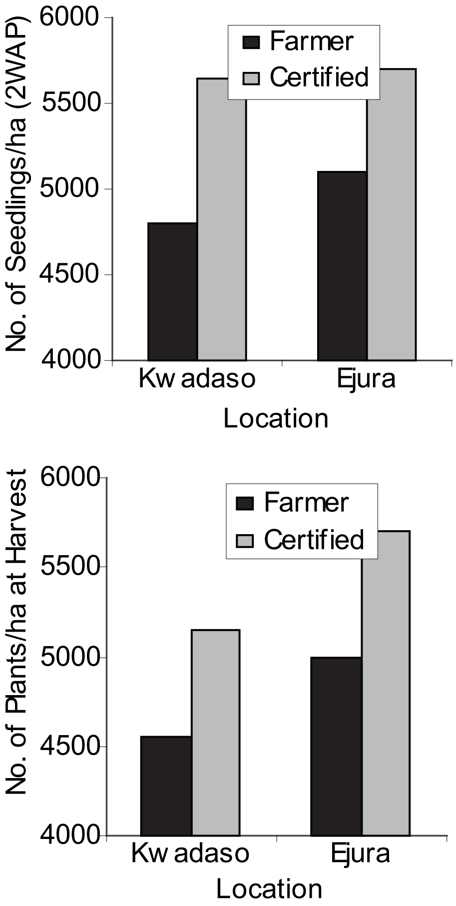

Figure 4 (a) Emergence count two weeks after planting and (b) plant count before harvest of maize crops produced from farmer-saved and certified seeds.

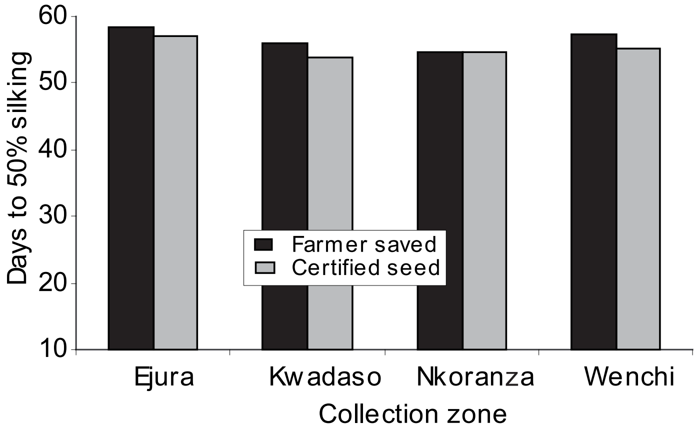

Figure 5. **Mean days to 50% silking of of maize crops produced from farmer-saved and certified seeds collected from four locations and tested at Kwadaso and Ejura in Ghana.**

Table 1. **Total lodging percentage of farmer-saved and certified seeds collected from four locations and tested at Kwadaso and Ejura.**

Location	Seed Source	Total lodging (%)	
		Kwadaso	Ejura
Wenchi	Certified	3,200	400
	Farmer	5,867	667
Nkoranza	Certified	2,667	0.0
	Farmer	4,800	667
Ejura	Certified	2,800	133
	Farmer	3,733	667
Kwadaso	Certified	2,000	0.0
	Farmer	5,200	800
Mean		3,783	292
LSD (0.05)		493	133

Much more lodging occurred in the trial conducted at Kwadaso than that at Ejura (Table 1). At both locations, plants originating from farmer-saved seeds lodged more, possibly due to the effect of fungal infection that was observed on these seeds and reduced resistance to stresses due to low vigour. The predominant fungus observed was *Fusarium moniliforme*, which is a seed-borne pathogen and develops as the seed germinates. It infects the seed and the seedling and continues to develop in the stem tissues and later appears in the developed cobs. The fungus therefore causes severe lodging and ear rot in maize. Percentage total lodging was very high at Kwadaso, possibly due to higher relative humidity, which is ideal for the development of fungi, such as *F. moniliforme*.

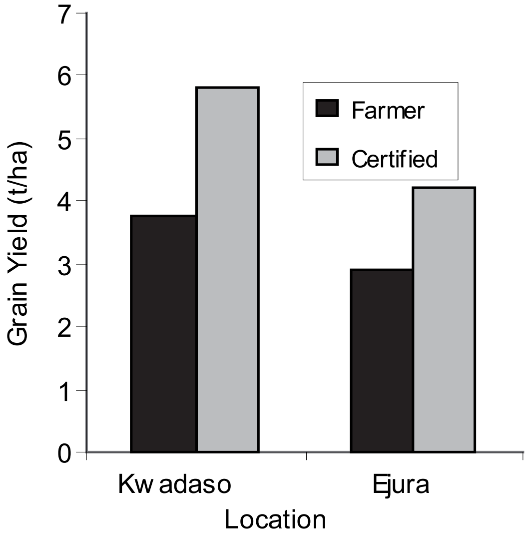

Figure 6. Mean grain yield (t/ha) of maize crops produced from farmer-saved and certified seeds collected at four locations and evaluated at Kwadaso and Ejura, Ghana.

The mean grain yields were 5.9 and 3.8 t/ha for the crops produced from certified and farmer-saved seeds at Kwadaso (Fig. 6). At Ejura, the mean grain yields were 4.2 and 2.9 t/ha for certified and farmer-saved seeds. Thus, at both locations, the mean yield increased by about 1.2 t/ha or 47% when certified seed was planted in place of farmer-saved seeds at the same management level. With the present seed price of ¢5,000.00 (about $0.6) per kilogramme, a farmer would need ¢100,000.00 (about $11) to purchase 20 kg seed to plant one hectare. Since this could increase his grain production level by 1.2 t, even at a minimum farm gate price of ¢10,00,000.00($110) per ton, a farmer could increase his income by over ¢1,100,000.00 ($110) per hectare. It is thus more economical for farmers to invest in certified maize seed.

There is, therefore, the need for the relevant governmental and non-governmental agencies to vigorously promote the use of improved certified seeds in maize growing communities of Ghana to achieve household food security, increased rural incomes and national production levels of maize.

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Maize research at IAR Samaru

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Abstract

Maize (*Zea mays* L.) research at the Institute for Agricultural Research (IAR), Samaru was initiated in the 1950s with the goal of developing adapted high yielding varieties and hybrids. Germplasm materials were collected from local sources as well as from different countries, including Columbia, Kenya, Mexico and the US. By the 1960s, IAR Samaru was actively participating in the National Cooperative Trials, the West African Maize Variety Trials of the OAU-STRC Joint Project as well as the East African Maize Variety Trial coordinated by the East African Agricultural and Forestry Research Organization (EAAFRO), Kitale, Kenya. By 1976, a total of nine new open- pollinated varieties had been developed and released to farmers. The new maize technology packages developed gave up to 98% higher grain yield than the farmers' traditional methods of production. In the 1990s, collaborative research continued under the West and Central African Collaborative Maize Research Network (WECAMAN) and the Sasakawa Global 2000 (SG-2000) which, in partnership with IAR, disseminated new maize technologies to Nigerian farmers. In 2001, three new varieties developed and tested in collaboration with IITA-WECAMAN were registered and released to Nigerian farmers. Recently, Quality Protein Maize (QPM) trials were initiated in collaboration with IITA-WECAMAN, SG-2000, and CIMMYT and promising results have been obtained. The Institute continues to collaborate with national and international research organizations in maize improvement. The five decades of collaborative maize research at Samaru have contributed to increased land area under maize, increased grain yield, and increased income to maize farmers.

Résumé

La recherche sur le maïs à Samaru a été initiée dans les années 50 avec le projet d'amélioration variétale centré sur le développement d'hybrides et de variétés adaptés à hauts rendements. Les ressources génétiques comprenaient du matériel de source locale ainsi que des introductions de différents pays incluant la Columbie, le Kenya, le

Mexique et les USA. Dans les années 60, l'IAR à Samaru a participé aux essais nationaux de collaboration, au projet conjoint OAU-STRC des essais variétaux en Afrique de l'ouest ainsi qu'aux essais variétaux de maïs pour l'Afrique de l'est, coordonnés par l'Organisation de recherche en Agriculture et en foresterie de l'Afrique de l'est basée à Kitaly, Kenya. En 1976, un total de neuf nouvelles variétés à pollinisation libre a été développé et vulgarisé auprès des agriculteurs. Pendant les années 80, les variétés hybrides développées par l'IITA en collaboration avec des chercheurs nationaux ont été homologuées et commercialisées par des entreprises privées de semences. Les nouveaux paquets technologiques développés donnaient jusqu'à 98 pour cent en rendement grain plus élevé que les méthodes traditionnelles de production des agriculteurs. Dans les années 90, l'IAR à Samaru en partenariat avec le Réseau de recherche sur le maïs pour l'Afrique de l'ouest et du centre (WECAMAN) et avec Sasakawa Global 2000, ont continué la recherche collaborative avec la promotion de nouvelles technologies maïsicoles auprès des agriculteurs Nigérians. En 2001, trois nouvelles variétés développées et testées en collaboration avec l'IITA-WECAMAN ont été homologuées et vulgarisées auprès des agriculteurs Nigérians. Récemment, des essais de maïs riches en protéines de qualité ont été initiés en collaboration avec l'IITA-WECAMAN, SG2000 et le CIMMYT et des résultats prometteurs ont été obtenus. L'institut continue à coopérer avec les organisations de recherche internationale et nationale pour l'amélioration variétale du maïs. L'impact des cinq décennies de recherche collaborative à Samaru a induit l'accroissement des superficies emblavées en maïs, l'augmentation des rendements grains et l'augmentation des revenus des agriculteurs qui cultivent le maïs.

Background

The Institute for Agricultural Research, Samaru, was established in 1922 as the administrative headquarters of the Department of Agriculture of the defunct Northern Region of Nigeria. In 1962 it was affiliated to the Ahmadu Bello University and mandated to conduct research for all the important crops grown in the entire Northern Region, including maize (*Zea mays* L.). Research programs of the Institute developed technological packages for improved crop production. Each research program is composed of various research projects and subprojects. Maize research is under the Cereals Research Program and it focuses on varietal improvement, cultural practices and management, crop protection, socioeconomics of production and technology adoption.

Varietal Improvement

The Maize Varietal Improvement Project (MVIP) was initiated in the 1950s with the aim of developing adapted but genetically diverse populations. The maize idiotype for the ecologies of northern Nigeria was defined as follows: plants with good root development to prevent root lodging, tasseling in 55–65 days, ear height of 1.5 m or less, tight husk cover to prevent damage from insects and birds, and ear shanks that allow the ears to droop upon maturing so that water from the heavy rains in September would not penetrate into the ears through the tip of the husks (Anon. 1969).

In practical terms, the main aims of the MVIP were to develop high yielding varieties or hybrids that could be planted early in June, reach anthesis in early August, and mature shortly before the dry season sets in early in October. To achieve these objectives, germplasm materials were collected locally as well as being introduced from different sources. Several introductions from Columbia in the early 1960s had ear placement varying from 0.8 to 1.3 m and they were more resistant to root lodging than the standard Mexico-5 that was the best available variety at that time (Anon. 1963). In 1964, mass selections were made from five maize populations (Anon. 1966) and recurrent selection continued in some other populations to extract new varieties and parental inbred lines for the production of hybrid varieties. The brachytic gene was incorporated into some of the populations to improve resistance to stalk breakage and root lodging. Opaque-2 gene was also incorporated into the breeding populations to improve the protein balance of the grain by increasing the lysine content. In 1967, maize introductions from the maize project at Kitale, Kenya, were tested in Zaria. The result showed that the introduced materials were poorly adapted to the northern Guinea savanna conditions but performed much better at Gembu on the Mambilla Plateau, south of Yola, at an elevation of about 1566 m. Some of the Kenyan introductions also produced good yields at Mokwa. By 1967 maize production in northern Nigeria was becoming important in the riverine areas. For that reason, IAR Samaru posted a plant breeder to Mokwa to support the Federal Program on Maize (Anon. 1969). In 1969, IAR Samaru released SAMMAZ-6, formerly Biu Yellow. In 1972, three new varieties, namely SAMMAZ-7, SAMMAZ-8 and SAMMAZ-9 bred at IAR Samaru were also released. These varieties had potential yields ranging from 5 to 7 t/ha (Anon. 1989). By 1973, the research on maize at IAR Samaru resulted in the production of Extension Bulletin No. 11 titled "Maize Production Guide", which was modified later to "Recommended Practices for Maize Production." By 1976, IAR breeders were busy developing synthetic varieties at Samaru as well as Mokwa and Kadawa substations. Genetic studies were conducted with emphasis on yield and protein content.

In collaboration with the International Institute of Tropical Agriculture (IITA), the varietal improvement project continued in 1982 at IAR Samaru with the European Economic Community (EEC) Project coordinated by Dr Khadr. The EEC Project focused on the development of intermediate white maize populations (110 days to maturity) through recurrent selection, development of mid-altitude populations resistant to streak and other diseases (*Helminthosporium turcicum, Puccinia sorghi*) in Jos and development of disease resistant and vigorous inbred lines with good combining ability. The Project was successfully conducted in collaboration with the staff of IAR, Samaru (Anon. 1983).

Fakorede *et al.* (1993; 2001) had presented excellent reviews of the Nigeria-IITA hybrid maize project. Initiated in 1982, the Nigerian government funded the project, which was executed by IITA in collaboration with the Nigerian NARES, including IAR Samaru. The era of hybrid maize in Nigerian agriculture started in 1984 when hybrids were planted to a total of 150 ha of farmers' fields. The hybrids have contributed to increased productivity of maize, expansion of land area planted to maize and establishment of private seed companies in Nigeria. IAR Samaru has continued to play an important part in the development and release of hybrid maize in Nigeria. Several hybrid varieties were tested and released over the years (Menkir *et al.* 2001). Among the hybrids tested in the early stages of the project, the white hybrid 8321-18 gave the best yield and was, therefore, the first hybrid to be released in 1985. Many other hybrids have since been developed, although the hybrids were susceptible to *Striga hermonthica* Del Benth, a parasitic weed of maize and several other crops in the savanna ecology.

Variety testing was initiated as a sub-project at IAR in 1966. Seeds of several mid-to-high altitude varieties from Kenya were planted on the Mambilla Plateau. The varieties showed greater potential for the area than the local varieties. IAR participated in the Regional Uniform Variety Trials (RUVTs) of the Semi-Arid Food Grains Research and Development (SAFGRAD) Project conducted in the late 1970s to early 1980s, tailored to develop suitable varieties for areas with shorter and unpredictable rainfall duration. Similarly when WECAMAN was established in 1987 to document maize production constraints and available resources in the region and to conceive a strategy to pool their resources with those of IARCs for the development of appropriate maize production technologies (Fajemesin *et al.* 1999), IAR was fully involved as an active collaborator. In 1984, the Nationally Coordinated Maize Research Programme (NCMRP) was initiated to link together research, production, industry and consumers (Fakorede 1993). NCMRP organizes the testing and release of superior varieties of maize with higher yield potential and better resistance to insect pests and diseases. Since 1990, IAR Samaru has been mandated to coordinate maize research in Nigeria.

Seed Production

Seed production is crucial to the transfer of improved maize technologies to farmers; therefore, IAR initiated a seed production sub-project in the 1960s. In the early 1960s, the multiplication and distribution of improved maize varieties from IAR took place substantially in five provinces as follows: ESI in Niger, Adamawa, Benue and Plateau Provinces; Mexico-5 in Plateau; ESII and EAAFRO 231 in Ilorin. In 1962, ESI was multiplied at Osara and Ochanja in Kabba Province as an early maturing variety and distributed to selected farmers who grew it as a second season crop. Other areas where maize seed multiplication was carried out were Zaria, Bornu and Katsina Provinces.

IAR has been a collaborator in the WECAMAN sponsored community-based seed production project since 1993 and large quantities of seed of released varieties are produced annually in Nigeria, among other WCA countries such as Bénin, Burkina Faso, Cameroon, Mali and Togo (Badu-Apraku *et al.* 1999). In 2001, in collaboration with IITA scientists, SAMMAZ 11, a *Striga hermonthica* resistant open-pollinated variety, was registered and released in Nigeria along with two extra-early varieties, SAMMAZ 12 and SAMMAZ 13 (Ado *et al.* 2002a,b).

Agronomic Research

The contributions of IAR in the area of cultural practices and management of maize are numerous and well documented. Several published and unpublished research reports on maize agronomy are available at IAR Samaru. Agronomy research in 1959 indicated that local maize varieties had low yield potential. Trials on inter-planting maize with sorghum in the riverine areas were conducted. Fertilizers were applied to maize, which was later inter-planted with sorghum that served as a residual crop. By harvesting the two crops in one year, marginal economic responses were obtained. Results of the 1959 fertilizer trials indicated a positive linear interaction between sulphate of ammonia and single super phosphate. By 1963, sufficient information had been obtained from the annual fertilizer trials that led to the conclusion that the northern part of the maize growing area of the savanna had a relatively high response to P while the southern part, which is the derived savanna, had a relatively high response to N. By 1965, accurate estimates of the requirements of N and P for sorghum and maize in the main growing areas of northern Nigeria were provided to the Ministry of Agriculture for recommendation to farmers. Recommendations had also been made to the Ministry of Agriculture on the use of compound fertilizer to replace separate application of single super phosphate and sulphate of ammonia. This would have the advantage of increased efficiency in the use of plant nutrients and of considerable savings in transportation and handling costs. Also uniform application of fertilizers at moderately high rates was found necessary to decrease variability in plant development and to measure the yield potential of the most productive varieties or hybrids.

At Mokwa, research results showed that K application up to 90 kg K2O/ha did not increase grain yield significantly. In some other trials no significant response to K2O and Zn was found in the savanna zones. However, application of K2O increased grain yield at Yandev (southern Guinea savanna, SGS), Ballah (SGS) and Kafin Maiyaki (northern Guinea savanna, NGS). In another fertilizer trial, 30 to 60 kg K2O/ha appeared optimum in the SGS while 2.5 kg Zn/ha gave maximum grain yields at Ballah and Kafin Maiyaki (Anon 1987). In a trial conducted for two years, there was no response to Zn at Yandev. In 1984, a linear response to N from 0 to 120 or 150 kg N/ha was reported in some studies, although the application of more than 90 kg N/ha did not result in significant increases in grain yield in much of the savanna ecology. Ear length and some other traits also responded linearly to N fertilizer up to 120 kg/ha. Split N applications did not, however, appear to enhance maize grain yield. The requirements for K and Zn increased with increased rainfall and clay content of the soil.

Data on planting date trials at Samaru revealed significant yield reduction for delayed plantings after early June. Plant spacing trials gave similar yields if plantings were one plant spaced 25 cm apart in the rows, two plants on hills spaced 50 cm apart or three plants on hills spaced 75 cm apart. In another trial conducted at Kadawa, three varieties SZV5, SZV3 and DMR-ESR-Y were compared with Bomo local in four planting dates. The interaction between sowing dates and varieties was not significant. The highest yield was, however, obtained when sown early in July. Decrease in grain yield associated with delayed planting was minimized when the plant density was reduced. The delayed planting resulted in lower yield as well as lower attack by ear rot organisms. Increasing plant density up to 100,000 plants/ha at early planting increased grain yield and other yield parameters. In another trial, a 26% yield increase was obtained when plant density was increased from 25,000 to 50,000 plants/ha. In this particular study, increasing plant density beyond 50,000 plants/ha had no appreciable effect on grain yield.

Early planting provided an escape to *Striga* attack because the *Striga* plants were just emerging when the maize had already established. Out of six hybrids tested, hybrid 8322-13 was the most resistant to *Striga*. In 1990, Weber *et al.* (1995) reported yield and *Striga* infestation on susceptible and *Striga* tolerant versions of maize varieties in 13 fields in Kaduna and Katsina States. Herbicides experiments showed that at Samaru, acetochlor at 0.5 kg a.i/ha, plus atrazine at 1.25 kg a.i/ha was the best treatment for weed control. Primagram gave the highest grain yield in comparison with other pre-emergence herbicides and herbicide mixtures.

Crop Protection

Research on crop protection revealed that in 1964 insect infestation associated with virus diseases prevented maize seeded in July from flowering at the Kagoro Ranch near Kafanchan. In the same year an epidemic of maize rust caused by *Puccinia polysora* (Anon 1966) developed in August and September in the Samaru experimental nurseries. A detailed study of virus diseases of maize and other grass host plants was subsequently advocated in Northern Nigeria. On stem borer damage, it was reported that maize stubble was not a source of carry-over of the two main stem borers *Sesamia calamistis* and *Eldana saccarina,* to the subsequent cropping season (Anon. 1969). Disease surveys conducted in 1983 indicated that maize streak virus (MSV), Drechslera (*Helminthosporium maydis*) and the yellow blotch bacterium were the major causal agents of diseases in maize. Rust and leaf spot diseases were severe in higher rainfall areas. Infestations by *Striga hermonthica* and stem borers were other biotic problems. Early sowing was of advantage against stem borers. However, sowing date did not significantly reduce infestation by *S. calamistis* and *E. saccarina*.

MSV affected 30% of the crops around Samaru but in areas north of Samaru the incidence was up to 60% probably because of late planting, which was due to late rains in 1984. Apart from host plant resistance, soil treatment with Furadan 3G was the most effective against the MSV disease under field conditions. Stem borers were of greater economic importance than earworms. By 1985, it was reported that granular carbofuran applied into the furrow at planting at the rate of 1.0 kg a.i./ha gave the best protection against the MSV disease and resulted in the highest grain yield. In 1986, the reaction of 38 exotic and local varieties of maize to four major diseases *Drechsler* leaf blight, MSV, rust and *Curvularia* (Anon 1987) were highly variable, suggesting the possible occurrence of different pathogenic strains. Granular and seed treated formulation of Furadan effectively controlled MSV disease and produced the highest grain yield. In another trial, 3% granular formulation of the systemic insecticide, carbofuron, applied at the rate of 1.0 kg a.i/ha to the furrow at planting gave the best protection for maize, the highest grain yield and the highest monetary return. On grain storage, loss in weight was significantly lower with Actellic EC and with Sumithion and Reldan at dosage rates of 5 and 10 ppm, respectively. Ear rot disease damage was least where maize was left to dry in the field. On nematodes control, both Furadan and Counter resulted in significant increase of maize grain yields. Sumithion treated maize grain was found to have the least numbers of *Sitophilus tribolium* and *Oryzaephilus* spp. in an on-farm trial.

Economics of Production

On economics of production and technology adoption, research at IAR revealed that new maize technology packages gave 98.8% higher grain yield than the farmers' traditional methods of production. All the components of the new technology contributed to increased grain yield. The new technology was, therefore, cost-effective. Although the labour requirements for the two types of maize (OPV and hybrids) were similar, results of on-farm trials indicated that, on average, hybrids out-yielded an OPV, TZB, by 53%. Therefore, there is a significant financial advantage of growing hybrids over TZB. At high rates of fertilizer application, hybrid varieties gave higher gross margin; however, at lower rates of fertilizer, TZB gave a higher gross margin in 1989. Under the lowest fertilizer rates, however, average net revenue from hybrid production was, on average, about 36% higher than that of the OPV.

Collaborative Trials

IAR has been collaborating with national and international research organizations on maize improvement since the 1960s. By 1962, IAR was fully collaborating with the Federal Department of Agriculture on maize research. In 1965, the IAR maize project was expanded to include not only the National Co-operative Trials, but also additional yield trials of varieties and hybrids. Mexico-5 used as a standard check at Samaru was only exceeded in yield by H5O3. By 1967, IAR researchers were conducting the National Zonal Trials as well as the West African Yield Trials in collaboration with OAU-STRC Joint Project with the seed for the trials provided by six countries. In 1975, IAR Samaru co-operated in the East African Maize Variety Trial Co-ordinated by East African Agricultural and Forestry Research Organization (EAAFRO), Kitale, Kenya. Regional Uniform Variety Trials (RUVTs) were used as the vehicle for testing the performance of elite varieties under different environmental and socioeconomic conditions and for the direct exchange of varieties and source germplasm among countries. The goal of the collaborative trials was to afford national scientists the opportunity to identify varieties for broad or narrow adaptation, as appropriate for their individual situations.

In 1983, in collaboration with IITA Ibadan, inbred lines resistant to MSV and selected hybrids developed from them were tested in comparison to the commonly grown OPVs. The hybrids were superior to the OPV checks. In 1988, seven entries of the Nationally Co-ordinated Trials (namely TZE Comp 3, Funtua 86 TZU TSR-W, Across 86 TZUTS R-7, EV8444-SR, Maracay 7921-SR, EV8422-SR and Farako Ba 85TZSR-Y-1) performed very well. For the Regional Trials, one entry (Pop CSP early) out of the 12 extra-early maturing varieties showed outstanding performance. Among the 12 medium maturing entries, 8 significantly out-yielded the check, with EV8444 SR producing the highest yield. In collaboration with NCRI and IITA, IAR contributed significantly to the development of improved varieties for different ecological zones. Some of the varieties released include TZA, TZB, TZESR-W, TZESR-Y and Bulk3. In 1989, the Nationally Coordinated Trials continued with 15 elite cultivars with TZESR as check. Also 13 SAFGRAD varieties included in a Regional Trial were planted at two locations in the NGS and one location in the SS. Among the early maturing varieties, Across 86 Pool 16 DT, significantly out-yielded the other 13 entries. Among the extra early materials, entries TZESR-W × Gua 313 BCF6 and TZEF-Y performed significantly better than most of the other entries.

The SG-2000 started activities in Nigeria in March 1992 to raise agricultural productivity and improve food marketing. SG-2000 initially concentrated on maize and wheat in Kano and Kaduna States but now has moved to other crops and other States of the Federation (Valencia and Breth, unpublished). In recent years high-yielding, early and extra-early maturing disease resistant maize, along with fertilizer became available, leading to the cultivation of the crop in "non-traditional" areas, such as some parts of the Sudan and Sahel savannas. The collaboration of SG-2000 with IAR Samaru, NARIs, IITA and States ADPs for technology transfer approach resulted in doubled or tripled crop yields over the national average. This has led to a marked improvement in income and living standards of farmers in the savanna zones of the country. SG-2000 in partnership with IAR, IITA, WECAMAN and CIMMYT is now promoting quality protein maize (QPM) in much of the savanna zone of Nigeria.

Impact of Maize Research

Van Eijnatten (1965) predicted that with improved transport facilities, the farmers in northern Nigeria would intensify the production of maize for export to southern areas. Nigeria does not need to import any type of maize whatsoever; on the contrary it could be a maize exporting country. Land area planted to maize and yields obtained per ha from 1982–2002 are presented in Fig. 1. The land areas under maize increased at about 2,800 ha per year from 1982 to 2000.

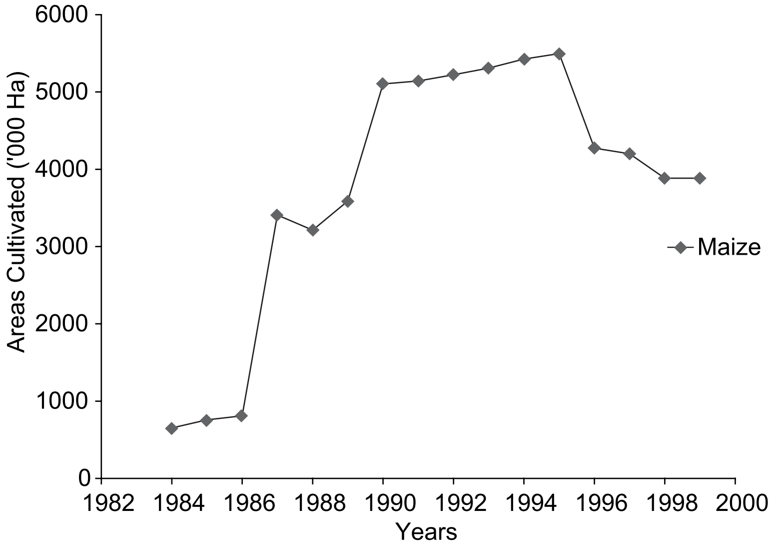

Figure 1. Trend of land area cultivated to maize in Nigeria, 1984–2000.

There has been a dramatic increase in the land area under maize in the northern Guinea savanna (Fakorede *et al.* 1993), which may now be described as the Corn Belt of Nigeria. Availability of fertilizers at affordable prices generally determines the increase in land area under maize production in any particular year. Thus, areas cultivated to maize decrease as fertilizer subsidies are withdrawn. When fertilizers were not readily available, the land put to maize was reduced because maize production depends on availability of fertilizers.

The trends for grain yield and production were similar to those of land area (Fig. 2). Average annual increase in total production was much higher than the annual increase in yield.

The average maize grain yield increased from 0.9 t/ha in 1980 to about 1.3 t/ha in 2001, an annual increase of 0.02 t/ha. Between 1980 and 2001, land area under maize increased significantly up to 440% (Fakorede *et al.* 2003).

Maize is rapidly being adopted in many marginal areas because of availability of early and extra-early maturing varieties. Grain yield has shown significant linear increases as a result of adoption of the improved technologies. Collaborative efforts in RUVTs, on-farm demonstrations, capacity building, exchange of ideas and technical experience of NARIs and international scientists, and promotion of community-based seed production have all contributed to the increased maize output (Fakorede *et al.* 2003). According to these researchers, estimated annual growth rate in maize production was 2.76%, which is lower than the 3.20% projected to meet local demands (Shaib *et al.* 1997). Despite the increase in production, the demand for maize is higher than even the target set for the attainment of selfsufficiency in the country (Fig. 3). In order for Nigeria to be selfsufficient in maize

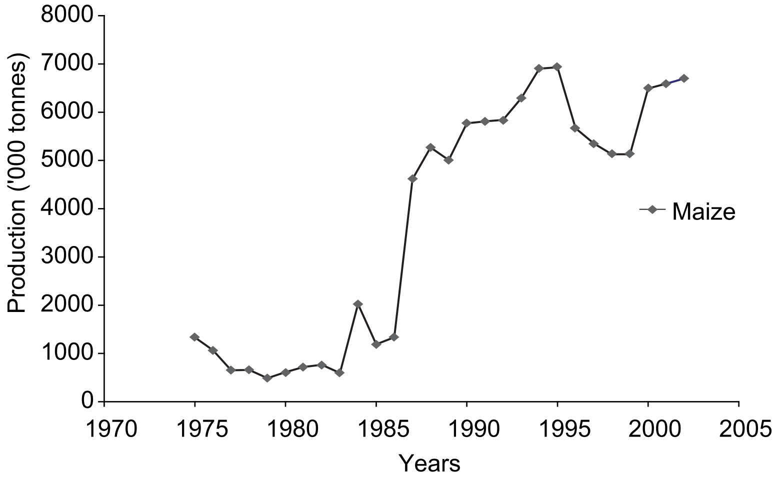

Figure 2. Production trend for maize in Nigeria, 1975–2005.

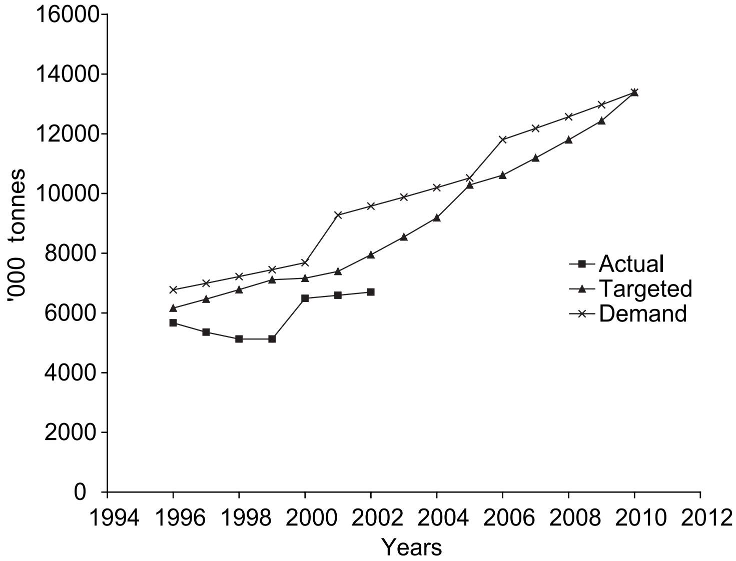

Figure 3. Trends of actual production, targeted production and projected demand for maize in Nigeria.

production, it must produce enough for consumption and have surplus for export. To satisfy this demand, the nation must be able to produce a minimum output of 10 million t annually (Azeez 1993).

Social gains from maize research in the northern Guinea savanna (NGS) of Nigeria during the 1986–97 period indicated varietal adoption rates of 7.8%, 49.6% and 42.6% per annum for local, improved OP and hybrid varieties, respectively, with an internal rate of return of 23%. Thus, the investments in maize research were well justified (Phillip 2001). Poor yields in farmers' fields were caused by low soil nutrients and poor management practices (Fakorede *et al.* 2001). To realize maize yield potential, there should be a combination of appropriate variety, soil and crop management practices.

Conclusion

In conclusion, the Institute for Agricultural Research, Samaru, Nigeria, together with international and other national research institutes and universities, is fully committed to the development of improved high yielding varieties, appropriate technologies and sustainable production systems. Through the collaboration of these institutions, land area under maize, total maize production and grain yield per ha have increased dramatically in the last two decades. In achieving this level of success, the particularly fruitful collaboration of IAR with IITA, WECAMAN, CIMMYT, SG-2000 and the Nigerian NARES deserves special mention.

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Section 2

Agronomy and Physiology

Effect of organic and inorganic nutrient sources on extra-early maize in the Nigerian savanna

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Abstract

Field studies were undertaken to evaluate the response of extra- early varieties of maize (*Zea mays* L.) to different sources of organic amendments alone and in combination with varying rates of inorganic fertilizer in an alfisol of the Nigerian savanna for three years. The treatments consisted of factorial combinations of 5 different organic material sources (cow dung, maize stover, *Leucaena leucocephala* prunings, *Mucuna pruriens* vines, applied at 5 t ha^{-1} and no amendment control) and four rates of chemical fertilizer (0, 25, 50 and 100% recommended rates). Organic and inorganic fertilizers as well as their interactions affected maize growth and yield. Yield differences were significant at each incremental level of inorganic fertilization. The relative effects of applications of the organic materials were in the order: cow-dung> *M. pruriens* vines>*L. leucocephala* prunings>maize stover respectively. The results showed that, under intensive systems, a combination of 5 t cow dung ha^{-1} and recommended optimum inorganic fertilizer rate could produce maximum yields. It was concluded that, in low input and nutrient deficient systems, application of cow dung or *M. pruriens* vines could reduce the inorganic fertilizer requirement of the maize crop.

Résumé

Des études au champ ont été conduites afin d'évaluer la réponse de variétés extra-précoces de maïs aux différentes sources d'amendements organiques spécifiques et en combinaison avec des taux variés d'engrais inorganiques dans un alfisol dans la savane nigériane pendant trois années. Les traitements ont consisté en des combinaisons factorielles de 5 différentes sources de matières organiques (fumure de vache, résidus de maïs, élagages de *L. leucocephala*, tiges de *M. pruriens* et témoins) appliquées à deux taux (0 et 5 tonnes/ha). Le traitement d'engrais chimique était appliqué à quatre taux (0, 25, 50 et 100% de la dose recommendée). Les paramètres de croissance et de rendement du maïs ont été affectés par les applications individuelles d'engrais inorganiques et organiques et à leurs interactions. Les différences de rendement maïs étaient significatives pour chaque augmentation du niveau d'engrais chimique. L'effet relatif de l'application de la fumure organique était dans l'ordre suivant: fumure de vache > tiges de *M. pruriens* > élagages de *L. leucocephala* > résidus de maïs. Le pourcentage moyen d'engrais équivalent aux applications des matières organiques était de 24, 18, 12, et 11% pour la fumure de vache, tiges de *M. pruriens*, résidus de maïs, et élagages de *L. leucocephala* respectivement. Les résultats ont montré que dans des systèmes intensifs, une combinaison de 5 tonnes fumier de vache ha^{-1} et des taux d'engrais inorganiques optimum recommandés, pourraient permettre d'atteindre les rendements élevés escomptés. En conclusion, dans les conditions de faibles intrants et dans les systèmes déficients en nutriments, l'application de fumier de vache ou de tiges de *M. pruriens,* pourrait mieux réduire les exigences en engrais inorganiques de la culture de maïs.

Introduction

Sole-planted maize (*Zea mays* L.) and maize-based cropping sequences are predominant cropping systems in the Nigerian savanna. Following the development and availability of extra-early maize varieties to farmers, maize production has expanded to new frontiers within the savanna. However, low inherent soil fertility and/or declining soil fertility is a major factor limiting grain yield of maize in the Nigerian savanna. Most of the soils are highly weathered and poorly buffered with meagre reserves of nutrients in the rooting zone. A large part of the savanna soils are, therefore, susceptible to nutrient depletion with intensive farming because of their low buffering capacity (Balasubramanian and Nnadi 1980; Kang and Wilson 1987). Although the application of inorganic fertilizers is an effective means of increasing crop yields in arable systems, fertilizer costs, amongst other constraints, prevent farmers from using them in recommended quantities and balanced proportions. On average, the estimated amount of inorganic fertilizer (N, P_2O_5 and K_2O) available to and used by farmers in Nigeria is about 4.5–5.6 kg nutrients ha^{-1} arable land (Ofori and Sant'Anna 1990; Ange 1995; Dudal 2002), an amount that is far below the recommended rates for maize and, therefore, insufficient to meet crop nutrient demands. There is increasing evidence that the most promising way to improve crop yields, especially in smallholder farming systems, is by increasing inorganic fertilizer use efficiency through the addition of organic amendments (Jones *et al.* 1997; Uyovbisere *et al.* 1999). Vanlauwe and Sanginga (2004) indicated that this approach was driven by the lack of a sufficient amount of either inorganic or organic amendments, the recognition that both inorganic and organic amendments fulfil a set of different functions and the potential for creating added benefits when applying organic resources in combination with inorganic amendments.

Farmers in Nigeria use a wide range of locally derived organic materials for soil management, principally in the form of crop residues and animal manure. Other materials such as prunings from trees, green manure, industrial wastes, municipal wastes, and sewage sludge, have not been extensively used in the Nigerian savanna because of problems with collection, processing, transportation and application. The objective of the present study was to determine the effect of cow dung, maize crop residue, *Mucuna pruriens* vines and *Leucaena leucocephala* prunings on the response of extra-early maturing maize to inorganic fertilizer in the Nigerian savanna.

Materials and Methods

Field experiments were conducted during the cropping seasons of 1998, 1999 and 2000 on a sandy loam soil (Alfisol) at the research farm of the Institute for Agricultural Research (IAR), Zaria, Nigeria (lat 11 ^{0}11′N, long 7 ^{0}38′ E and altitude 686 m asl). The field was previously cultivated to *Vigna unguiculata* (L.) Walp and left to fallow for three years, a typical practice of farmers in the northern Guinea savanna of Nigeria. Rainfall distribution at this location is characterized by distinct wet and dry seasons in alternation (Fig. 1).

The treatments consisted of factorial combinations of four different organic material sources (cow dung, maize stover, *L. leucocephala* prunings, *M. pruriens* vines, applied at 5 t ha^{-1} each), four rates of chemical fertilizer treatments (0, 25, 50 and 100% recommended rates of NPK), and a control. The current fertilizer recommendation for open-pollinated maize in the Nigerian savanna is 120-60-60 N, P_2O_5, and K_2O kg ha^{-1}. The cow dung was obtained from dairy cattle at the National Animal Production Research Institute, Shika, Nigeria.

The maize stover, *M. pruriens* vines and *L. leucocephala* prunings used in this study were obtained from research fields of the Institute for Agricultural Research, Zaria, Nigeria. Daudu *et al.* (2005) have reported in greater details the methodology, including the chemical properties of the organic materials. Equivalent amounts of the organic materials on dry weight basis, corresponding to 5000 kg ha^{-1} were applied as appropriate and properly incorporated into the soil before ridging. Similarly, phosphorus levels (P_2O_5) at 0, 25%, 50% and 100% recommended rates of single super-phosphate were also applied on the appropriate plots before ridging. Potassium levels of muriate of potash (K_2O) and the first split (dose) of nitrogen (urea at 0, 25, 50 and 100% of the recommended rate) were applied at planting using factorial arrangement. The second split dose of N was applied at 4 weeks after planting. The study was conducted on the same site and treatments were repeated on the same plots in each of the three years. In the first year, the field was ploughed, harrowed and ridged using a tractor, while in the second and third years

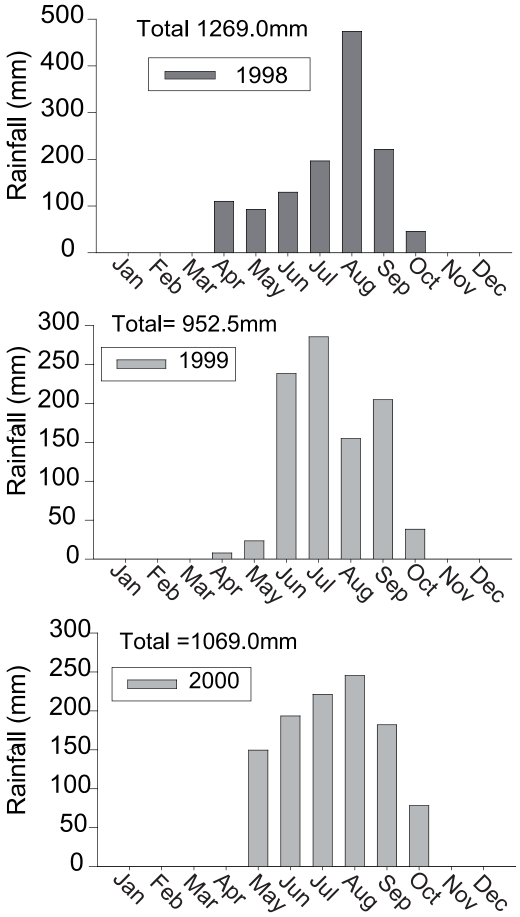

Figure 1: Rainfall pattern in Samaru from 1998 to 2000.

the plots were prepared manually to maintain plot properties. Plot size was 4 m x 6 m, representing an area of 24 m^2. An extra-early maturing open-pollinated maize variety, 95 TZEE-W was the test crop.

The soil characteristics of the site at the initiation of the study were determined from composite samples of surface soils. Particle size distribution was carried out by the hydrometer method (Bouyoucos 1951), while the Micro-kjeldhal wet digestion method was used to determine total N (Bremner 1965).

Walkley and Black method was used to determine organic carbon (Page *et al.* 1982). Soil pH was determined in water and in 0.01M $CaCl_2$ at a soil:solution ratio of 1:2.5 (weight:volume) with a glass electrode. Exchangeable bases were displaced with 1N NH_4OAc buffered at pH 7.0. Potassium and sodium in the extract were determined with the flame photometer; calcium and magnesium were determined with the atomic absorption spectrophotometer. Available P was determined by the Bray I method (Bray and Kurtz 1945). The ECEC was determined by summing the values of exchangeable bases and exchangeable acidity, which was determined by 1N KCl extraction.

Table 1. Initial physico–chemical characteristics of surface soils of the experimental site.

Soil property	Amount in soil
Clay (%)	11
Silt (%)	27
Sand (%)	62
pH (H_2O; 1:2.5 w/v)	5.1
pH (0.01M Ca Cl_2; 1:2.5 w/v)	4.9
Bray-1 P (mg kg^{-1})	5.9
Organic Carbon (g kg^{-1})	5.5
Total N (g kg^{-1})	0.4
Exchangeable calcium (cmol kg^{-1})	2.2
Exchangeable magnesium (cmol kg^{-1})	0.6
Exchangeable potassium (cmol kg^{-1})	0.4
Exchangeable sodium (cmol kg^{-1})	0.1
Effective cation exchange capacity (cmol kg^{-1})	3.4

Data were obtained on stover and grain yields from the four central rows of each plot. The following yield derivatives were calculated, using the formulae given by Chien *et al.* (1990):

$$\text{Relative yield at each fertilizer level (\%)} = \frac{\text{Yield}_{\text{treatment}}}{\text{Yield}_{\text{Chemical fertilizer}}} \times 100$$

$$\text{Relative yield increase (\%)} = \frac{\text{Yield}_{\text{treatment}} - \text{Yield}_{\text{control}}}{\text{Yield}_{\text{chemical fertilizer}} - \text{Yield}_{\text{control}}} \times 100$$

Analysis of variance (ANOVA) for each variable was done each year, using the GLM procedure of the Statistical Analysis System (SAS 1989).

Results and Discussion

Characteristics of the soil and organic materials

The soil was characteristically low in macronutrients especially N and P, organic carbon content and cation exchange capacity (Table 1).

Nitrogen, P and K contents have important agronomic and environmental implications for the soil application of organic materials (Avnimelech 1986; Ishikawa 1988).

The carbon quality of an organic material depends on the relative proportions of soluble carbon, lignin and cellulose. Mean values for the carbon quality as well as the NPK components of the organic materials are presented in Figure 2. Cow dung, *M. pruriens* vines and *L. leucocephala* prunings had N and P values above the critical levels (2.0, 0.2 and 0.2%, respectively) required for nutrient release (Blair and Boland 1978; Palm 1995). Both N and P values of maize stover were below critical values. When the organic materials were evaluated

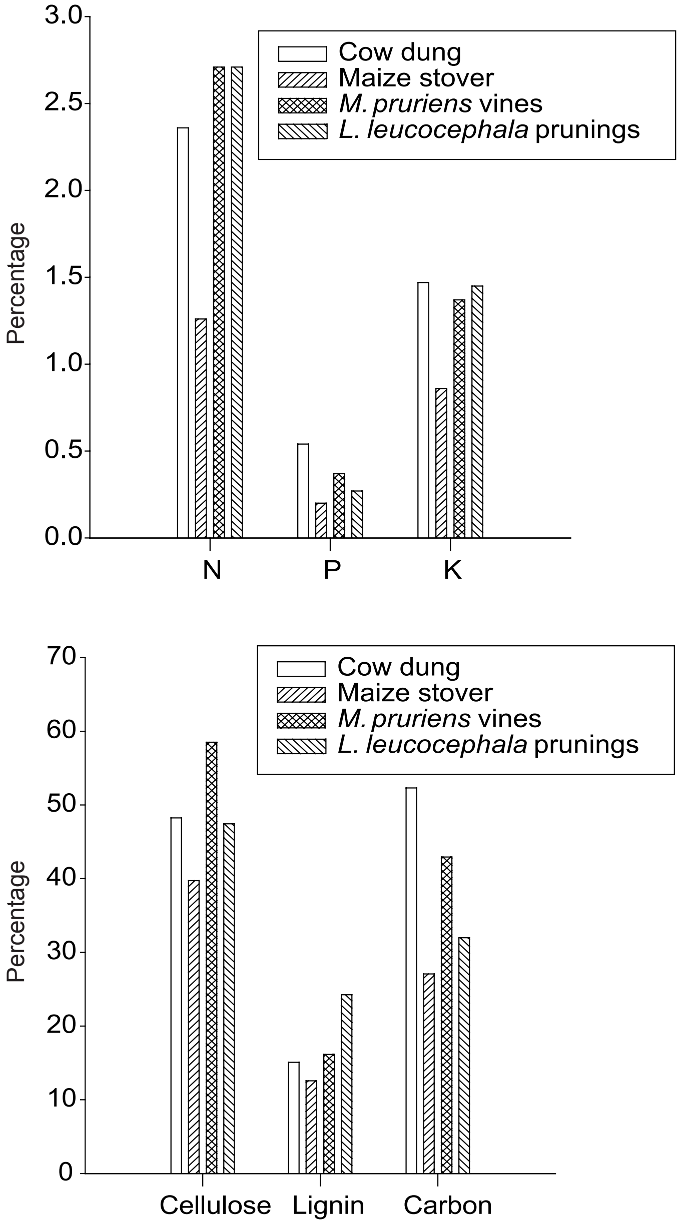

Figure 2: Mean comparison of nutrient and carbon quality of different organic inputs.

based on the contents of nutrients and deduced ratios, cow dung, *M. pruriens* vines and *L. leucocephala* prunnings were characterized as high quality materials; maize stover was considered to be a low quality material (Daudu *et al.* 2005).

Maize grain and dry matter yields

Maize growth parameters responded positively to individual as well as combined applications of organic and inorganic materials each year (Tables 2 and 3). Generally, the application of organic materials increased grain yield in the following order: cow dung > *M. pruriens* vines > *L. leucocephala* prunings > maize stover.

Averaged over years and fertilizer levels (Fig. 3), grain and stover yields of plots amended with cow dung were similar to those of plots amended with *M. pruriens* vines; plots amended with *L. leucocephala* prunings had significantly lower yields. Since the N contents of *M. pruriens* vines and *L. leucocephala* prunings were almost identical, it may be concluded that the decomposition and nutrient release of *M. pruriens* vines was in better synchrony with the demands of the maize crop than *L leucocephala* prunings.

The release of nutrients such as N, K and S, can lead to formation and accumulation of NO^{-3}, K^{+} and SO^{-4}, and the associated cations or anions being leached down the soil profile, with the wetting front, so that the crop does not have ready access to the released nutrients (Blair *et al.* 1997). In soils of low nutrient capacity, such nutrients may be leached below the rooting zone of the crop. A rapid release of nutrients from residues, which was observed with *L. leucocephala* prunings, may therefore be inappropriate in tropical systems with such soils. Giller and Cadish (1995) similarly observed that under field conditions, the contribution of prunings to crop nutrition is often small. The poor yields obtained following application of maize stover could be attributed solely to the low N content, particularly as the N content was below the critical value. This suggests that the maize stover decomposed and released nutrients too slowly to meet crop requirements, due to possible immobilization following the application.

Averaged over the three years, grain yield decreased by 54, 76, 58, and 70% for the treatments with cow dung, maize stover, *M. pruriens* vines and *L. leucocephala* prunings, relative to the recommended inorganic fertilizer treatment. It is important to note that the organic materials were added only once before planting and the urea was applied in two equal split doses. It was, therefore, possible to time the application of the N fertilizer to the crop, when demand was high. Thus, the inorganic fertilizer had a better synchrony of N release with crop demand and was thus made more efficient for grain production. Nutrient release from organic materials is spread over time, and there is usually no sharp peak in mineralization that can be synchronized with plant demand. The application of organic materials at the rates used in this study would almost always require application of inorganic fertilizer, at least at the initial stages of plant growth.

Maize yield was high when organic materials and an optimum quantity of fertilizer were applied together. Significant interaction between organic matter type and inorganic fertilizer rate was observed for grain and stover yields in 1999 and 2000. The interaction showed that at 0, 25 and 50% of recommended rates of inorganic fertilizer

Table 2. Effect of organic materials and inorganic fertilizer applications on maize grain yield, 1998–2000.

Trts^{+}	1998					1999					2000				
	Mo	M_{CD}	M_{CR}	M_{GM}	M_{GL}	Mo	M_{CD}	M_{CR}	M_{GM}	M_{GL}	Mo	M_{CD}	M_{CR}	M_{GM}	M_{GL}
F_O	317	1172	478	979	744	195	1043	667	1041	797	257	1451	754	1313	817
F_1	1069	1367	927	1565	1350	1416	1446	1182	1531	1453	1434	1959	1432	2135	1791
F_2	1647	2336	1725	2336	1968	1971	2514	2080	2138	2144	2285	2822	2241	2720	2649
F_3	2358	3128	2313	2845	2648	2592	3471	2646	3334	2896	2947	3630	2924	3417	3292
Sources (l.s.d. at p = 0.05)															
F	<0.0001					<0.0001					<0.0001				
M	<0.0001					<0.0001					<0.0001				
F x M	<0.8759					<0.0001					<0.0019				
SE	250.97					124.58					135.65				

$^{+}F_O$ – no fertilizer; F_1 F_2 F_3 – 25, 50, 100% NPK rates, respectively. Mo – no organic manure; M_{CD} , M_{CR}, M_{GM}, M_{GL} cow dung, maize stover, *M. pruriens* vines and *L. leucocephala* prunings, respectively.

Table 3. Effect of organic materials and inorganic fertilizer applications on maize stover yield, 1998–2000.

Trts	1998					1999					2000				
	Mo	M_{CD}	M_{CR}	M_{GM}	M_{GL}	Mo	M_{CD}	M_{CR}	M_{GM}	M_{GL}	Mo	M_{CD}	M_{CR}	M_{GM}	M_{GL}
F_O	814	2178	1111	2050	1312	884	2550	1369	2484	1542	1026	2586	1412	2611	1709
F_1	2285	2919	2002	2917	2470	2502	3087	2265	3678	2988	2765	3678	2417	3866	3346
F_2	2959	4116	2848	4001	4108	4084	4678	3032	4604	4447	4358	5268	3579	5167	4806
F_3	4428	5081	4463	4709	5125	4871	6005	5075	5891	5247	5023	6654	5376	6462	5968
Sources (l.s.d. at p = 0.05)															
F	<0.0001					<0.0001					<0.0001				
M	<0.0001					<0.0001					<0.0001				
F x M	<0.0465					<0.0001					<0.0295				
SE	325.95					258.32					265.48				

$^{+}F_O$ – no fertilizer; F_1 F_2 F_3 – 25, 50, 100% NPK rates, respectively. Mo – no organic manure; M_{CD} , M_{CR}, M_{GM}, M_{GL} cow dung, maize stover, *M. pruriens* vines and *L. leucocephala* prunings, respectively.

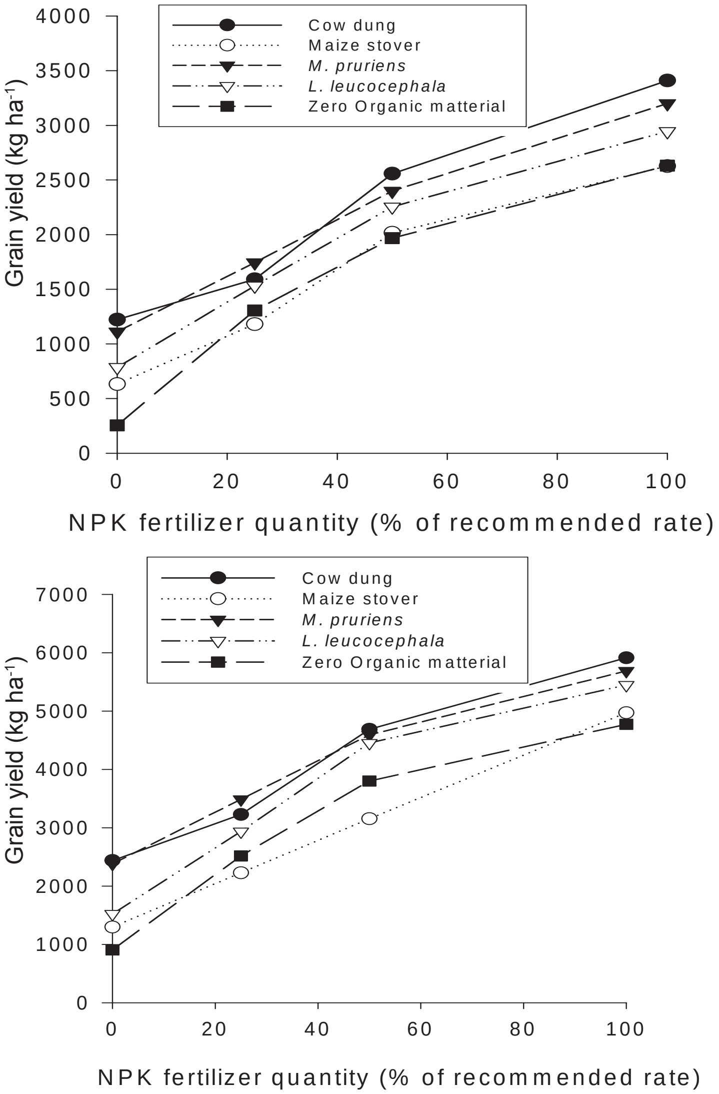

Figure 3: Grain and stover yield effects (averaged over 3 years) of organic materials on the response of maize to inorganic fertilizer.

application, the effects of cow dung and *M. pruriens* were equal and better than in plots treated with maize stover and *L. leucocephala,* whose effects were also equal. However, at 100% of recommended fertilizer rates, there was a significant increase in grain and stover yields of plots in which cow dung were applied over plots treated with *M. pruriens,* which was in turn significantly greater than in plots treated with maize stover, while the effect of *L. leucocephala* was equal to those of cow dung and *M. pruriens*. The advantage derivable from organic materials on maize grain and stover yields, therefore, depends upon the rate of inorganic fertilizer applied with the organic matter. The implication of these results is that recommendation of inorganic fertilizer rates will differ with the type of organic material applied.

Yield increase and relative yields

Tables 4 and 5 show maize and stover yields resulting from the application of the different organic materials on maize grain and stover yields at various inorganic fertilizer rates. Relative yield response to the organic material at zero and low fertilizer rates were greater in the second and third years, probably due to residual effects of the organic materials (Jokela 1992). The results indicated that the relative yields of sole applications of the leguminous residues and cow dung were consistently lower for stover than for grain. This suggests that, with the application of these organic materials, nutrients had a greater relative effect during the reproductive period than during the vegetative stage. This occurred, perhaps, because the nutrients mineralised from organic materials were becoming increasingly available, while the unfertilised plots were becoming increasingly deficient in nutrients as the season progressed. The relative effects of the treatments on grain and stover yields were consistent, and the magnitude varied with the type of organic material in the following order: cow dung > *M. pruriens* vines > *L. leucocephala* prunings > maize stover.

Relative yields of treatments with organic materials without inorganic fertilizers and at low inorganic fertilizer rates were higher at the end of the study. Kang (1993) similarly reported that maize yield appeared to be sustainable at low fertilizer rates in combination with *L. leucocephala* prunings. This indicated an improvement in soil fertility conditions due to the capacity of the organic materials to arrest degradation and maintain the productivity of the soils. Relative yields of plots amended with maize stover and varying rates of inorganic fertilizers were generally lower than for the other organic materials. This was true even at the recommended optimum rate of inorganic fertilizer application, indicating the negative effects of maize stover on soil productivity. This is probably due to the low nutrient contents, relatively slower rate of decomposition and, hence, little nutrient release from the maize stover.

The results showed that, with the exception of maize stover, the addition of the organic materials with and without fertilizer led to increases in yield. Possible explanations for this response pattern may include more favourable physical, inorganic and biological conditions of the soil amended with green manure. The application of inorganic fertilizer had a greater effect when combined with *M. pruriens* vines than with any of the other organic materials. The relative effects of the organic materials on grain yield decreased as inorganic fertilizer rates increased. This is expected since the base yield increased with each increment of inorganic fertilizer. Earlier studies led to similar conclusions (Uyovbisere and Elemo 2000). The results revealed a wide range of increases in maize grain yield with the application of different organic

Table 4. Relative grain and stover yields at each inorganic fertilizer level.

Treatment combination		Relative grain yield (%)			Relative stover yield (%)		
Organic materials type	Inorganic fertilizer rate	1998	1999	2000	1998	1999	2000
Cow dung	0	410.68	552.14	629.94	271.11	294.40	261.79
Cow dung	¼ opt	127.00	106.53	137.15	128.87	126.60	133.74
Cow dung	½ opt	140.92	128.31	123.44	145.61	114.54	121.59
Cow dung	opt	132.64	134.08	123.12	114.72	123.45	132.47
Maize stover	0	166.27	352.62	319.45	136.93	156.79	137.60
Maize stover	¼ opt	86.47	86.09	99.75	88.38	92.09	87.36
Maize stover	½ opt	101.56	106.06	98.15	97.88	74.33	82.63
Maize stover	opt	97.57	101.98	99.21	100.37	104.18	106.98
M. pruriens	0	373.83	550.34	556.67	253.95	285.77	257.16
M. pruriens	¼ opt	146.31	111.55	149.37	128.20	150.25	140.43
M. pruriens	½ opt	143.42	108.54	119.10	140.24	112.45	119.82
M. pruriens	opt	120.81	128.63	116.19	106.39	120.99	128.80
L. leucocephala	0	275.06	418.56	343.93	161.56	172.96	167.61
L. leucocephala	¼ opt	125.77	107.76	124.74	107.52	121.36	120.95
L. leucocephala	½ opt	122.84	109.55	116.02	146.39	108.97	111.38
L. leucocephala	opt	111.96	111.72	111.83	115.43	107.95	118.84

Table 5. Relative grain and stover yield increases at each inorganic fertilizer level.

Treatment combination		Relative grain yield increase (%)			Relative stover yield increase (%)		
Organic materials type	Inorganic fertilizer rate	1998	1999	2000	1998	1999	2000
Cow dung	¼ opt	141.56	107.95	144.18	145.32	142.15	153.38
Cow dung	½ opt	151.46	131.93	126.25	165.40	118.90	128.49
Cow dung	opt	137.71	136.75	125.24	118.00	128.70	140.83
Maize stover	¼ opt	81.65	84.00	99.77	82.09	88.65	80.27
Maize stover	½ opt	102.83	106.90	97.89	97.55	67.28	77.39
Maize stover	opt	97.78	102.13	99.11	100.79	105.27	108.72
M. pruriens	¼ opt	167.26	113.89	158.98	143.81	182.16	164.61
M. pruriens	½ opt	153.57	109.63	121.31	157.58	116.36	126.48
M. pruriens	opt	123.48	130.94	117.79	107.70	126.68	136.41
L. leucocephala	¼ opt	139.66	109.51	129.86	111.37	134.38	133.11
L. leucocephala	½ opt	126.82	110.89	117.89	166.65	111.43	115.19
L. leucocephala	opt	114.16	112.63	113.32	119.09	109.76	123.76

materials at zero chemical fertilizer levels. In systems where the major constraints to crop production are nutrient limitations, as in soils of the Nigerian savanna, single and combined applications of inorganic and organic materials could be used to increase maize grain production.

Conclusion

The study demonstrated that in low input and nutrient deficient systems, the application of cow dung or *M. pruriens* vines could reduce the inorganic fertilizer requirement of a maize crop. The results also showed that under intensive systems, a combination of 5 t of cow dung ha^{-1} and the recommended optimum rate of inorganic fertilizer such as 120-60-60 could achieve the required high yields. Performance of yield-related traits varied with the source of organic material. The timing of incorporation of organic materials to ensure maximum benefit from nutrients released from the materials needs to be further investigated.

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Residual benefits of soybean genotypes and natural fallow to subsequent maize in the northern Guinea savanna of Nigeria

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Abstract

Genotypic variations have been shown to exist in residual benefits of promiscuous lines of soybean [*Glycine max* (L.) Merr.] to subsequent maize (*Zea mays* L.) crop. The knowledge of combined effects of crop rotation and fertilization on soil properties and grain yield is the key to sustainable crop production. Soil properties and grain yield were evaluated where different crop rotations were used. Two promiscuous, improved soybean lines (TGx 1448-2E and Samsoy-2), natural fallow, and a maize hybrid (Oba Super 2) were grown in 2003 and followed by a test crop of maize in 2004 with and without fertilizer (0 and 90 kg N ha^{-1}) application. Rotation and N fertilizer significantly ($P<0.05$) influenced the organic carbon (OC) and total N contents of the soil. Unfertilized continuous maize resulted in the lowest soil OC and total N contents. Soil total N of maize plots following Samsoy-2 (1.01 g kg^{-1}) was not significantly different from that following TGx 1448-2E (0.97 g kg^{-1}). Exchangeable bases were significantly ($P<0.05$) higher in all fertilized maize-legume than in fallow-maize and continuous maize treatments. Fertilizer application significantly decreased soil pH with the highest decrease in the two soybean-maize rotations. Maize grain yield was significantly higher when grown after Samsoy 2 than after maize and natural fallow. The increases were 46% higher than that of maize-maize and 34% higher than that of the fallow-maize system even though the soybeans were not inoculated with Rhizobia. The results obtained in the study were consistent with the conclusion that crop rotation is a viable management option that helps to increase maize yield without deleterious effect on chemical soil fertility.

Résumé

Des variations génotypiques ont été identifiées dans les bénéfices résiduels de lignées promiscues de soja [*Glycine max* (L.) Merr.] à la culture subséquente de maïs (*Zea mays* L.). La connaissance des effets combinés de fertilisation et de rotation des cultures sur les propriétés du sol et des rendements grains, est la clé d'une production de culture durable. Les propriétés du sol et les rendements grains ont été évalués pour les différents types de rotations de cultures. Deux variétés promiscues de soja; la lignée améliorée (TGX 1448-2E) et la variété locale (Samsoy 2), la jachère naturelle, et un hybride de maïs (Oba Super 2) ont été cultivés en 2003 et suivis par une culture d'essai de maïs en 2004 avec et sans engrais (0 et 90 kg N ha^{-1}). La rotation et la fertilisation azotée ont significativement (P<005) affecté la teneur du sol en azote et en carbone organique (CO). Le maïs non-fertilisé cultivé en continu a résulté en une quantité de carbone organique et d'azote total la plus faible dans le sol. La teneur totale de l'azote du sol des traitements de maïs consécutifs à samsoy-2 (1,01 g kg^{-1}) n'est pas significativement différente de celle consécutive à la variété TGx 1448-2E (0,97 g kg^{-1}). Les bases échangeables étaient significativement (P<0.05) plus élevés dans toutes les cultures de maïs fertilisées suivant les légumes, que dans la jachère – maïs et dans les traitements de maïs en continue. L'application d'engrais diminuait considérablement le pH du sol. La diminution la plus forte a été observée dans les deux types de rotations soja – maïs. Le rendement grain du maïs suivant Samsoy 2 était significativement plus élevé que le maïs et la jachère naturelle. Les augmentations étaient 46% plus élevées que celles obtenues avec la rotation maïs – maïs et 34% plus élevées que celles obtenues avec le système jachère – maïs bien que le soja n'ait pas été inoculé au rhizobium. L'étude a montré que la rotation de culture est une option de gestion viable qui pourrait contribuer à augmenter le rendement maïs sans effet délétère sur la fertilité chimique du sol.

Introduction

Traditionally, smallholder farmers in the northern Guinea savanna of Nigeria (NGSN) have maintained soil fertility through shifting cultivation and natural fallow. Because of mounting demographic pressure and the widespread conversion of natural fallow and shifting cultivation systems to semi-permanent and permanent agriculture, soils are no longer allowed enough time to recuperate after a period of cropping, and are therefore more prone to land degradation. Cereal-legume rotations rather than monocropping have been proposed as an effective means of increasing soil productivity. In addition to improving soil physical and chemical properties, legume-based rotations may also decrease the incidence of pests and diseases. However, fertilizer application may influence the degree of changes in the soil properties.

The cultivation of leguminous crops in rotation with other food crops offers a potential for meeting the soil fertility requirements at minimal cost to the farmer (Giller and Wilson 1991). Continuous cropping and application of inorganic fertilizers have been found to impair many soil properties in the Nigerian savanna. Reduced cation exchange capacity, exchangeable cations and upset in the cationic balance have been reported by Agbenin and Goladi (1997). However, the residual benefits of legumes to a subsequent non-N_2-fixing crop are also irregular and are not restricted only to N contribution. Soil pH, exchangeable bases, cation exchange capacity (CEC), total N and organic carbon (OC) are some key soil properties that are influenced in crop rotation trials. Rotation–induced changes in the pH of the bulk or the rhizosphere soil of legumes may enhance phosphorus (P) availability (Ae and Otani 1997), which may be very important in the poorly buffered kaolinitic soils of the Nigerian savanna.

Despite high yield, surface soil acidity and associated loss of cations were detected in a 10-year wheat-lupin rotation compared with continuous wheat (Chan and Heenan 1993). Odell *et al.* (1984) and Johnston (1986) reported that the introduction of legumes in crop rotation improved soil organic matter and crop productivity. Omay *et al.* (1997) reported that the inclusion of soybean in a maize-soybean rotation was found to decrease the amount of stable and active organic fractions of carbon and nitrogen in the soil.

Soybean that was once a minor component of the cropping system is now becoming the second crop after maize in the Guinea savanna of Nigeria (Sanginga 2003). The production and utilization of soybean has expanded approximately 10-fold in Nigeria over the past 10-15 years (Carsky *et al.* 1997; Sanginga 2003) and studies on the contribution of soybean to subsequent maize have been targeted mainly to nitrogen and grain yield (Sanginga *et al.* 2002; Bala *et al.* 2003). This may not be unconnected with the fact that N is the most limiting nutrient affecting maize production in the region and legumes symbiotically fix part of their N requirement, thereby sparing some of the soil N for use by the following non-N_2-fixing crop. However, genotypic variations have been shown to exist in soil N uptake potential by promiscuous soybean and those with a low N harvest index have a positive net N balance (Sanginga *et al.* 1997). Soybean harvested for grain only was shown to supply an average of minus 8 kg N ha^{-1} to over 47 kg N ha^{-1} to following maize (Sanginga *et al.* 1997). This indicates that additional N may still be required for a good maize crop following soybean, depending on the cultivar, and supports the fact that the increased yields of maize following soybean were not due entirely to the carryover of N from the soybean residue and to the soil N-conserving effect (Giller and Wilson 1991).

Bala *et al.* (2003) recorded maize grain yield after soybean of only 600 kg ha^{-1} with 40 kg N ha^{-1} application to maize when all the soybean stover were removed from the field. They concluded that maize production cannot rely wholly on N accruable from soybean litter and suggested that supplementary N needs to be added to the soil. However, Kasasa *et al.* (1999) reported that yields of maize grown after soybean on an alfisol increased to between 2500 and 4500 kg ha^{-1} compared with only 1800 kg ha^{-1} in continuous cropping.

A thorough understanding of the effects of crop rotation and fertilization on soil fertility is necessary for increased soil productivity. Most studies conducted on the variations in the residual benefits of soybean genotypes to subsequent maize in NGSN focused on N dynamics and grain yields. There are only a few reports of studies that evaluated the combined effects of crop rotation and fertilizer application on other soil properties. The primary objective of this study was, therefore, to assess the residual effects of maize rotation with two promiscuous soybean cultivars, natural fallow and fertilization on some selected soil properties. A secondary objective was to estimate the effect of the previous crop on the grain yield of the subsequent maize crop.

Materials and Methods

Experimental site

A field study was conducted at the Institute for Agricultural Research, Samaru Experimental Research Station, located in the northern Guinea savanna of Nigeria (7 ^{0}38′ E, 11 ^{0}11′N). The rainfall pattern is monomodal with a mean annual rainfall of about 1050 mm. Mean annual temperature is about 27 ^{0}C. The study, which was initiated in 2003, was part of a larger trial to evaluate the effects of genotypic differences on rotation effects and fixed-N contributions by grain legumes to maize-based cropping systems. The experimental field was under fallow two years before the commencement of the trial. Common weeds on the experimental field were *Setaria viridis* and *Vernonia galamensis*. The main soil sub-group is Typic Haplustalf (Jibrin 1999). At the start of the trial, the surface 0-15 cm layer had a loam texture, a pH (water) of 6.4, an organic carbon content of 5.0 g kg^{-1}, and a total N content of 0.7 g kg^{-1}. Exchangeable bases were Ca, 0.8; Mg, 0.36; and K, 0.28 $cmol_c$ kg^{-1}.

2003 Experimental layout

In 2003, soybean and maize crops were established using a randomized complete block design with three replications. Two promiscuous soybean cultivars, Samsoy-2 (IAR) and TGx 1448-2E

(IITA), natural fallow and a late maturing N-efficient hybrid maize, Oba Super 2 (8644-27) were used. Soybean seed were not inoculated with rhizobia. Plots were 3.0 m wide (4 rows per plot) and 12.0 m long. Spacing between ridges was 0.75 m. Soybean seeds were hand-drilled on the ridges and seedlings were thinned to a spacing of 5 cm 2 weeks after planting (WAP). Two maize seeds were sown per stand at an intra-row spacing of 0.25 m and later thinned to one plant per stand 2 WAP. This gives a total plant population of 53,333 plants ha^{-1}. Natural vegetation was maintained in the fallow plot. The three crop varieties and fallow were grown on a plot in each replicate making a total of 12 plots on the field. All plots (including maize) received 20 kg N ha^{-1} to meet the recommended starter N dose requirement of soybean in the agro-ecological zone. Above-ground maize, soybean and fallow residues were left on the plots, except samples harvested for yield calculations.

2004 Experimental layout

Maize was sown in all the plots previously left fallow or cropped to soybean or maize in 2003. These treatments are hereafter designated as fallow-maize (MF), maize-maize (MM), TGx 1448-2E-maize (MS1) and Samsoy 2-maize (MS2). Each plot was divided into two with each half receiving either 0 (unfertilized) or 90 kg N ha^{-1} (fertilized) as urea. One-third of the 90 kg N ha^{-1} was applied at 2 WAP and the remaining two-thirds at 6 WAP. The choice of N rates was conceived to allow for estimation of benefits derivable in crop rotation with and without fertilizer N; 90 kg N ha^{-1} is perceived to give the highest maize yield following a promiscuous soybean. Similar inter- and intra-row spacings were maintained as in the 2003 maize plots. The experimental design was a split-plot with randomized complete blocks, replicated thrice. The previous crops constituted the main plots and N rates were the sub-plots. The two center rows were harvested for yield determination, excluding the two plants at the end of the ridges (5.0 m length). Cobs were harvested at maturity and sun-dried before shelling. Grain yield was recorded after shelling early in the dry season.

Soil sampling and analyses

Soil sampling was done in October 2004 (just before maize harvest) to evaluate gross differences in the top 0–15 cm layer, especially in relation to soil chemical properties. Five replicate samples were obtained from each plot (across both diagonals). The samples were collected from the inner rows at 12.5 cm (mid-point) between two maize stands at the edge of the ridges towards the furrow. Soil pH was measured in 1:2.5 soil/water suspension. Organic C was determined by the Walkley and Black method (Allison 1965). Total N was determined using a

Table 1. Grain yield of maize and soybean and fallow biomass in 2003.

Crop	Grain yield (kg ha^{-1})
TGx 1448-2E	1533
Samsoy-2	1536
Maize	2165
Fallow	2877[+]

[+] Above-ground biomass.

semi-micro Kjeldahl digestion (Bremner 1965). Exchangeable cations were displaced with 1.0 M NH_4OAc. Exchangeable potassium (K) was determined by flame photometry, and calcium (Ca) and magnesium (Mg) by atomic absorption spectrophotometry. Exchangeable acidity was determined by extracting with 1.0 M KCl and titrating with 0.1 M NaOH and the CEC of the soils were estimated by the summation of exchangeable cations and acidity (Rhoades 1986; Agbenin and Goladi 1997).

Statistical analyses

All variables collected were subjected to analyses of variance (ANOVA) using the PROC GLM procedure (SAS 1989). Where there was a significant effect of the treatments or their interactions, the Least Significant Difference (LSD) was used to establish differences between means at $P = 0.05$.

Results and Discussion

2003 Experiment

Fallow biomass and grain yield of maize and soybean. The difference between the grain yield of Samsoy-2 and that of TGx 1448–2E was small and not statistically significant (Table 1).

Olufajo *et al.* (1988) reported that N application stimulates plant growth by supplying the seedling with N before initiation of nodules and onset of fixation especially if nodule development is delayed and both seed and soil nitrogen cannot meet the plant's N requirement. This initial increase in seedling vigour is often accompanied by an increase in grain yield. Maize grain yield was 2165 kg ha^{-1} expressed on sun-dried basis while all fallow plots produced biomass of 2877 kg ha^{-1} also expressed on sun-dried basis.

2004 Experiment

Soil Chemical Properties. The F ratios from the analyses of variance for soil chemical properties are presented in Table 2. Rotation and N fertilizer had significant effects on soil pH, organic carbon (OC), total N, exchangeable Ca, Mg, K, CEC and of rotation × fertilizer interaction on exchangeable Ca, exchangeable K, and CEC. On the other hand the effect of the two factors and their interaction had no significant effect on exchangeable acidity.

Soil pH. There were significant differences among rotation treatments and fertilizer application for soil pH (Table 3). Compared to the unfertilized treatments, fertilizer application significantly ($P < 0.05$) decreased soil pH as was reported by Thomas *et al.* (1981) and Juo *et al.* (1995). Mean value of 6.18 was obtained for MM, 5.97 for MF, 5.90 for MS2 and 5.77 for MS1.

Changes in soil pH are related to crop management and in this study, it was found that soils under legume rotation had lower pH, especially in fertilized soils, than continuous maize system. However, the reduction did not reach levels limiting maize growth. Several authors have reported rotation induced changes in the pH of the bulk or the rhizosphere soil of legumes (Chan and Heenan, 1993; Alvey *et al.* 2001; Xu *et al.* 2002). These changes are derived through the exudation of organic acids or ligand exchange on the epidermal cell surfaces of the root and may enhance P availability (Ohwaki and Hirata 1992; Ae and Otani 1997). Carbon dioxide from rapidly decomposing legume residues and root respiration may dissolve in soil water to form weak organic acid to reduce soil pH.

Soil Organic Carbon. Rotation and fertilization significantly affected soil OC contents of the 0-15 cm layer (Table 4). The mean OC content was in the order MS1 ≥ MS2 > MF > MM, with values of 6.5 g kg^{-1} for MS1 and MS2, 5.6 g kg^{-1} for MF, and 5.4 g kg^{-1} for MM. Soil OC was lowest in the unfertilized MM plot perhaps due to poor crop cover both in the first and the second year. The greater part of the soil was left bare and therefore directly exposed to wind and water erosion. The Alfisols of the Guinea savanna of Nigeria are poorly structured and highly prone to crust and compaction, which affects crop emergence and aggravates soil erosion (Ogunwole *et al.* 1999; Wuddivira *et al.* 2000). A slope of 0.3% in Samaru led to a 25.2% runoff with soil loss of 3.0 t yr^{-1}, in sorghum fields (Bationo *et al.* 1996). OC contents increased with fertilizer application in all treatments.

This is related to the amount of residue left in the soil. About 80% of the soybean leaves had fallen before the crop was harvested from the field in 2003. All maize residues were left on the field after removing the cobs in 2004. A combination of the legume residues in 2003 and that from the following fertilized maize in 2004 could be responsible for the higher OC observed in MS1 and MS2. Other complementary factors include good soil cover, reduction in runoff and losses of fertilizer and topsoil due to soil erosion. There was no significant difference in OC between MF and MM. Odell et al. (1984)

Table 2. The F-ratios determined from analyses of variance for soil chemical properties.

		F ratios							
					Exchangeable cations			Exch. acidity	CEC
		pH	OC	Total N	Ca	Mg	K	Al + H	
Source	df		g kg^{-1}	%	--------------------cmol$_c$ kg^{-1}			----------------------	
Rotation (R)	3	5.9**	12.5**	4.4**	13.8**	41.2**	4.4**	0.9	19.6**
Fertilizer (F)	1	25.9**	42.5**	16.9**	98.6**	40.4**	16.9**	0.9	114.6**
R x F	3	0.7	1.7	0.1	7.7**	1.1	5.8**	0.3	5.0*

*, ** Significant F-test at the 0.05 and 0.001 level of probability, respectively.

Table 3. Rotation† and fertilizer effects on soil pH of 0-15 cm of a Typic Haplustalf.

	Rotation				
	MS1	MS2	MF	MM	Mean
Fertilizer (kg N ha^{-1})	-----------------------Organic carbon, g kg^{-1} -------------------------------				
0	6.0	6.1	6.2	6.3	6.2
90	5.5	5.7	5.8	6.1	5.8
Mean	5.8	5.9	6.0	6.2	
LSD (0.01)					
Rotation (R)	0.45				
Fertilizer (F)	0.23				
R x F	0.47				

† MS1 = TGx 1448-2E-Maize; MS2 = Samsoy-2-Maize; MF = Fallow-Maize; MM = Continuous maize.

Table 4. Rotation† and fertilizer effects on organic carbon of 0-15 cm of a Typic Haplustalf.

	Rotation				
	MS1	MS2	MF	MM	Mean
Fertilizer (kg N ha^{-1})	----------------Organic carbon, g kg^{-1}---------------				
0	5.8	5.7	5.4	5.0	5.5
90	7.1	7.2	5.9	5.9	6.5
Mean	6.5	6.5	5.7	5.4	
LSD (0.01)					
Rotation (R)	0.06				
Fertilizer (F)	0.06				
R x F	0.12				

† MS1 = TGx 1448-2E-Maize; MS2 = Samsoy-2-Maize; MF = Fallow-Maize;
MM = Continuous maize.

Table 5. Rotation† and fertilizer effects on total nitrogen of 0-15 cm of a Typic Haplustalf.

	Rotation				
	MS1	MS2	MF	MM	Mean
Fertilizer (kg N ha^{-1})	---------------------Total N, g kg^{-1}------------------				
0	0.85	0.87	0.80	0.74	0.82
90	1.08	1.15	1.06	0.88	1.04
Mean	0.97	1.05	0.93	0.81	
LSD (0.01)					
Rotation (R)	0.37				
Fertilizer (F)	0.27				
R x F	0.53				

† MS1 = TGx 1448-2E-Maize; MS2 = Samsoy-2-Maize; MF = Fallow-Maize;
MM = Continuous maize.

and Johnston (1986) reported improvement in organic matter due to the inclusion of legumes in a cropping system. However, Lal et al. (1994) observed that tillage practices also influence soil OC contents in legume-based rotations.

Total Nitrogen. The effect of soybean rotation on residual soil N is well documented. Fallow-based rotations have also been found to improve soil total N (Juo and Lal 1977). Expectedly, soil total N followed a significantly similar trend to that of OC. The mean total N of the surface soil (0-15cm) was 0.97 g kg^{-1} in MS1 and 1.01 g kg^{-1} in MS2 more than 0.93 g kg^{-1} in MF and 0.81 g kg^{-1} in MM (Table 5). There was no significant difference between MS1, MS2, and MF but the MM treatment was significantly lower than MS1 and MS2. Apparently, N_2-fixation by grain legumes and the presence of residue mulch on fallow plots increased soil total N. Using the bulk density of 1.4 kg dm^{-3} commonly reported in the NGSN (Adeoye 1986; Adeoye and Mohammed-Saleem 1990) and the weight of a hectare furrow slice of

$2.1*10^6$ kg, the additional total N in unfertilized plots will be 231 kg ha^{-1} in MS1, 273 kg ha^{-1} in MS2 and 126 kg ha^{-1} in the MF rotations.

The soil N level was significantly higher in fertilized than unfertilized treatment plots with unfertilized maize having the least value. Much of the total N observed in the soybean and fallow plots could be in organic form, which may not be available immediately for crop use, therefore a maize crop will still respond to inorganic N application. Similarly, the residual N reported on hectare basis is just an estimate from the surface 0-15 cm whereas N content may not be uniform throughout the profile and organic N tends to be more concentrated on the surface soil while inorganic N (NH_4-N and $N0_3$-N) is dominant in the lower depth (root zone) of the profile. The low total N level in the unfertilized continuous maize is due to exploitation of soil N by the crop.

Exchangeable cation and effective cation exchange capacity. In terms of fertilization, concentrations of exchangeable Ca, Mg, and K followed similar trend (Tables 6 and 7) while there was a little variation in terms of the rotation systems. The concentration was in the order of MS2 > MS1 > MF > MM for exchangeable Ca and Mg and MS1 > MS2 > MF > MM for exchangeable K. There was a significant difference between MS2 and other rotation systems in terms of exchangeable Ca. MS1 and MF had no significant effects, whereas the effect of MM was significantly lower than MS1. It is thus clear that soybean-based rotations improve the status of exchangeable Ca more than the continuous maize system. Similar observation was also recorded for exchangeable Mg. However, while there was significant rotation x fertilizer interaction in terms of exchangeable Ca, such relationship did not occur with exchangeable Mg. Calcium is often the dominant cation in soil solution. It is found in association with potassium, the cation with which it is most likely to exchange. Although a significant difference was observed between the treatments in terms of exchangeable K, the difference was not significant between MS1, MS2, and MF (Table 7); the effect of MS1 was significantly different from MM. The main effect of the rotation on exchangeable K revealed that maize plots following TGx 1448-2E had higher mean value than maize following Samsoy-2 although the difference was just about 0.03 unit. The interaction between rotation and fertilizer also revealed that unfertilized maize plot following TGx 1448-2E had higher exchangeable K than fertilized maize following all the crops. This result is in conformity with the observation made on the effect of the treatments on soil pH and exchangeable acidity. Soil pH was lowest in unfertilized MS1 indicating that the hydrogen ions and hydroxyl aluminium ions are held tightly preventing the potassium ions from being closely associated with the colloidal surfaces thus releasing more K into the soil solution. A plausible inference from this observation is that TGx 1448-2E has

Table 6. Rotation† and fertilizer effects on exchangeable Ca and exchangeable Mg of 0-15 cm of a Typic Haplustalf.

	Rotation					Rotation				
	MS1	MS2	MF	MM	Mean	MS1	MS2	MF	MM	Mean
Fertilizer (kg N ha^{-1})	------------Exchangeable Ca, cmol$_c$ kg^{-1} -----------					-----------Exchangeable Mg, cmol$_c$ kg^{-1} -------------				
0	1.18	1.57	1.39	1.15	1.32	0.32	0.41	0.22	0.25	0.30
90	2.80	3.19	1.93	1.74	2.42	0.41	0.54	0.28	0.37	0.40
Mean	1.99	2.38	1.66	1.45		0.37	0.45	0.25	0.31	
LSD (0.01)										
Rotation (R)	0.44					0.05				
Fertilizer (F)	0.36					0.04				
R x F	0.71					0.08				

† MS1 = TGx 1448-2E-Maize; MS2 = Samsoy-2-Maize; MF = Fallow-Maize; MM = Continuous maize

Table 7. Rotation† and fertilizer effects on exchangeable K and exchangeable acidity of 0-15 cm of a Typic Haplustalf.

	Rotation					Rotation				
	MS1	MS2	MF	MM	Mean	MS1	MS2	MF	MM	Mean
Fertilizer (kg N ha^{-1})	------------Exchangeable K, cmol$_c$ kg^{-1} ------------					----------Exchangeable acidity, cmol$_c$ kg^{-1}--------				
0	0.37	0.31	0.27	0.20	0.29	0.09	0.09	0.09	0.06	0.08
90	0.36	0.36	0.35	0.35	0.36	0.15	0.13	0.05	0.09	0.11
Mean	0.37	0.34	0.31	0.28		0.12	0.11	0.07	0.08	
LSD (0.01)										
Rotation (R)	0.06					0.07				
Fertilizer (F)	0.06					0.09				
R x F	0.12					0.19				

† MS1 = TGx 1448-2E-Maize; MS2 = Samsoy-2-Maize; MF = Fallow-Maize; MM = Continuous maize

Table 8. **Rotation† and fertilizer effects on cation exchange capacity of 0-15 cm of a Typic Haplustalf.**

	Rotation				
	MS1	MS2	MF	MM	Mean
Fertilizer (kg N ha^{-1})	----- Cation exchange capacity, cmol$_c$ kg^{-1}------				
0	2.09	2.52	2.07	1.79	2.12
90	3.76	4.30	2.83	2.66	3.39
Mean	2.93	3.41	2.45	2.23	
LSD (0.01)					
Rotation (R)	0.49				
Fertilizer (F)	0.39				
R x F	0.77				

† MS1 = TGx 1448-2E-Maize; MS2 = Samsoy-2-Maize; MF = Fallow-Maize; MM = Continuous maize

high capacity to extract non-exchangeable K thus indicating that it recycles soil K effectively. The exchangeable K level in the unfertilized MM plot dropped below the initial soil K, whereas it was maintained at a relatively high level in the fertilized plot.

Exchangeable acidity was not affected either by rotation, fertilization or their interaction (Table 8). The mean values were 0.117, 0.110, 0.090 and 0.057 cmol$_c$ kg^{-1} for MS1, MS2, MF, and MM, respectively. In terms of fertilization, mean values were 0.080 and 0.102 cmol$_c$ kg^{-1} for 0 and 90 kg N ha^{-1}, respectively. Trend in exchangeable acidity was similar to that of exchangeable K. Soil OC or soil organic matter (SOM) plays a dominant role in the cation exchange capacity (CEC) of this soil, which is dominated by kaolinite. Jones and Wild (1975) indicated that over 80% of CEC of savanna soils is contributed by SOM. When combined with other measures of soil fertility, CEC is a good indicator of soil quality and productivity. A comparison of change in CEC values and exchangeable bases of various treatments is shown in Table 7. There were significant effects of rotation on CEC and exchangeable bases (Ca, Mg, and K) and rotation x fertilizer interaction. Generally, MS2 treatment gave the highest effective CEC (sum of cations) and the lowest was observed on MM treatments.

Low pH in unfertilized continuous maize may be responsible for the low CEC value. A non-N benefit of soybean rotation was evident from the CEC values obtained. The CEC value obtained from unfertilized MS2 plot was similar to the value obtained in fertilized MM. This confirms that the increased maize yield normally reported in soybean-maize rotation system is not solely influenced by N supply but due to other rotation effects. These effects also include reduced disease incidence and addition of growth promoting substances in addition to improvement in soil physical and chemical properties. Fertilized maize plots in all the rotations resulted in a significant increase in CEC and exchangeable bases compared to the unfertilized plots.

Table 9. Rotation† and fertilizer effects on maize grain yield on a Typic Haplustalf.

	Rotation				
	MS1	MS2	MF	MM	Mean
Fertilizer (kg N ha^{-1})	------------------ Grain yield, kg ha^{-1} ---------------				
0	2275	2446	1934	1251	1977
90	6883	7533	6343	5575	6584
Mean	4579	4990	4139	3413	
LSD (0.01)					
Rotation (R)	2342				
Fertilizer (F)	899				
R x F	1799				

† MS1 = TGx 1448-2E-Maize; MS2 = Samsoy-2-Maize; MF = Fallow-Maize; MM = Continuous maize.
*Sun-dried basis.

Maize grain yield. Rotation and fertilization significantly affected maize grain yield (Table 9). Average grain yield for different fertilizer rates was 1977 kg ha^{-1} for 0 kg N ha^{-1} and 6834 kg ha^{-1} for 90 kg N ha^{-1}. Rotation effects on mean grain yield were in the order of MS2 > MS1 > MF > MM with values of 4990, 4579, 4139, and 3413 kg ha^{-1}, respectively. The higher grain yield in the MF rotation compared with MM may be due to residue mulch, which prevents rapid decomposition of humified organic matter due to high temperature in the savanna agro-ecological zone. The favourable effects of MS1 and MS2 compared with MM are partly attributed to residual N benefits and improvement in other soil properties.

Clear evidence that N supply was a major factor influencing grain yield following soybean is shown when yield between MS1 and MM are compared. First, unfertilized maize after TGx 1448-2E (MS1) yielded 1024 kg ha^{-1}more than maize after maize (MM). With the application of 90 kg N ha^{-1} to the second year maize crop, the residual benefit was 1308 kg ha^{-1}. Secondly, the response of continuous maize to 90 kg N ha^{-1} showed that N was a major constraint. A yield increase of 4324 kg ha^{-1} (77.5%) was recorded from application of 90 kg N ha^{-1} to continuous maize. Thirdly, maize grain yield (Table 9) and total soil N (Table 5) were significantly higher following soybean cultivars than following maize. In addition to the field-N benefits, the non-N effects were equally important. The results of the analysis of variance showed no interaction between the rotational and fertilizer effect indicating that both effects are at play at the same time. Other rotational benefits of cereal-legume include elimination of phytotoxic substances and reduced disease incidence (Reeves and Wood 1994). Weber *et al.* (1995) observed reduced incidence and severity of nematode damage on maize plants following soybean (TGx 923-2E) compared with a previous cereal crop. Soybean-maize rotation produces crop residue with low C:N ratio. This residue enhances microbial activity, which may increase soil aggregation among other soil physical properties (Lal *et al.* 1994).

In addition to the favourable soil chemical properties observed in the soybean rotation systems, the significant difference observed in the maize yield following the two soybean cultivars is partially due to the soybean cultivars absorbing less soil N than the other systems. Soybean residues decompose rapidly leading to rapid mineralization of organic N, which contributes to the inorganic soil N pool almost immediately following crop harvest. This effect, otherwise known as 'nitrate sparing' is responsible for the increased yield of maize following legumes than cereal (Peoples *et al.* 1995). The slight difference in grain yield between the two soybean cultivars could be due to the ability of Samsoy-2 to fix more N on the same experimental site (Akande 2004 unpublished). Being an adapted improved variety in the ecological zone, Samsoy-2 was able to fix more N perhaps due to its compatibility with the indigenous rhizobia strains present in the soil. Even though a promiscuous variety, N_2–fixation may as well be improved in TGx 1448-2E by inoculating with correct strain of rhizobium. However, its effectiveness and persistence have to be monitored in the soil.

Conclusions

This study estimated the residual effects of two soybean cultivars, natural fallow and maize on selected soil chemical properties and subsequent maize grain yield. Residual benefits varied among crop rotations. Soybean-maize systems had positive effect on selected soil chemical properties. However, these properties were relatively more pronounced in MS2 than MS1. The differences in soil total N between the two soybean cultivars cannot be responsible for the greater yield increase in maize grown after Samsoy-2. Hence, the increased yields were also due to improvement in other soil properties. On the contrary, continuous maize system resulted in lower OC, total N, exchangeable cations, and higher pH compared with MS1, MS2, and MF. Large residue mulch on the soil surface improved soil chemical properties of the fallow-maize plot. Shifting cultivation involving natural fallow may be an effective system where population density is low and other social and economic conditions prevent the introduction of more productive and skilled systems of cultivation. The somewhat lower pH of soybean-maize rotation compared to other systems may be attributed to rotation-induced changes in the pH of the bulk or the rhizosphere soil commonly observed in legume-cereal mixtures. Contrary to expectations, fertilization had no adverse effects on soil chemical properties. Leaving larger quantities of below-ground residue in the soil enhanced OC, concentrations of exchangeable cations, and CEC in the top 0-15 cm layer and also contributed to higher grain yield. Application of 90 kg N ha^{-1} to maize grown after soybean may not be economical to all cultivars. Therefore, future studies should focus on wider range of fertilizer rates and roles of cultivar characteristics. In this study, TGx 1448-2E may be recommended for low-income farmers because when grown in rotation with maize, the subsequent maize may not require a high amount of fertilizer N to produce reasonable yield.

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Contributions of nitrogen from grain and herbaceous legumes to a succeeding maize crop in the moist savanna of Nigeria

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Abstract

As a result of increased N availability in the soil, the inorganic N fertilizer need of maize (*Zea mays* L.) is reduced when rotated with legumes. The objective of this study was to estimate the N fertilizer replacement value (NFRV) of two grain legumes, soybean (*Glycine max* Mer.) and cowpea [*Vigna unguiculata* (L) Walp], one herbaceous legume (*Centrosema pascuorum*), and fallow when their residues are incorporated into the soil for the succeeding maize crop. The legumes and fallow fields were established in 2001 followed by a test crop of maize in 2002 with application of 0, 20, 40 and 60 kg N ha^{-1}. The soil inorganic N significantly ($P<0.05$) increased by 100 and 150% with soybean and *Centrosema* residue incorporation, respectively. Incorporation of cowpea residue increased soil N by only 11% while fallow residue incorporation did not change the level. Residue incorporation of soybean, cowpea and fallow increased the soil total N by 30, 11 and 6% respectively while that of *Centrosema* did not alter the level. Grain yield of maize planted after incorporation of legume residues was significantly ($P<0.05$) higher than that after fallow. Maize succeeding soybean had low response while maize succeeding *Centrosema* and fallow had high response to inorganic N fertilizer application. Available soil P status was higher after *Centrosema* and fallow. Soybean had the greatest NFRV of 61 kg N ha^{-1} followed by *Centrosema*, 31 kg N ha^{-1} and cowpea, 13 kg N ha^{-1}. The effects of the legumes on the grain yield and N needs of the succeeding maize were due to the improved soil N status after the legumes. To enhance maize production, legume-maize rotation and incorporation of legume residue into the soil prior to planting maize in the cropping system of the northern Guinea savanna agroecological zone are highly recommended.

Résumé

Les besoins du maïs en engrais inorganiques azotés N sont réduits lorsqu'il est cultivé en rotation avec les légumineuses, suite à l'augmentation de la disponibilité d'N dans le sol. Notre objectif était d'utiliser la méthode de la valeur de remplacement de l'engrais azoté (VREN), afin d'estimer la contribution en N de deux légumineuses grains (soja et niébé) et une légumineuse herbacée (*Centrosema pascuorum*) à la culture successive de maïs, lorsque les résidus de légumineuses sont incorporés. Les légumineuses et les jachères ont été établies en 2001, suivies par une culture test de maïs en 2002 avec quatre taux d'N (0, 20, 40 et 60 kg d'N ha^{-1}). L'incorporation de soja et de résidus de *Centrosema*, a significativement ($P<0.05$) augmenté l'N inorganique du sol par 100 et 150% respectivement. L'incorporation de résidus de niébé l'a fait augmenter de 11% tandis que l'incorporation de résidus de jachère n'a pas fait changer le niveau d'N inorganique du sol. L'incorporation de résidus de soja, de niébé et de la jachère a fait augmenter la quantité totale d'N du sol par 30, 11 et 6% respectivement contrairement à *Centrosema* qui n'en a pas modifié le niveau. Le rendement grain du maïs cultivé après les légumineuses était significativement ($P<0.05$) plus élevé qu'après la jachère. Le maïs consécutif au soja avait une réponse faible tandis que le maïs consécutif au *Centrosema* et la jachère a eu une bonne réponse à la fertilisation d'N inorganique. Le rendement grain le plus élevé qui était de 8501 kg ha^{-1} a été obtenu par le maïs cultivé après le soja avec 20 kg N ha^{-1}. Le statut du phosphore disponibilité dans le sol était plus important après *Centrosema* et la jachère que les autres traitements. Le soja avait la valeur la plus élevée de VREN de 61 kg N ha^{-1}, suivi par *Centrosema* avec 31 kg Nha^{-1} et le niébé, 13 kg N ha^{-1}. Les effets des légumineuses sur le rendement grain et sur les besoins en N du maïs consécutif étaient dûs à l'amélioration du statut de l'N du sol après les légumineuses. La rotation maïs-légumineuse et l'enfouissement des residues de légumineuses dans le sol avant les semis est fortement recommandée dans les systèmes de production des zones agroecologiques de la savane nord guinéenne afin d'améliorer la productivité du maïs.

Introduction

For centuries, scientists and farmers have recognized the beneficial effects of legumes in crop rotations. The N fixed by the legume apart from being utilized by the legume also contributes to the succeeding non-fixing crops upon mineralization of their residues left on the field (Muyinda *et al.* 1988).

Relative to continuous maize, the yield of maize has been found to be higher when rotated with herbaceous legumes (Tarawali 1991;

Oikeh *et al.* 1998) and grain legumes (Carsky *et al.* 1997; Carsky *et al.* 2001) and the inorganic N need of the maize is reduced or in some cases eliminated (Ashari and Hanson 1984; Nafziger *et al.* 1984; Singh *et al.* 2001). The availability of N is usually identified as responsible for the greatest proportion of the beneficial effects of legumes/cereal rotation though other factors including reduced weed, disease and insect problems can also be important (Varvel and Wilhelm 2003).

One of the commonly used methods to determine the N contribution from the legumes included in crop rotation is the N fertilizer replacement value (NFRV). The NFRV of a legume is defined as the amount of fertilizer N required by a non-legume in the absence of legumes, to obtain grain yields equivalent to those obtained when the non-legume followed legume in rotation (Hesterman 1988). Management of the legume residue affects the amount of the NFRV of a legume. Higher values are obtained when the residues are incorporated into the soil than when the residues are exported from the field. Singh *et al.* (2001) estimated the NFRV of soybean to be 20 kg ha^{-1} with residues incorporated and only 8 kg ha^{-1} when the residues were exported from the field. Cowpea appeared to have a higher NFRV (60 kg ha^{-1}) than soybean when incorporated to the soil but the values were about the same for the two crop species (10 kg ha^{-1} for cowpea) when exported from the field (Dakora *et al.* 1987; Carsky *et al.* 1999). It has been suggested that the higher values obtained with residues incorporation could be attributed to faster release and availability of N from residues because of direct contact with the soil enzymes, which facilitate decomposition (Costa *et al.* 1989).

In the moist savanna of Nigeria, the soils are characteristically low in plant available N and the high N requirements of maize makes the external application of N in the form of fertilizer inevitable. Unfortunately, the government has removed fertilizer subsidy thus resulting in high cost and a reduced amount of N fertilizer that the local farmers can afford to purchase and apply to the maize crop. Also, the farmers in the savanna use crop residues for fodder, firewood and as building materials (Weber *et al.* 1995) thereby rendering incorporation of crop residues into the soil less attractive to them. It is, therefore, critical that an accurate estimate be made of the N contribution of the preceding legume to the succeeding maize when the residue is incorporated. The objective of this study was to estimate the NFRV of grain and herbaceous legumes when their residues were incorporated to the succeeding maize crop.

Table 1. Monthly distribution and total amount of rainfall at the experimental site, 2001 and 2002.

Month	Amount of rainfall (mm)	
	2001	2002
January	0.0	0.0
February	0.0	0.0
March	0.0	19.9
April	83.9	60.9
May	160.3	10.6
June	177.7	133.1
July	388.4	229.0
August	330.7	201.4
September	256.3	193.9
October	0.0	125.2
November	0.0	0.0
December	0.0	0.0
Total	1397.3	974.0

Table 2. Soil physical and chemical properties before establishment of legumes and fallow in 2001.

Properties	Amount in soil
Sand (g kg^{-1})	470
Silt (g kg^{-1})	430
Clay (g kg^{-1})	100
Texture	Silty loam
pH(H_2O)	5.2
Organic carbon (g kg^{-1})	5.37
Total N (g kg^{-1})	0.45
Available P (g kg^{-1})	11
Exchangeable Ca (cmol kg^{-1})	2.32
Exchangeable Mg (cmol kg^{-1})	0.40
Exchangeable K (cmol kg^{-1})	0.20

Materials and Methods

Study site characteristics

The study was conducted in 2001 and 2002 at the Research Farm of the Institute for Agricultural Research, Samaru, Zaria (11°11′N; 7°38′E; 680m asl) in the northern Guinea savanna (NGS). The mean annual rainfall is about 1061mm with a mono-modal pattern mostly concentrated between May and September. The amount of rainfall received in each year of cropping is presented in Table 1. The soil of the site is an Alfisol (USDA) with silty loam surface texture. Selected physical and chemical properties of the surface soil (0-15cm) before commencement of study in 2001 are shown in Table 2. The analysis showed that the soil had adequate available P (Bray P1) for legume cropping. The site had been left fallow for more than three years and was vegetated mostly with *Cyperus* spp. and a few plants of *Crotolaria retusa*.

Experimental design and treatments

At the commencement of study in 2001, there were four treatments: two grain legumes (soybean and cowpea), one herbaceous legume (*Centrosema pascuorum*; hereafter referred to as centro) and a natural fallow. The field was divided into four plots separated from one another by a strip of 5 m and the treatments were assigned randomly to each plot.

In 2002, the experimental design was a split-plot arrangement fitted to a randomized complete block with four replicates. The main plot treatments were the three legumes and the fallow plots while the subplots were the inorganic N fertilizer rates of 0, 20, 40 and 60 kg N ha^{-1} randomized within each main plot to give a total of 64 experimental plots. The size of the gross plot was 4 m by 6 m (24 m^2).

Crop establishment and management

Prior to the establishment of the experiment in 2001, the field was ploughed and harrowed twice. A ridger set at 75 cm apart was used to ridge the entire field. Cowpea (IT89KD-288), which is a dual-purpose variety, was planted on 16 July at 3 seeds per hill spaced at 25 cm on the ridges. The seedlings were thinned to one plant per hill at 2 weeks after planting (WAP). Soybean (TGX 1448-2E), which is a medium-maturing variety was planted on 18 July, while centro (I.9857) was planted on 22 July, both by drilling on each ridge in the plot at approximately 50 kg seed ha^{-1}. Soybean seeds were not inoculated with rhizobia. Weeds were controlled in the legume blocks with pre-plant application of glyphosate [N-(phosphonomethyl)glycine], 14 days before planting. Subsequently hoe-weeding was regularly carried out during the season. The fallow block was never weeded. Cowpea plants were sprayed with cypermethrine plus dimethoate formulation three times from flowering to minimize insect infestation. Cowpea was harvested by picking the pods on 14 November while soybean was harvested by cutting the plants at the ground level on 16 November. After harvest, dried litter and haulms of the grain legumes without the seed, and the residues of the centro and fallow plots were incorporated into the soil of the appropriate subplots.

In 2002, all plots had maize as the test crop. The plots were cleared of all residues and P at the rate of 60 kg P_2O_5ha^{-1} as triplesuperphosphate (TSP) was broadcast uniformly in each plot and incorporated during ridging, which was done manually with hoes. Maize variety, Oba super 2 was planted manually on 6 July at 3 seeds per hill spaced 25 cm within rows that were 75 cm apart, giving a plant population of about 53,333 plants ha^{-1}. The seedlings were thinned to one plant per hill 2 WAP. Inorganic N fertilizer (urea) was split-applied to plots that were to receive fertilizer treatment. At 2 WAP, one-third of the fertilizer was applied about 5 cm deep, made along the ridge, 5–10 cm away from the plants. The remaining two-thirds of the fertilizer was applied after weeding 5–6 WAP. In both cases, fertilizer application was by by single band placement followed by incorporation into the soil. Weeds were controlled using the West African hoe when necessary. All plots were remoulded manually with the hoe at 8 WAP to control weeds.

Sampling and analysis

Surface soil (0-15 cm) samples were collected with an auger before commencement of the study, after harvest in 2001 and before land preparation in 2002. Air-dried 2 mm-sieved soil was used for analysis. Particle size distribution was determined by the Bouyoucos hydrometer method (Klute 1986). Soil reaction was determined potentiometrically in 1:2.5 soil to water ratio with the glass electrode pH meter. The Walkley and Black wet oxidation method was used to determine the organic carbon (C) content (Nelson and Sommers 1982). Exchangeable bases were determined by extraction with neutral 1N NH_4OAc. Potassium (K) in the extract was determined with flame photometer while calcium (Ca) and magnesium (Mg) were determined using the atomic absorption spectrophotometer (Kundsen *et al.* 1982). Available P was extracted by Bray P1 method. The P concentration in the extract was determined colorimetrically using the spectromic 70 spectrophotometer. Total and inorganic N were determined by the micro-Kjeldahl digestion procedure (Bremner 1982; Bremner and Mulvaney 1982).

Maize grain yield analysis was determined by harvesting maize ears in the three central rows leaving out border plants at both ends (net plot of 8.7 m^2). These were shelled, air-dried and weighed. The grain yield was adjusted to 12 % moisture content for each plot.

The NFRV of the legumes was estimated by the method described by Carsky *et al.* (2001). The response of maize to urea N in the fallow plot was fitted to a linear model. The intercept is the grain yield after fallow with no N fertilizer and the slope is the response of maize to fertilizer N.

$$\text{NFRV} = \frac{\text{Yield after legume with no N fertilizer} - \text{Intercept}}{\text{Slope}}$$

The General Linear Model Procedure of SAS (SAS Inst. 1999) was used for statistical analysis of the data, including analysis of variance (ANOVA) and means separation by Student-Neuman Keuls test. Paired t-tests were also used to compare means of the chemical properties before and after treatments.

Results and Discussion

Total and inorganic nitrogen

The incorporation of soybean and cowpea residues increased the total soil N by 30 and 11%, respectively (Table 3). Residue of each legume significantly increased the inorganic N. The low C/N ratio of the legume residues (Swift 1987), the rapid rate of residue decomposition in this location (Wild 1972), and the direct contact of the residue with the soil by incorporation will ensure a fast rate of decomposition of the residue resulting in increased soil N within a short period of time, as observed in this study.

Thonnissen (1996) reported that N in soybean residue was quickly released into the soil and almost totally mineralized for the following crop within a short period of time. Some other researchers have also reported improved soil N status after legumes in the Guinea savanna zone (Carsky *et al.* 1997; Oikeh *et al.* 1998). Similarly, Tian *et al.* (1993) reported increased soil inorganic N with incorporation of residue with low C/N ratio. It has also been found that soybean increases mineralization of soil N and prevents N immobilization (Gentry *et al.* 2001).

In the present study, the incorporation of fallow residue slightly increased the soil total N by 6% to 0.53 gkg^{-1} but did not change the level of the soil inorganic N. The inorganic N did not change probably because of N immobilization in the soil, as previously reported by Carsky *et al*. (1998).

Grain yield

The effect of the previous legumes and fallow on maize grain yield was statistically significant ($P<0.01$). Grain yields of maize succeeding the legumes were significantly ($P<0.05$) different from grain yield of maize succeeding fallow (Fig. 1); perhaps a consequence of improvement in soil N status especially inorganic N supplied by the legumes (Table 3). The soil inorganic N status was reflected in the grain yield. For example, soybean rotation, which produced the highest inorganic N, had the highest grain yield followed in order by centro, cowpea, and fallow rotations. Gentry *et al*. (2001) reported a significant positive relationship between grain yield and soil inorganic N.

Inorganic N fertilization had a significant ($P<0.01$) effect on grain yield. The highest grain yield of 5167 kg ha^{-1} was obtained with 60 kg N ha^{-1} (Fig. 2). This confirms that N is a major nutrient that limits maize production in the experimental site. Carsky and Iwuafor (1999) made a similar observation in the NGS zone.

Maize after soybean and cowpea had a low response to inorganic N fertilizer. Maize following soybean and cowpea with application of 20

Table 3. Effects of legumes and fallow residue incorporation on soil total and inorganic N at the Research Farm of IAR, Zaria, Nigeria, 2001–2002.

Residues incorporated	Total N (g kg^{-1})		Increase %	Inorganic N (g kg^{-1})		Increase %
	Before incorporation	After incorporation		Before incorporation	After incorporation	
Soybean	0.54	0.70(0.00)	30	0.04	0.11*(0.00)	175
Cowpea	0.53	0.59(0.06)	11	0.045	0.05*(0.00)	11
Centro	0.53	0.53(0.00)	0	0.04	0.10*(0.06)	150
Fallow	0.50	0.53(0.00)	6	0.04	0.04(0.00)	0

Significant difference (t-test) at $P<0.05$ between before and after residue incorporation. Standard errors of means are in parenthesis.

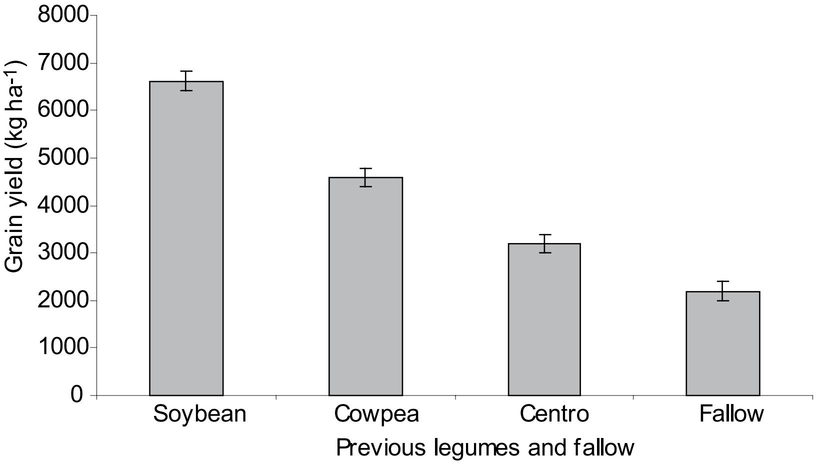

Figure 1: Grain yields of maize following the legumes and fallow.

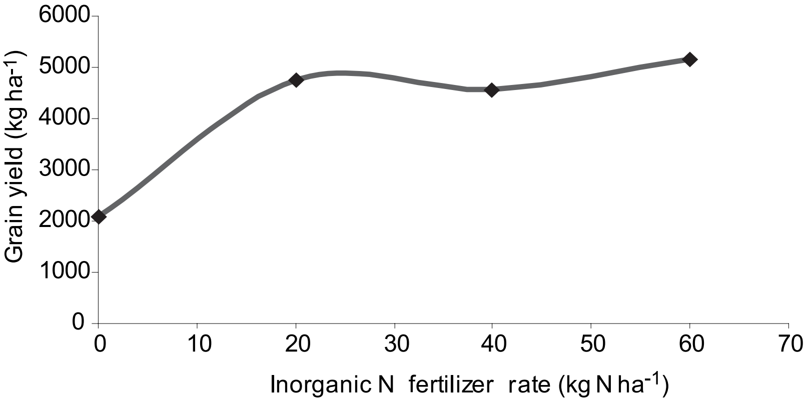

Figure 2: Response of maize grain yield to inorganic N fertilizer.

kg N ha^{-1} had significantly ($P<0.05$) higher grain yield than maize with application of 60 kg N ha^{-1} (Fig. 3). Gallo *et al.* (1983) suggested that N contribution of soybean following maize is often responsible for the low or lack of response of maize following soybean to inorganic N fertilization.

The reduced response of maize to high levels of inorganic N fertilizer indicates that N nutrition was less of a constraint, following soybean and cowpea. Similar observations have been made by Carsky *et al.* (1997) for a similar medium maturing variety of soybean in the zone. The response to inorganic N fertilizer by maize succeeding both centro and fallow was high. The highest maize grain yield was obtained in the treatments that had maize following both centro and fallow with 60 kg inorganic N ha^{-1} and lowest grain yield with 0 kg N ha^{-1} (Fig. 3). These results provided additional evidence that N was a major limiting factor to maize grain yield at this location. Centro may have fixed less N while fallow may have caused N immobilization thereby limiting N availability. The response is also an indication that

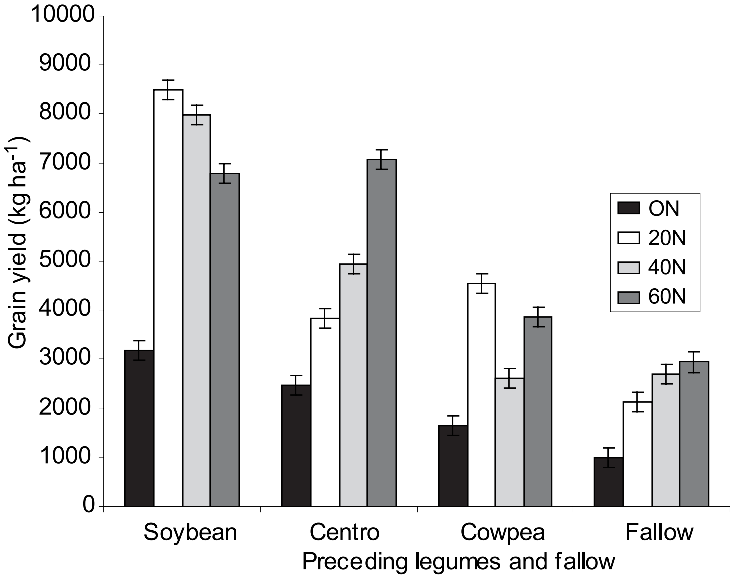

Figure 3: Grain yield of maize as affected by preceding legumes and fallow and inorganic N fertilizer application.

the preceding legumes were unable to supply the N requirement of maize for optimum yield.

Nitrogen fertilizer replacement value

The graph and linear equation showing the response of maize succeeding fallow (control) to urea N are shown (Fig. 4). The estimated NFRV of the soybean, cowpea, and centro were 61, 13 and 39 kg N ha^{-1}, respectively. The relatively high value obtained for soybean compared to both centro and cowpea may be attributed to relatively high soil N status after soybean and or other non-N benefits of soybean rotation such as reduced nematodes in the soil (Weber *et al.* 1995).

The NFRV of soybean and centro were both higher than that of cowpea probably due to higher soil N status with the incorporation of soybean and centro residue compared to incorporation of cowpea residue (Table 3).

The NFRV of soybean obtained in the present study was higher than the 20 kg N ha^{-1} obtained by Singh *et al.* (2001) with residue incorporation in the same ecological zone. This is perhaps due to lower acidity and higher available P status of the soil at the site of the study compared to the site used by Singh *et al.* (2001). At low pH, available P precipitates as insoluble compounds of P, thereby becoming unavailable (Brady 1999). The NFRV for cowpea obtained in this study was similar to those reported by Carsky *et al.* (1999) but lower than 40–80 kg N ha^{-1} obtained in several earlier studies conducted in this ecological zone (Dakora *et al.* 1987; Kaleem 1993; Horst and Hardter 1994; Carsky *et al.* 2001). Carsky *et al.* (2001)

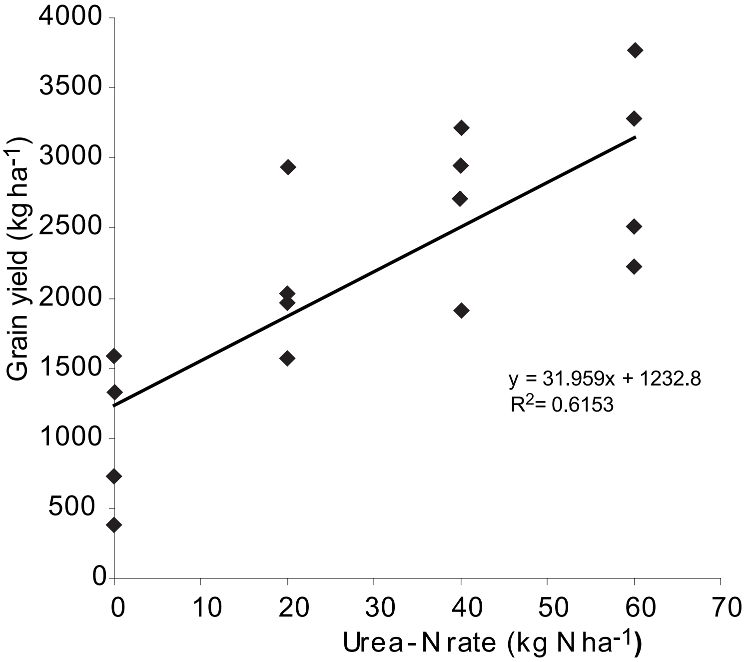

Figure 4: Maize grain yield after fallow as a function of urea - N rate.

have suggested that the relatively high value they obtained may be due to the planting of the maize immediately after cowpea harvest within the same rainy season, which made the N from the cowpea to be efficiently utilized by the subsequent maize crop. The relatively lower value obtained in this study compared to that of Dakora *et al.* (1987) and Horst and Hardter (1994) may be attributed to the use of fallow instead of a crop as control. The use of fallow probably gave a lower estimate of NFRV because of nutrient accumulation in the fallow plots. Dakora *et al.* (1987) and Horst and Hardter (1994) both used maize as the control while Kaleem (1993) used yam as the control. The growth of two crops of legume in one season, as done by Horst and Hardter (1994), may also give higher estimates of NFRV.

The estimated NFRV of centro after one year of cultivation was similar to values obtained by Tarawali (1991) after 2- to 4-year fodder banks and values quoted by Carsky and Iwuafor (1999) after two years of cultivation for some other herbaceous legumes. The similarity of NFRV, despite differences in years that the experiments were conducted, suggests that farmers should be encouraged to incorporate the aboveground residues into the soil rather than allow them to be blown away by the wind or eaten by livestock during the long dry season (Carsky and Iwuafor 1999). Incorporation of the residue with seeds will ensure that higher N is returned to the soil for the use of the subsequent crop.

Conclusion

From the results of this study, it may be concluded that greater yield benefits are realized when maize is rotated with legumes compared to fallow. The yield benefit is a result of improved soil N availability by the legumes. The inorganic N fertilizer need of the maize succeeding legumes is reduced, especially when the residue of the legume is incorporated into the soil. The inorganic N fertilizer need of the maize was reduced by as much as 61, 31 and 31 kg N ha^{-1} when maize succeeded soybean, cowpea and centro, respectively.

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Effects of sole cropping, intercropping and rotation with legume trap-crops on *Striga* control and maize grain yield in farmers' fields in the northern Guinea savanna

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Abstract

On-farm trials were conducted in 2001 to 2003 in the northern Guinea savanna of Nigeria to evaluate integrated *Striga hermonthica* control methods under farmer-managed conditions. These included intercropping a *Striga*-resistant maize variety with cowpea (*Vigna unguiculata* L.) and also cropping this maize in rotation with legume trap-crops – soybean [*Glycine max* (L) Merr.] and cowpea. Intercropping *Striga*-tolerant maize variety, Acr. 97 TZL Comp. 1-W, with cowpea or rotating it with the soybean cultivar TGX1448-2E) or the cowpea cultivar IT93K452-1 proved effective in reducing *Striga* incidence and infestation compared with three years of continuously cropped maize as control. *Striga* incidence was reduced by 73% in intercropped maize, 64% in maize after two years soybean, and by 68% in maize after two years of cowpea than in continuously cropped maize. However, maize grain yield was considerably reduced when intercropped with cowpea, probably due to competition from the cowpea crop. Maize grain yield was 28% higher after one year of soybean and 21% higher after one year of cowpea than in the continuously cropped maize. Maize grain yield was 85% higher after two years of soybean, and 66% higher after two years of cowpea than in the continuously cropped maize.

Résumé

Des tests en milieu paysan ont été conduits de 2001 à 2003 dans le nord de la savane guinéenne au Nigeria, pour évaluer les méthodes de lutte intégrée de *Striga hermonthica* dans les conditions de gestion de l'agriculteur. Ces conditions incluaient une variété de maïs résistante à *Striga*, var. 97TZL Comp.1-W, cultivée en association avec le niébé [*Vigne unguiculata* L. (cultivar IT93K452-1)] et la rotation de culture de maïs avec le soja qui est une légumineuse - culture piège [*Glycine max* (L) Merr. (cultivar TGX1448-2E)] ou le niébé. L'association de la variété de maïs tolérant à *Striga* avec le niébé ou la rotation avec les cultivars de soja ou de niébé a été efficace dans la réduction de l'incidence et l'infestation de *Striga*, comparé à trois années de culture de maïs en continue, utilisée comme témoins. L'incidence du *Striga* est reduit de 73% dans le maïs cultivé en association, 64% dans le maïs après 2 années de culture de soja et de 68% dans le maïs après 2 ans de culture de niébé comparativement à la culture continue de maïs. Cependant, le rendement grain de maïs était considérablement réduit quand il était associé au niébé. Ceci est probablement du à la compétition due au niébé. Le rendement grain du maïs était 28% plus élevé après une année de soja et 21% plus élevé après une année de niébé comparativement à la culture continue de maïs.

Le rendement grain du maïs cultivé était de 85% plus élevé après deux années de soja et 66% plus élevé après deux années de niébé comparativement à la culture continue de maïs.

Introduction

Striga hermonthica (Del.) Benth is an important parasitic weed of cereals in the semi-arid tropics. In decreasing order of susceptibility, maize (*Zea mays* L.), sorghum [*Sorghum bicolor* (L.) Moench] and millet (*Eleusine coracana* L.) are the most important hosts. The parasite also infects upland rice (*Oryza sativa* L.). It has been estimated that about 40 to 70 million ha of cereal crops are severely or moderately infested in West African countries (Lagoke *et al.* 1991). Severe *Striga* infestation can cause 70-80% yield loss in maize and sorghum and losses can be much higher under heavy infestations, sometimes resulting in total crop failure (Emechebe *et al.* 2004). Farmers often have to abandon infested agricultural lands as a result of high soil infestation by noxious weeds (Kroschel 1999). The present trend of moving away from traditional practice of soil fertility restoration, which included prolonged fallow and intercropping, towards continuous cereal monocropping to meet the food needs of an increasing population has intensified the *Striga* problem. In addition to many factors already known, grazing cattle, crop seeds, and wind contribute to the spread of *Striga* infestation to new areas (Berner *et al.* 1996). The problem is compounded by the high reproductive capacity of *Striga* plants. A single *Striga* plant can produce over 50,000 seeds, which can remain viable in the soil for 15-20 years (Musselman 1987; Doggett 1988).

Striga research in Africa has a long history and a range of effective component control technologies has been identified (Parker and Riches 1993). Control options for *S. hermonthica* range from use of leguminous trap-crops to the use of resistant host-crop cultivars. Leguminous trap-crops stimulate suicidal germination of *Striga* seeds and, therefore, reduce the seed bank and improve soil fertility. Schulz *et al.* (2003) found that tolerant maize following a soybean trap-crop yielded 1580 kg ha^{-1} of grain and out-yielded farmers' maize variety by more than 80%. Carsky *et al*. (2000) also reported that *S. hermonthica* incidence in maize after soybean, compared to maize after sorghum, was significantly reduced from 3.2 to 1.3 emerged plants per maize plant, resulting in greatly improved grain yields.

In addition to host-plant resistance and legume trap-crops, a substantial amount of research has been conducted on the effect of soil fertility on *Striga* infestation. Infestation is frequently associated with low soil fertility (Carsky *et al.* 2000; Schulz *et al.* 2003). Improved soil fertility conditions are likely to lead to reduced *Striga* infestation (Debra *et al.* 1998). The use of grain legumes can contribute to soil N (Carsky and Iwuafor 1999). Sanginga *et al.* (2001) found that grain yield of maize grown after soybean increased by an average of 25% across two locations. They attributed this to enhanced N availability following soybean and other rotation effects, such as the reduction of soil-borne disease organisms. Intercropping, particularly of cereals with cowpea [*Vigna unguiculata* (L.) Walp], is a common practice in many parts of the semi-arid zone of West and Central Africa (WCA). This is because food production is diversified, the risk of crop failure is reduced, and resources for crop growth are utilized more efficiently than with sole cropping (Carsky *et al.* 1994).

Intercropping of cereals with legumes has also been proposed as a means of suppressing *Striga* in the cereal crop (Vernon 1995; Kureh *et al*. 2000). Most *Striga*-infested areas have high seed banks of the parasite in the soil. The adoption of control measures that aim at reducing the level of the seed bank, which is a potent source of *Striga* inoculum, has to be encouraged. The potentials and beneficial effects of intercropping and 1-year legume-cereal rotation for *Striga* management have been demonstrated under both researcher- and farmer-managed conditions. *Striga* control is better when intercropping and rotation periods are longer. However, farmers seldom grow the same crop on a piece of land for more than 1 year. Thus, rotation of trap-crops for a long period before growing the host-crop has a greater chance of reaping the benefits of long period of rotation.

The present study was designed in 2001 by the agronomic group of the West and Central Africa Collaborative Maize Research Network (WECAMAN) for implementation by member countries. The objectives were to demonstrate and promote the adoption of the use of *Striga*-tolerant maize in rotation with legumes for a longer period. The controls were maize intercropped with cowpea and continuous sole cropping of *Striga*-tolerant maize. The expected benefits of long-term rotation include among others reduction of the *Striga* seed bank, incidence and infestation, improvement of soil fertility and improved maize yield.

It is necessary to validate that these technologies work efficiently under farmer-managed conditions and are indeed appropriate for African farmers (Fisher 1999). The study reported in this paper was designed to evaluate the effects of one and two-year rotations with legume trap-crops.

Materials and Methods

The trials were established on 12 *Striga*-infested farmers' fields selected in two neighboring villages in Kaduna State, northern Nigeria, from 2001 to 2003. The fields are located in the northern Guinea savanna zone, which is characterized by a sub-humid climate with monomodal rainfall of 900-1200 mm. Rainfall distribution extends over an annual growing period of 5-6 months. Total rainfall was 1322 mm in 2001, 1007 mm in 2002 and 1135 mm in 2003.

The following treatments were evaluated:

i. cowpea-maize intercrop for three years,
ii. one year of soybean followed by maize for two years,
iii. one year of cowpea followed by maize for two years,
iv. two years of soybean followed by one year of maize,
v. two years of cowpea followed by one year of maize, and
vi. continuous farmers' practice of sole cropping of maize for three years.

An improved *Striga*-tolerant open-pollinated maize variety (Acr. 97 TZL Comp1-W), an *Alectra*-tolerant, high N-fixing soybean variety (TGX1448-2E) and an early maturing cowpea variety (IT 93K 452-1) were used in the study. The two legume varieties have been found to cause suicidal germination of *Striga* in screen house experiments (Berner *et al.* 1996).

The trials were successfully established on eight farmers' fields at Ungwa Shamaki and four at Tashan Kaya. Each farm with the six plots constituted a replicate. The gross plot size was 400 m^2 and the net size was 340 m^2. In 2001, each crop was planted on ridges as a sole crop except for the maize-cowpea intercrop. Maize was sown at 3 plants $hill^{-1}$ at a spacing of 75 x 50 cm. Two weeks after sowing (WAS), the maize was thinned to two plants per stand. Soybean was drilled at a spacing of 5 cm on ridges 75 cm, apart. In the sole cowpea, two seeds were planted on ridges at a spacing of 75 x 25 cm without thinning but in the intercrop one stand of cowpea was planted between two maize stands. The field operations performed in 2001 were all repeated in 2002 and 2003. All crops were hoe weeded at 3 and 6 WAS followed by a careful hand-pulling of weeds other than *Striga*. Fertilizer was applied to maize at the recommended rate of 100 kg N ha^{-1}, 40 kg P_2O_5 ha^{-1} and 50 kg K_2O ha^{-1} using NPK (15:15:15) and urea. The nitrogen fertilizer was

Table 1. **Effects of sole and intercropping on plant population, *Striga* infestation and incidence, crop damage severity and grain yield of maize in two villages in northern Nigeria (2001).**

Cropping systems	Maize plants ha^{-1} at 12 WAS	*Striga* number ha^{-1} at 12 WAS	Number of maize plants infested ha^{-1} at 12 WAS	Crop damage severity*	Grain yield (kg ha^{-1})
Sole maize	21,013a**	1158a	414a	2.33a	810.42a
Maize-cowpea intercrop	17,371b	433b	295b	2.58b	613.54a

WAS = weeks after sowing.
* = Crop damage severity using a scale of 1 - 9, where 1 = healthy plants and 9 = completely dead plants.
**Means followed by the same letter(s) within a column are not significantly different at the 0.05 level of probability (DMRT).

split-applied at 3 and 6 WAS. Fertilizer was applied to the soybean and cowpea at the rate of 20 kg N ha^{-1}, 40 kg P_2O_5 ha^{-1}, and 20 kg K_2O ha^{-1} at 2 WAS using NPK (15:15:15) and single superphosphate. The cowpea crop was sprayed with cyper-plus at the rate of 1 l ha^{-1} at flower bud initiation while benlate was applied at 0.4 kg ha^{-1} during podding to control diseases and insect pests. At the end of each year, the cowpea residue was fed to livestock while the maize stalks were used either for fencing or fuel. However, withered soybean leaves were allowed to rot and were plowed back to the soil to improve soil fertility.

Data collected included maize stand count, *Striga* shoot count (infestation), number of maize plants infested (incidence), host damage severity on a scale of 1–9 (where 1=healthy plants and 9 = completely dead plants), and grain yield of maize. The data were subjected to analysis of variance and treatment means were separated using Duncan Multiple Range Test (DMRT). Data on yields of soybean and cowpea are not reported in this paper.

Results

Sole and intercropping effects on Striga *and maize in the first year (2001)*

In 2001, the sole-cropped and intercropped maize exhibited similar low levels of crop damage severity. The sole maize had better plant establishment than the intercropped maize although these were planted at the same density. *Striga* infestation and incidence were lower when maize was intercropped with cowpea than when planted sole. However, maize grain yield was 32% higher when planted sole than when intercropped with cowpea (Table 1).

Table 2. **Effects of previous crops on plant population, *Striga* infestation and incidence, crop damage severity, and grain yield of maize in two villages in northern Nigeria (2002).**

Cropping systems	Maize Plant ha^{-1} at 12 WAS	*Striga* number ha^{-1} at 12 WAS	Number of maize plants infested ha^{-1} at 12 WAS	Crop damage severity*	Grain yield (kg ha^{-1})
Sole maize	21,433c**	1191a	343a	4.08a	1147.6b
Maize after soybean	22,954ab	772b	272b	3.50b	1468.4a
Maize after cowpea	23988a	1025ab	431ab	3.67b	1384.0a
Maize-cowpea intercrop	22513bc	375b	202b	4.17a	782.5c

WAS = weeks after sowing.

* = Crop damage severity using a scale of 1 - 9, where 1 = healthy plants and 9 = completely dead plants.

**Means followed by the same letter(s) within a column are not significantly different at 0.05 level of probability (DMRT).

Effects of one-year of rotation and intercropping on Striga *and maize in 2002*

In 2002, plant population at harvest was generally lower than optimal for all treatments. This is because farmers rushed and planted their crops with the first rains, which stopped abruptly, resulting in drought conditions in the early part of the season. The drought caused poor crop establishment and a lot of missing stands. The overall effect was relatively low plant population densities. Maize grown after soybean and cowpea had similar and higher plant populations than the intercropped and continuously cropped maize. The number of emerged *Striga* plants was significantly higher in continuously cropped maize than in maize after soybean, maize after cowpea and intercropped maize (Table 2).

Striga incidence was lowered by 218% in intercropped maize, 54% in maize after soybean and 16% in maize after cowpea than in the farmers' practice of continuous sole cropping of maize for two years. Crop damage severity was similar and higher in continuously cropped and intercropped maize than in maize after soybean and maize after cowpea. Maize after soybean and maize after cowpea had higher grain yield than the intercropped and continuously sole cropped maize. Maize grain yield was 28% higher after soybean and 21% higher after cowpea than after the farmers' practice of continuous sole cropping of maize for two years. Continuously cropped maize produced 47% higher grain yield than the intercropped maize (Table 2).

Table 3. **Effects of previous crops on plant population, *Striga* infestation and incidence, crop damage severity, and grain yield of maize in two villages in northern Nigeria, 2003.**

Cropping systems	Maize plants ha^{-1} at 12 WAS	*Striga* no. ha^{-1} at 12 WAS	No of maize plants infested ha^{-1} at 12 WAS	Crop damage severity*	Grain yield (kg ha^{-1})
Sole maize	23,022b**	489a	273a	4.5a	1167c
Soybean followed by 2 yr of maize	23,296a	291ab	173ab	3.8ab	1569bc
Cowpea followed by 2 yr of maize	23,216a	293ab	178ab	4.1a	1398c
Two yr of soybean followed by maize	23,263a	111b	98b	3.3b	2185a
Two yr of cowpea followed by maize	23,076b	121b	86b	3.7ab	1939ab
Maize-cowpea intercrop	22,611c	94b	73b	4.1a	1400c

WAS = weeks after sowing.
* = Crop damage severity using a scale of 1 - 9, where 1 = healthy plants and 9 = completely dead plants.
**Means followed by the same letter(s) within a column are not significantly different at 0.05 level of probability (DMRT).

Effects of two-year rotations and intercropping on Striga *and maize in 2003*

As in 2001 and 2002, the plant population at harvest was lower than the recommended for all treatments in 2003 (Table 3). However, there was improvement in plant population from 2001 to 2003. Maize grown after two years of soybean and one year of soybean or cowpea followed by two years of maize produced significantly higher plant populations than intercropped maize, continuously cropped maize or maize grown after two years of cowpea. Maize grown after two years of cowpea and continuously cropped maize had higher plant populations than intercropped maize. The number of emerged *Striga* was significantly higher in continuously cropped maize than in maize grown after two years of soybean or cowpea and intercropped maize. *Striga* incidence was reduced by 73% in intercropped maize, 64% in maize after two years of soybean, and 68% in maize after two years of cowpea than in the farmers' practice of continuous sole cropping of maize for three years. The *Striga* incidence was reduced by 64% in maize after two years of soybean and by 80% after two years of cowpea than in maize after one year of soybean and cowpea, respectively. Crop damage severity was higher in continuously cropped and intercropped maize and one year rotation with cowpea than in maize grown after two years of soybean. Maize grain yield was 85% higher after two years of rotation with soybean, 66% higher after two years of cowpea, than in the farmers' practice of continuous sole cropping of maize for three years. Intercropped maize recorded 19.9% higher grain yield than the continuously sole cropped maize.

Discussion

Results of this study have demonstrated the potential of appropriate soybean and cowpea cultivars to reduce *Striga* parasitism in maize. It also demonstrated the potential of maize-cowpea intercrops to control *Striga*. The two legume cultivars used were able to reduce *Striga* parasitism in the rotation systems.

Intercropping maize with cowpea reduced the density of emerged Striga plants. This reduction may be attributed to shading effects from the cowpea canopy. Carson (1989) reported a positive relationship between soil temperatures and the density of emerged *Striga* plants under groundnut (*Arachis hypogaea* L.) intercropped with sorghum. He found that the temperature at a soil depth of 10 cm at 6–7 weeks after sorghum emergence was about 2°C lower in sorghum rows and that *Striga* density at the time of harvesting sorghum was reduced by 60-70% in the treatment with sorghum and groundnut in the same row. Carsky *et al*. (1994) reported that the number of mature capsule-bearing *Striga* plants was low when the cowpea groundcover was high in a sorghum-cowpea intercrop. This suggests that any spatial arrangement that increases cowpea groundcover at the base of maize or sorghum can reduce the density of mature *Striga*. Carsky *et al.* (1994), therefore, concluded that in the long term, this might reduce the *Striga* seed bank, provided no importation of *Striga* seed to the field was allowed. They also found no significant reduction in sorghum yield by intercropping sorghum with cowpea. In the present study, intercropping cowpea with maize reduced maize yield by 47% despite the reduction in the number of emerged *Striga* plants. This could be due to competition from the cowpea. This corroborates the findings of Kureh *et al.* (2000) and Kuchinda *et al.* (2003). Maize and sorghum appear to have different responses to competition effects from other crops in intercropping systems. Maize has a shorter maturity period than sorghum. Hence, sorghum may recover from the effects of intercropping long after the cowpea has been harvested.

Several studies have shown a significant reduction in *Striga* parasitism in cropping systems that include intercropping and rotations (Carsky *et al.* 1994; 2000; Schulz *et al.* 2003; Kuchinda *et al.* 2003). Several other mechanisms can be suggested to explain the reduction of *Striga* damage when maize is intercropped or rotated with legume trap-crops. In addition to shading out *Striga* in intercropping systems, the cowpea or soybean has been shown to stimulate the germination of *Striga* without acting as hosts (Carsky *et al.* 1994;

Berner *et al.* 1996; Carsky *et al.* 2000; Kureh *et al.* 2000; Kuchinda *et al.* 2003). The nitrogen fixed by the legumes may also suppress *Striga* germination. This, however, is not likely because the legumes do not release much nitrogen into the soil during their growth (van der Heide *et al.* 1985; Carsky *et al.* 1994; Sanginga *et al.* 2002). Usually large amounts of nitrogen are required to reduce *Striga* density (Munera and Below 1993). However, improved growth and vigor due to N fertilization may help the maize crop to reduce *Striga* parasitism. There were no significant differences in *Striga* emergence and maize grain yield between the cowpea and soybean treatments in the rotation systems, suggesting that the varieties of both crops were efficacious in the reduction of *Striga* parasitism on the maize crop. Thus, these two varieties could be recommended to farmers for rotation with maize.

Although there were some reductions in *Striga* infestation and yield loss due to *Striga,* one- year rotation in heavily infested fields was not sufficient to reduce the effects of *Striga*. This is corroborated by the minimal differences between the levels of *Striga* damage severity among all the treatments following one-year rotation.

Although the benefits of legume rotation in *Striga* control may be related to N supply, the additional N supply coupled with other rotational effects may have increased the yield of subsequent maize. Carsky *et al.* (1997) found that N supply was the major influence that soybean had on subsequent maize. This was demonstrated by a reduction in maize yield response to inorganic N following soybean. The increased N supply in previous cowpea and soybean treatments and yield of subsequent maize was probably due to additional N fixed and left in the soil for the subsequent maize crop. Sanginga *et al.* (2002) found that a nodulating soybean fixed about 103 kg N ha^{-1} of its total N with an estimated net N balance input from fixation following grain harvest of 43 kg N ha^{-1}. They also reported that maize growing after this soybean had 1-2 fold increases in yield compared to the sole cropped maize control.

Conclusion

Crop rotation with grain legumes reduced *Striga* infestation and incidence in maize. However, the reduction was more pronounced in maize after two years of legumes than after one year. Intercropping maize with cowpea also reduced *Striga* infestation considerably, although maize yield was significantly reduced in the cowpea intercrops probably due to competition effects from cowpea. Legume-cereal rotations resulted in higher maize grain yield. The use of *Striga* tolerant cultivars, intercropping and legume-cereal rotations (especially for two years) in an integrated approach is a good strategy for effective *Striga* management. Therefore, the component *Striga* technologies should be emphasized and promoted for adoption.

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Potential of drought-tolerant maize varieties in nitrogen-deficient soils of the Guinea savannas

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Abstract

The Guinea savannas of Nigeria have a high potential for the production of maize because of favorable environmental conditions. Despite this high potential, the yields obtained under farmers' conditions are still very low. Low soil fertility and intermittent drought are among major constraints limiting the production of maize in the Guinea savannas of West Africa. Low soil fertility is due to soil degradation and nutrient depletion arising from intensification of land use. Nitrogen (N) is the major nutrient limiting maize production in the Guinea savannas where the use of inorganic fertilizers is low. One strategy for improving productivity of maize is to select varieties that perform well under sub-optimal soil N conditions and/or tolerate intermittent drought stress. This study compared the performance under low-N conditions of maize genotypes selected for tolerance to drought with that of maize genotypes selected for tolerance to N-deficient conditions. Growth and grain yield differed significantly between the genotypes at all N levels. These variations were more pronounced at 0 and 30 kg N ha^{-1}. The drought-tolerant genotypes and 4 maize genotypes previously selected for tolerance to N-deficient conditions performed better than the widely grown adapted genotype under 0 and 30 kg N ha^{-1}. The drought-tolerant genotypes generally performed better than the genotypes selected for tolerance to low N-conditions. At 0 kg N ha^{-1}, grain yield of maize decreased with advances in cycles of selection for tolerance to sub-optimal N conditions suggesting that N deficiency in the selection environment was not sufficient to discriminate among genotypes. Grain yield under N-deficient conditions was correlated with increased number of ears per plant, stay-green rating, leaf chlorophyll concentration, leaf area index, reduced anthesis-silking interval and reduced days to silking suggesting that these traits are linked to tolerance to N deficiency. The good performance of drought-tolerant varieties under sub-optimal N conditions suggests that selection for drought tolerance may confer tolerance to N-deficient conditions.

Résumé

Les savanes guinéennes du Nigéria ont un potentiel élevé de production de maïs à cause des conditions écologiques favorables. Malgré ce potentiel élevé, les rendements obtenus dans les conditions paysannes sont encore très faibles. La faible fertilité des sols et la sécheresse intermittente sont parmi les contraintes majeures qui limitent la production de maïs dans les savanes guinéennes d'Afrique de l'Ouest. La faible fertilité des sols est dûe à la dégradation des sols et à l'épuisement en éléments nutritifs suite à l'intensification de l'exploitation des terres. L'azote (N) est le nutriment majeur limitant la production de maïs dans les savanes guinéennes, où l'utilisation d'engrais inorganiques est faible. Une des stratégies pour améliorer la productivité du maïs est de sélectionner des variétés tolérantes au stress intermittent de la sécheresse et/ou qui ont de bonnes performances dans des conditions sub-optimales d'N. Cette étude a comparé la performance dans des conditions faibles d'N, les génotypes de maïs sélectionnés pour la tolérance à la sécheresse à ceux sélectionnés pour la tolérance à des conditions de déficience en N. Le rendement grain et la croissance différaient considérablement entre les génotypes à tous les niveaux d'N. Ces variations étaient plus prononcées à 0 et 30 kg N ha^{-1}. Les génotypes de maïs tolérants à la sécheresse et 4 génotypes de maïs précédemment sélectionnés pour la tolérance à des conditions de déficience en N, ont eu de meilleures performances par rapport au génotype largement cultivé et adapté, sous 0 et 30 kg N ha^{-1}. Les génotypes de maïs tolérants à la sécheresse ont en générale eu de meilleures performances que les génotypes sélectionnés pour la tolérance à des conditions de déficience en N. A 0 kg N ha^{-1}, le rendement grain du maïs diminuait avec les cycles avancés de sélection pour la tolérance à des conditions sub-optimales d'N, suggérant que la déficience en N dans l'environnement de sélection n'était pas suffisante pour discriminer entre les génotypes. Le rendement grain sous les conditions de déficience en N était corrélé au nombre élevé d'épis par plant, l'évaluation de la capacité à demeurer vert, la concentration de chlorophylle dans les feuilles, l'index de superficie de la feuille, la réduction de l'intervalle floraison mâle – floraison femelle et la réduction du nombre de jours à la floraison, suggérant que ces traits sont liés à la tolérance à la déficience en N. La bonne performance des variétés tolérantes à la sécheresse, sous des conditions sub-optimales d'N, suggère que cette sélection pour la tolérance à la sécheresse peut conférer la tolérance aux conditions de déficience en N.

Introduction

The moist savannas of West Africa have great potential for maize (*Zea mays* L.) production. Higher radiation levels, lower night temperatures, and reduced incidence of diseases and insect pests increase yield potential in comparison to the traditional area (forest zone) for maize cultivation (Kassam *et al.* 1975). In the past two decades, maize has been spreading rapidly to the savannas, replacing traditional cereal crops such as sorghum [*Sorghum bicolor* (L) Moench] and pearl millet (*Eleusine coracana* L.), particularly in areas with good access to fertilizer inputs and markets. Maize yields in farmers' fields in the West African savanna average about 1-2 t ha^{-1} in contrast to the higher yields reported in breeding stations in the region (Fakorede *et al*. 2003).

Land-use intensification in the northern Guinea savanna has resulted in serious land degradation and nutrient depletion (Oikeh *et al.* 2003). Nitrogen (N) is the most deficient nutrient in the soils and it most often limits maize yield in the Guinea savanna (Carsky and Iwuafor 1995). Unfortunately, due to high cost and poor infrastructure, the availability of N fertilizers to the farmers is limited. The problem of poor soil fertility in the Guinea savanna is compounded by recurrent drought at various stages of crop growth. For maize, drought at the flowering and grain-filling stages can cause serious yield losses (Grant *et al.* 1989). This indicates that farmers' fields are rarely characterized by only one biotic stress. It would, therefore, be desirable to increase the tolerance of crops to several stresses that occur in the target environment (Bañziger *et al.* 1999).

One strategy for improving the productivity of maize is to select varieties that perform well under sub-optimal N conditions. Enhancing higher utilization of available N either by incorporating high N-uptake capacity into the varieties, or developing varieties characterized by more efficient use of absorbed N in grain production may be an approach to achieve this strategy (Lafitte and Edmeades 1994). However, selection of maize varieties for tolerance to low-N conditions is sometimes difficult in the West African savanna ecology. Because of soil variability, attaining uniform levels of N in the soil for screening of maize varieties has often proved to be a daunting task. Therefore, results presented in most cases for maize performance under low-N conditions could at best be described as screening for the maize varieties responding to N. This clearly reduces selection efficiency and progress of breeding for low-N tolerance.

In addition to low-N tolerance, efforts are also being made in the West African savannas to select varieties that are tolerant to drought. However, studies to identify or develop maize genotypes tolerant to drought or low soil-N in the Guinea savannas are being done independently. Breeders often use the same secondary traits to select maize varieties that are tolerant to drought or low-N conditions. Because of this, it may be possible to select varieties that are tolerant to both stresses. Bañziger *et al.* (1997) found that drought-tolerant genotypes performed well under N-deficient conditions. If these results were confirmed in

Table 1. Physio-chemical characteristics of the soils of the experimental site at the beginning of each cropping season.

Properties	2002[a]	2003[b] High- N block	2003[b] Low- N block
pH (1:1 H_2O)	6.20	5.20	4.90
Organic C (g kg^{-1})	4.39	3.70	3.40
Total N (g kg^{-1})	0.52	0.31	0.27
P (Bray 1) (mg kg^{-1})	31.40	27.20	17.60
Effective CEC (mol_c kg^{-1})	4.00	2.70	2.00
Exchangeable K (cmol kg^{-1})	0.16	0.20	0.10
Exchangeable acidity (cmol kg^{-1})	0.40	0.10	0.20
Cu (mg kg^{-1})	0.40	0.50	0.40
Zn (mg kg^{-1})	0.52	0.80	0.90
Mn (mg kg^{-1})	9.40	12.20	10.30
Fe (mg kg^{-1})	22.00	16.10	15.30

[a] At the beginning of 2002, all blocks were uniformly depleted. Therefore, composite samples were taken to determine fertility levels.

[b] In 2003, high-N block refers to blocks supplied with 90 kg N ha^{-1} while low-N block refers to blocks supplied with no N fertilizer or 30 kg N ha^{-1}. All samples were collected before fertilizer application in each year.

the West African savanna, it would make selection for low-N tolerance more efficient because the selection environment for drought-tolerance is more uniform and easier to control than that for low-N tolerance. The objective of the study reported here was to determine the effect of low soil-N conditions on the performance of diverse maize genotypes developed for tolerance to either N deficiency or drought stress.

Materials and Methods

Site and experimental design

The study was conducted in 2002 and 2003 at the experimental farm of the Institute of Agricultural Research, Zaria, Nigeria (7 °38′ E, 11 °11′ N, 686 m asl). The soil is a fine-loamy, isohyperthermic Plinthustalf; USDA taxonomy. The experimental field was divided into three blocks (high-N block: 90 kg N ha^{-1}, low-N blocks (N-deficient): 30 kg N ha^{-1} and 0 kg N ha^{-1}) without randomization of N treatments. All experiments at low N levels (0 and 30 kg N ha^{-1}) were conducted in fields that had been depleted of N for two cropping seasons by planting maize at high densities without N fertilizer and by cutting and removing the biomass after each crop season. The physio-chemical characteristics of the soil of the experimental site at the beginning of each cropping season are summarized in Table 1.

In each block (for each N level), the experiments were laid out in a randomized complete block design with three replications. Plots consisted of four rows, 5 m long with spacing of 0.75 m between rows and 0.25 m between plants to give a plant population of 53,333 plants ha^{-1}. Fields were planted on June 27 in 2002 and July 5 in 2003. At planting, P in the form of single superphosphate and K as muriate of potash were applied at the rate of 40 kg ha^{-1} each. N in the form of calcium ammonium nitrate was applied in two equal splits. One half was applied one week after planting (WAP) and the other half at 5 WAP. Weeds were controlled manually at 2 and 5 WAP and by using paraquat (1:1-dimethly-4,4′-bipyridinium dichloride) at 7 WAP.

Genotypes

Three drought-tolerant (Menkir *et al.* 2001; Kamara *et al.* 2003), five low-N tolerant (J. Kling, personal communication), two hybrids and four adapted or *Striga* tolerant, late maturing open-pollinated varieties (OPV) developed at IITA, were evaluated in this study (Table 2). One of the OPVs (ACROSS 8328 C7 BN) was developed at the International Center for Maize and Wheat Improvement (CIMMYT) using recurrent selection procedures. One of the hybrids (Oba Super 2) has been found to be N-efficient (Sanginga *et al.* 2003) while one of the OPVs (TZB-SR), though widely grown in the Guinea savanna of West Africa, is N-inefficient.

Data collection

Data were collected from the two central rows leaving the outside rows and the plants at the beginning and end of each row to serve as borders. Days to 50% pollen shed (anthesis date) and 50% silk extrusion (silking date) were recorded and the anthesis-silking interval (ASI) was calculated as the difference in days between 50% silking and 50% anthesis. Plant and ear heights were determined approximately two weeks after anthesis.

Stay-green scores were recorded in the N-deficient plots on a scale of 1 to 9; where 1 = almost all leaves below the ear were green and 9 = virtually all leaves below the ear were dead. Grain yield was recorded for 26 plants harvested from the two central rows of each plot (4.7 m^2), excluding the end plants of each row. The total number of plants and ears were counted in each plot at the time of harvest. The number of ears/plant was then calculated as the total number of ears at harvest divided by the total number of plants harvested. Ears harvested from each plot were shelled and the percentage grain moisture was determined using a Dickey-John moisture tester (Model 14998, Dickey-John Corporation, Auburn, USA). Grain yield adjusted to 12% moisture was computed from the shelled grain.

Data analysis

The General Linear Model procedure (GLM) of the Statistical Analysis Systems (SAS) Package (SAS Institute Inc. 1990) was used to analyze the data and significant differences among varieties were compared

Table 2. Characteristics of maize genotypes evaluated for low-N tolerance at the Research Farm of the Institute for Agricultural Research (IAR), Samaru, Zaria, Nigeria in 2002 and 2003.

No.	Genotypes	Abbreviation	Grain color	Type of genotype
1	DTSR-WC0	DTSR-WC0	White	Drought-tolerant
2	DTSR-Y	DTSR-Y	Yellow	Drought-tolerant
3	STR-EVIWD	STRIWD	White	Drought- and *Striga*-tolerant
4	Across 8328 C7 BN	ACR8328	Yellow	Low-N tolerant
5	LNPC1	LNPC1	White/Yellow	Low-N tolerant
6	LNPC2	LNPC2	White/Yellow	Low-N tolerant
7	LNPC3	LNPC3	White/Yellow	Low-N tolerant
8	LNTPF1	LNTP	Yellow	Low-N tolerant
9	Oba Super 1	OBA1	White	Hybrid
10	Oba Super 2	OBA2	Yellow	Hybrid
11	Across 91 Suwan 1	ACR91SU	Yellow	Adapted check
12	New Synthetic	NEWSTY	Yellow	*Striga*-tolerant
13	TZB-SR	TZBSR	White	Adapted check
14	Across 98 TZUT-SR-W	TZUT	White	Adapted check

using the standard error of the mean. Simple correlation coefficients were calculated to detect the relationships between all possible pairs of the traits measured.

Results

There were no significant year × genotype interactions for most traits. Where interactions occurred, for example grain yield at 30 kg N ha^{-1}, the genotypes only had slight changes in ranking for such traits over the two years with non-significant differences. The data were therefore combined for the two years. There were also no genotype × N interactions for all traits measured.

N-deficiency delayed days to anthesis and silking and increased ASI in all genotypes (Table 3). The hybrid Oba Super 1 and TZB-SR had significantly longer days to anthesis and silking than the drought-tolerant and N-efficient genotypes at 0 and 30 kg N ha^{-1}. ACR 91SU flowered earlier than all other genotypes at all N levels. At 0 kg N ha^{-1}, only the drought-tolerant genotypes, the N-efficient genotype ACR 8328 and the hybrid Oba Super 2 had ASI significantly lower than TZB-SR. At 30 kg N ha^{-1}, all the N-efficient genotypes, the drought-tolerant genotypes and the hybrid Oba Super 2 had significantly lower ASI than TZB-SR, TZUT, ACR91, and NEWSTY.

Leaf stay-green ratings ranged from 5.6 to 8.3 at 0 kg N ha^{-1} and from 3.9 to 6.3 at 30 kg N ha^{-1} (Table 4). All drought-tolerant and N-efficient genotypes recorded significantly lower stay-green ratings than TZB-SR. Mean number of ears/plant increased with increasing rates of N application (Table 4).

Table 3. Means for days to silking, tasseling and anthesis- silking interval (ASI) of fourteen maize cultivars evaluated under three N-levels.

	Fertilizer rate, kg N ha^{-1}								
	0	30	90	0	30	90	0	30	90
Variety	Days to silk			Days to anthesis			ASI, days		
DTSR-WC0	69	66	61	64	63	60	5.0	2.4	1.0
DTSR-Y	70	63	59	64	60	58	5.7	2.6	0.7
STRIWD	71	67	61	65	64	61	5.7	2.6	0.7
ACR8328	73	68	63	68	65	62	4.8	2.7	0.5
LNPC1	73	67	63	67	65	62	6.0	2.6	1.0
LNPC2	73	68	64	69	65	63	4.4	2.5	1.0
LNPC3	73	67	62	66	65	62	6.8	2.3	0.5
LNTP	74	66	62	67	64	61	6.8	1.8	0.5
OBA1	75	67	63	69	64	62	6.2	3.2	0.5
OBA2	72	67	63	67	64	62	5.3	2.5	1.0
ACR91SU	66	61	58	59	58	58	5.7	3.0	0.5
NEWSTY	73	68	61	66	65	60	6.5	3.8	1.0
TZBSR	75	68	64	69	65	63	6.4	3.3	1.3
TZUT	70	64	60	65	61	60	4.8	2.8	0.5
Mean	72	66	62	66	63	61	5.7	2.7	0.8
S.E	0.69	0.55	0.47	0.72	0.54	0.43	0.21	0.13	0.07

Table 4. Means for stay-green ratings and ears/plant of 14 maize cultivars evaluated under three N-levels.

	Fertilizer rate, kg N ha^{-1}				
	0	30	0	30	90
Cultivar	Stay-green (1-9)*		Ears/plant		
DTSR-WC0	6.2	4.2	0.7	0.8	1.1
DTSR-Y	7.2	4.4	0.5	0.8	1.1
STRIWD	6.3	4.5	0.6	0.8	1.1
ACR8328	6.5	3.9	0.6	0.8	1.2
LNPC1	6.2	5.2	0.6	0.9	1.1
LNPC2	5.6	5.6	0.6	0.9	1.2
LNPC3	6.5	5.3	0.5	0.7	1.2
LNTP	7.2	4.8	0.5	0.8	1.1
OBA1	7.8	5.4	0.5	0.9	1.2
OBA2	6.8	4.1	0.5	0.9	1.1
ACR91SU	8.3	6.3	0.7	0.9	1.1
NEWSTY	8.2	5.5	0.5	0.7	1.1
TZBSR	7.8	6.1	0.4	0.8	1.2
TZUT	8.0	5.8	0.6	0.9	1.1
Mean	7.0	5.1	0.6	0.8	1.1
S.E	0.23	0.21	0.02	0.02	0.01

Severe N stress at 0 kg N ha^{-1} reduced the number of ears/plant by 49% compared to results at 90 kg N ha^{-1}. There were significant differences among the maize genotypes for number of ears/plant at all N levels. The differences were more pronounced at 0 kg N ha^{-1}, the rate at which N-deficiency stress was most severe. At 0 kg N ha^{-1}, the drought-tolerant, N-efficient genotypes and the hybrids had a significantly higher number of ears/plant than the broadly adapted and

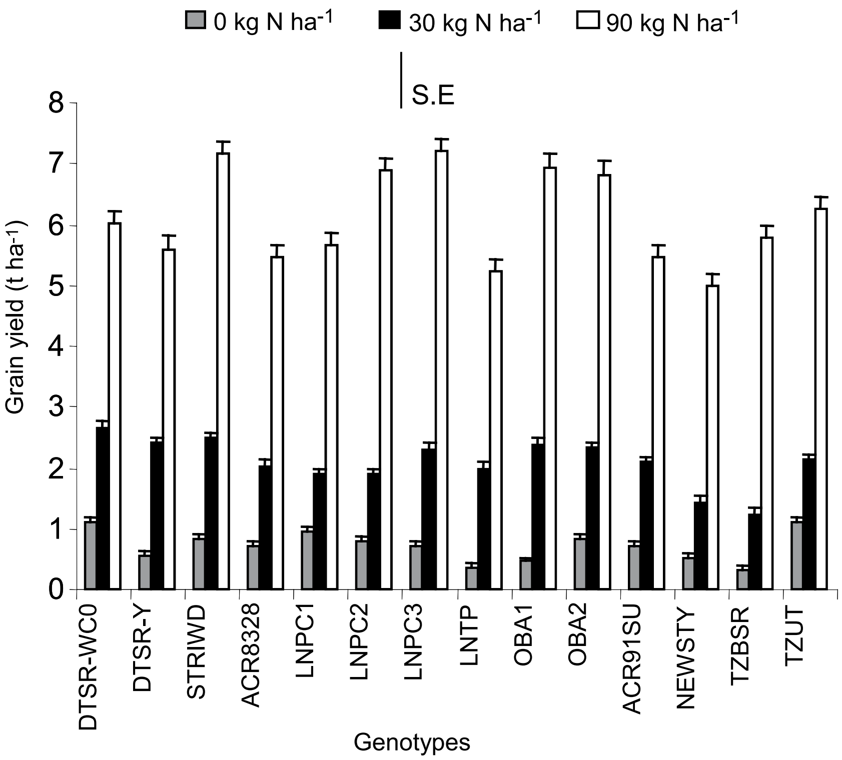

Figure 1. Yield performance of maize genotypes evaluated under three N levels.

widely grown genotype, TZB-SR. These differences were, however, not significant at 30 and 90 kg N ha^{-1}. The N-efficient, drought-tolerant genotypes and the hybrid Oba Super 2 did not differ significantly in the number of ears/plant at any of the N levels.

Significant differences in grain yield were detected among the maize genotypes at all N levels (Fig. 1). As expected, grain yield increased with N rates for all genotypes. At 0 kg N ha^{-1} the drought-tolerant and N-efficient genotypes, as well as TZUT (a genotype widely grown in the savanna) and the hybrid Oba Super 2 produced more grain than TZB-SR. The drought-tolerant genotypes were also found to be similar to or more productive than most N-efficient genotypes. The same trend was observed at 30 kg N ha^{-1}. At 0 kg N ha^{-1}, grain yield of N-efficient genotypes (LNPC1, LNPC2, LNPC3) tended to decrease with advances in the cycles of selection. Grain yield at 30 and 90 kg N ha^{-1}, however, increased with advances in cycles of selection for the LNP populations (LNPC3>LNPC2>LNPC1).

At 0 and 30 kg N ha^{-1}, grain yield had a significant positive correlation with ears/plant (r=0.73; $P<0.003$) and stay-green rating (r=0.55, $P<0.04$). Contrarily, grain yield had significant negative correlation with days to silking (r = -0.52; $P< 0.05$) and ASI (r = -0.66; $P<0.01$) at the two fertilizer rates.

Discussion

The observed effects of N on agronomic and yield traits confirmed that N stress was a major factor limiting maize productivity. The use of fields that have been previously depleted of N resulted in severe N stress as indicated by soil nutrient levels and crop responses. Increasing N fertilization was accompanied by increases in the growth and grain yield of the maize genotypes consistent with the findings of other studies in the Guinea savannas of Nigeria (Akintoye *et al.* 1998) and elsewhere (Bañziger *et al.* 1999). Genotypic differences were observed for all traits at all N levels. As was expected, genotypes selected for tolerance to N-deficient environments and the hybrid Oba Super 2 performed better than the widely adapted and widely grown check (TZB-SR) at 0 and 30 kg N ha^{-1}. The good performance of Oba Super 2 under N-deficient conditions is contrary to the widely held view in West and Central Africa that maize hybrids are inherently susceptible to low soil fertility. Due to the high yield potential, hybrids may require more N to attain maximum yields than open-pollinated varieties (Akintoye *et al.* 1998). However, the greatest advantage of hybrids over open-pollinated varieties may be realized at moderate N levels (Akintoye *et al.* 1998). Akintoye *et al.* (1999) attributed the good performance of maize hybrids under moderate N levels to high N-use efficiency. They found that, relative to open-pollinated varieties, hybrids were more efficient in N-use as well as its component traits such as N-uptake and N-utilization efficiencies.

The drought-tolerant genotypes were also found to be as good as or better than genotypes selected for tolerance to sub-optimal N conditions. These findings suggest that the selection of maize genotypes for drought tolerance may confer tolerance in these genotypes to sub-optimal N, consistent with the findings of Bañziger *et al.* (1997). Bañziger *et al.* (1999) showed that drought-tolerant maize populations perform well under N-deficient conditions. They also found that gains from selection under well-fertilized, drought-stressed conditions did not diminish as the level of N stress increased. This may be due to the fact that the physiological mechanisms for the tolerance of maize to drought may not be different from those of tolerance to N-deficient conditions. For example, maize cultivars with early proliferation of roots in the top soil would allow the plants to efficiently use the soil inorganic N while a deep, dense root system allows the plant to extract nutrients from deeper layers of soils (Jackson *et al.* 1986). Similarly, the response of maize to drought is related to the root system development, which influences water-uptake (Aina and Fapohunda 1986). Although the root systems of the maize genotypes were not evaluated in the present study, Kamara *et al.* (2002) found a positive correlation between the vertical root-pulling resistance (a measure of the root systems) and N-uptake in maize. Similarly, Oikeh *et al.* (1999) found the widely cultivated maize cultivar TZB-SR to have a poor root system in the surface soil layer and was therefore more prone to drought than a semi-prolific cultivar, which had a dense root system in the surface soil layer. It may therefore be concluded that those genotypes that performed well under N-deficient conditions may have good root systems, which enabled them to take up N from deeper layers of the soil. They may also possess traits that enabled them to utilize absorbed N more efficiently. Kamara *et al.* (2003) found a set of breeding lines to vary in their capacity to take up N and utilize it efficiently. The genotypes used in this study appear to vary in their capacity to take up N and utilize it efficiently.

Kamara *et al.* (2003) and Bañziger *et al.* (1999) have investigated the physiological basis for tolerance of maize genotypes to drought and concluded that shorter ASI, stay-green trait, reduced barrenness, and increased biomass under severe drought are associated with high grain yield. Similarly, Lafitte and Edmeades (1994) found these traits to be positively correlated with maize grain yield under sub-optimal N conditions. In addition, Bañziger *et al.* (2002) found that selection for tolerance to drought stress led to changes in the establishment of reproductive structures that also contribute to increased tolerance to N-deficiency and high plant density. Specifically, they found selection for tolerance to drought stress to consistently reduce ASI and to increase ear numbers of four tropical maize populations when evaluated across N levels ranging from well-fertilized to severely N-stressed. In the present study, although the root systems of the maize genotypes were not measured, significant phenotypic correlations were observed between grain yield and many of the secondary traits measured under 0 and 30 kg N ha^{-1}. Leaf stay-green ratings measured under sub-optimal N levels (0 and 30 kg N ha^{-1}) were positively associated with grain yield. These traits are therefore linked with tolerance to N-deficiency stress.

ASI and days to silking were negatively correlated with grain yield, a finding consistent with results from Lafitte and Edmeades (1994). A characteristic of maize under environmental stress such as N deficiency, drought and high plant density is an increase in the ASI (Bolaños and Edmeades 1993). Edmeades *et al.* (1993) postulated that a reduced ASI is a symptom of increased partitioning of assimilates to ears around flowering time enabling stress tolerant genotypes to reach silking earlier and have greater ear biomass at anthesis.

The reduction in grain yield and other growth parameters with cycles of selection of N-efficient maize genotypes under severe N stress and the increases in these traits with cycles of selection at moderate and high N levels indicate that breeding efforts succeeded in increasing the yield potential of the genotypes with each cycle of selection, while performance under severe N stress declined. This may be due to problems of attaining uniformly low levels of fertility in the soils in the selection sites. It appears that selection was done on sites that still had high levels of residual N in the soil. To make progress in selection for tolerance to sub-optimal N, Bañziger *et al.* (1997) suggested that, in maize, direct selection under severe N stress may be more efficient than indirect selection. Ceccarrelli *et al.* (1992) compared predicted responses of grain yield to indirect and direct selection to assess the value of high yielding or well-watered environments for improving grain yields in low yielding or drought-stressed environments. Although heritabilities for grain yield were usually lower under stress conditions, they concluded that direct selection was often superior in targeted stress environments. For example, Byrne *et al.* (1995) found little or no gain under drought when maize was selected under irrigated conditions. Similarly, Bañziger *et al.* (1997) found that selection under high-N conditions for performance under N-deficient conditions was predicted to be significantly less efficient than selection under N-deficient conditions. They therefore suggested that maize breeding programs targeting N-deficient environments should include selection environments that are poor in N. This means that for rapid progress to be made from selection for N tolerance in the Guinea savanna, there may be a need to refine the selection environments. This is often difficult to achieve because of the variability of some soils in the savannas.

Conclusions

This study reveals significant variations in the response of maize genotypes to sub-optimal N. Drought-tolerant and N-efficient genotypes performed better than the widely grown open-pollinated variety at 0 and 30 kg N ha^{-1}. They also performed similar to or better than the widely grown maize hybrid, Oba Super 2. Grain yield under N-deficiency was associated with increased number of ears/plant, stay-green rating, reduced anthesis-silking interval and reduced days to silking suggesting that these traits are linked to low-N tolerance. At 0 kg N ha^{-1} when N deficiency was very severe, tolerance to N deficiency decreased with advances in cycles of selection for sub-optimal N tolerance (LNPC1>LNPC2>LNPC3) suggesting that selection environment was not good enough to discriminate among maize genotypes. The good performance of drought-tolerant varieties under N stress suggests that the selection for drought tolerance may confer tolerance to suboptimal N. These findings are very important to breeders in the savannas of West Africa where soil micro-variability often renders selection for low fertility tolerance inefficient. However, there is a need to screen a wide range of drought-tolerant maize germplasm under low-N conditions in the savanna to confirm these results.

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Genotypic variation of soybean for phosphorus use efficiency and their contribution of N and P to subsequent maize crops in three ecological zones of West Africa

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Abstract

Soybean is a relatively new crop to most African smallholder farming communities. Cultivation is expanding rapidly because of its perceived potential to enhance soil fertility through biological nitrogen fixation and its source as food and cash. High N_2 fixation in promiscuous soybean genotypes is, however, likely to be constrained in low P soils where fertilizer is rarely applied. Thirteen soybean genotypes were evaluated in three ecological zones of Nigeria for (1) N_2 fixation, tolerance to low soil P (0P), and response to P fertilizer application (90 kg P ha^{-1} as Rock Phosphate (RP) or 30 kg P ha^{-1} as Triple Superphosphate (TSP)), and (2) the potential contribution of N and P to a subsequent maize crop. Results showed that soybean grain yields were generally low without P fertilization. Increases in grain yield in response to P application were genotype- and location-dependent and ranged from 3 to 308% within TSP treatments and from –16 to 152% within RP treatments. P exported in the grain of soybean genotypes also increased in response to P application at all the locations and ranged from 16 to 327%, depending on genotype and location. Total N exported in the grain of soybean was greater than N derived from the atmosphere (Ndfa) in most genotypes, resulting in negative N balances in almost all soybean plots with or without P application. Biomass, total P, and N content of grain of maize following soybean were also influenced by soil P and N contents at the three locations. There were few instances of significant positive N and P contributions from the previous P application and soybean cultivation. Also, the cultivation of P-efficient and high N-fixing genotypes did not consistently result in a significantly positive N and P contribution to the subsequent maize crop.

Résumé

Le soja qui est relativement une nouvelle spéculation pour la plupart des communautés des petits exploitants d'Afrique, se développe rapidement à cause de son potentiel connu d'augmentation de la fertilité des sols par la fixation biologique d'azote, dans l'alimentation et comme culture de rente. La fixation élevée en N_2 des génotypes de soja promiscues, est cependant, probablement restreinte dans les sols pauvres en P où l'engrais est rarement appliqué. Treize génotypes de soja ont été évalués dans trois zones écologiques du Nigéria pour (1) la fixation de N_2, la tolérance aux sols pauvres en P (0P), et la réponse à l'application d'engrais riche en P (90 kg P ha^{-1} comme Phosphate naturel (PR) ou 30 kg P ha^{-1} comme Triple Superphosphate (TSP), et (2) pour leur contribution potentielle de N et P à une culture subséquente de maïs. Les rendements grains de soja étaient généralement faibles sans fertilisation de P. Les génotypes de soja variaient dans leurs réponses en fonction de la fertilisation en P. Les accroissements de rendements grains en réponse à la fertilisation de P étaient dépendants des génotypes et de la localité et variaient de 3 à 308% dans les traitements TPS et de -16 à 152% dans les traitements PR. Le P exporté dans le grain des génotypes de soja a aussi augmenté en réponse à l'application de TSP dans toutes les localités et variait de 16 à 327% en fonction des génotypes, la source de P et la localité. L'azote N total exporté dans le grain des génotypes de soja était toujours plus élevé que l'N dérivé de l'atmosphère (Ndfa) dans la plupart des génotypes. Cela a aboutit en des bilans négatifs dans presque toutes les parcelles de soja avec ou sans application de P. La biomasse, le P total et N contenu dans le grain du maïs consécutifs aux génotypes de soja ont été aussi influencés par les la teneur du sol en P et N dans les trois localités et étaient caractérisés par quelques exemples de contributions significatives et positives de N et P, de précédentes application de P et de culture de soja. La culture de génotypes efficaces dans l'utilisation de P et dans la fixation de N n'a pas régulièrement aboutit à la contribution significative et positive de N et P à la culture subséquente de maïs.

Introduction

Soybean [*Glycine max* (L) Merril] is a relatively new crop to most African smallholder farming communities. The cultivation is expanding rapidly due to its popularity as a source of high-value protein and oil. Moreover, farmers have the perception that soybean cultivation enhances soil nutrient stocks (Manyong *et al.* 2001) to the benefit of suceeding cereal crops. This apparent enhancement of soil fertility has been attributed to the availability of extra N through biological nitrogen fixation (BNF) and other rotation effects (Sanginga *et al.*

2002). Therefore, high BNF in soybean is important for sustaining yields of cereals in rotation, as socio-economic constraints prevent most farmers from applying the requisite rates of N fertilizer to their crops. The low input approach to sustained soybean and cereal yields is, however, likely to be compromised by low soil P availability since BNF has relatively high P requirements.

Mokwunye *et al.* (1986) reported that more than 50% of soils of the African savannas have bicarbonate-extractable P contents of less than 8 ppm. In addition, losses of soil P through excessive cropping and land degradation account for the removal of soil P at a rate of at least 10 kg ha^{-1} year^{-1} (Stoorvogel and Smaling 1998).

For successful and sustainable use of promiscuous soybean as a component of integrated soil fertility management systems, and for enhanced human and livestock nutrition, the selection of soybean with enhanced capability to access and utilize P from less readily available sources and/or make efficient use of P fertilizer sources will, therefore, be a strategic option. If the improved P nutrition of such genotypes results in greater BNF, then they will benefit cereals used in association or rotation. Unlike the important contribution of N made to cereals by grain legumes, as illustrated in studies of BNF by promiscuous soybean (Sanginga *et al.* 1997; 2002, Sanginga 2003) under low input systems, information is scanty on the potential for the P-efficiency characteristics of promiscuous soybean to benefit cereals. A number of characteristics may lead to such benefits, including enhanced ability to take up P from the soil, particularly from sources that are not normally available; better response to applied P fertilizer; better use of the P taken up for dry matter production or BNF; and lower P harvest index to minimize P removal in grain. These attributes can be combined with agronomic measures to recycle and conserve N and P in cropping systems and minimize their removal in crop residues.

The objectives of the present study were to (i) evaluate 13 soybean genotypes for N_2 fixation under low and high P conditions; (ii) assess the variation in P utilization efficiency of the genotypes; and (iii) assess the contribution of N and P from the soybean genotypes to a subsequent maize crop.

Materials and Methods

Study sites

Field experiments were conducted at Fashola and Shika in Nigeria, and Davié in Togo in 2001, 2002, and 2003. One maize (*Zea mays* L.) and 13 soybean genotypes were planted with three P treatments in 2001 and again in 2002 on different but adjacent plots followed by maize in 2002 and 2003. Fashola (7° 50´N, 3° 55´E; soil type,

Table 1. Physico-chemical characteristics of topsoil (0-15 cm) from the experimental sites in Fashola, and Shika in Nigeria and Davié in Togo.

Soil characteristics	Fashola		Shika		Davié	
	2001	2002	2001	2002	2001	2002
pH (H_2O)	6.3	6.0	6.3	6.5	5.5	6.0
Mechanical (g kg^{-1})						
Sand	670	730	790	790	430	450
Silt	220	100	100	100	400	380
Clay	110	170	110	110	170	170
Exchangeable cations ($cmol_c$ kg^{-1})						
Ca	2.0	1.7	2.1	1.9	3.2	3.1
Mg	0.8	1.0	1.5	1.3	2.2	2.0
K	0.2	0.3	0.2	0.2	0.8	0.4
P fractions (mg kg^{-1})						
Labile						
Resin-P	3.2	1.5	0.7	2.5	6.9	3.8
HCO_3-Pi	3.2	0.8	2.6	3.8	4.6	1.5
HCO_3-Po	4.1	7.1	4.3	9.2	5.0	8.2
Moderately labile						
NaOH-Pi	7.3	3.6	7.2	10.5	10.4	10.0
NaOH-Po	27.7	17.5	27.1	34.3	38.8	36.6
Ca bound						
1M HCl	2.7	3.7	2.0	4.6	5.4	13.5
Stable						
Conc. HCl- Pi	27.4	6.0	26.2	8.9	23.8	17.3
Conc. HCl- Po	1.0	5.4	22.2	5.9	6.9	11.1
Residual P	15.3	10.0	31.5	48.7	31.5	32.9
Total P	91.6	55.6	123.6	128.4	133.2	134.8

Ferric Luvisol) is in the derived savanna of south western Nigeria and has a bimodal rainfall pattern with about 1200 mm annually. Shika (11° 13´N, 7° 12´E; soil type, Haplic Lixisol) is in the northern Guinea savanna (northern Kaduna State) and has a unimodal rainfall pattern with about 1100 mm annually. Davié (6° 23´N, 1° 11´E; soil type, Rhodic Ferralsol) is in the coastal savanna of Togo and has a bimodal rainfall pattern with about 1200 mm annually.

Soil characteristics

Soil chemical characteristics measured (Table 1) at the beginning of the trials included pH (1:1, soil:H_2O), (IITA 1989), and exchangeable bases (Mehlich 1984). In addition, sequential P fractionation was done using the modified Hedley's procedure, as described by Tiessen and Moir (1993), and the extracted P was determined colorometrically by the method of Murphy and Riley (1962).

Experimental layout, planting and crop management

Fields were cleared at the three locations, ploughed and ridges spaced 75 cm apart were constructed with a tractor-mounted ridger. The experiment was laid out in split plots in a randomized complete block design with four replications. The main plots were the three P treatments, 0 kg P ha^{-1} (0P), 30 kg P ha^{-1} as Triple Superphosphate (TSP), and 90 kg P ha^{-1} as Rock Phosphate (RP). The RP (36%P_20_5, 52%CaO, 0.5%H_20, 0.1%SO_4^{2-}; IFDC 1986) was sourced from the Republic of Togo. The phosphate fertilizers were broadcast on the ridges before sowing. The subplots were 13 soybean genotypes (TG×1456–2E, TGm1420, TGm1511, TGm1293, TGm1360, TGm1566, TGm0944, TGm1540, TGm1196, TGm1251, TGm1419, TGm1039, and TGm1576) and one maize genotype (Oba Super 1), all obtained from the germplasm collection of IITA, Ibadan. The plot size was 4 m × 4 m with six rows $plot^{-1}$, a 1 m alley between plots, 1.5 m between treatments, and 2 m between replications.

Soybean was sown by drilling along the ridges and thinned to obtain an interplant spacing of 5 cm. Maize was sown at four seeds $hole^{-1}$ at 25 cm spacing and thinned to one plant/hole at 2 weeks after planting (WAP). The plots were weeded manually using hoes at 3, 5, 8, and 10 WAP. Shoot biomass, and vesicular arbuscular mycorrhiza (VAM) colonization of roots, percentage N derived from N_2 fixation (%Ndfa), and total N and P uptake were measured at 50% podding stage ($R_{3.5}$) for soybean (Fehr *et al.* 1971). The colonization of roots by VAM was measured using the method of Giovanetti and Mosse (1980) after clearing and staining, following the procedure of Philips and Hayman (1970). The %Ndfa was measured by determining the concentrations of ureide-N, amino-N, and NO_3-N in xylem sap, as described by Peoples *et al.* (1989). The proportion of ureide-N, which is a reflection of %Ndfa, was obtained using the following equations:

$$Total\ N\ in\,sap = \left[Ureide - N + NO_3 - N + A\min o - N\right]$$

$$Relative\ ureide\,index(\%) = \frac{Ureide - N}{Total\ N\ in\ sap} \times 100$$

But ureide contains 4N atoms, thus ureide N is calculated as 4×ureide molar concentration. Therefore,

$$Relative\ ureide\ index(\%) = \frac{4 \times ureide - N}{4 \times ureide - N + \text{Amino} - N + NO_3 - N} \times 100$$

The corresponding values for %Ndfa were then read from tables provided by Peoples *et al.* (1989). Subsequently, the net contribution of BNF to the N balance of the soil was estimated at soybean podding stage ($R_{3.5}$) using the equation proposed by Peoples and Craswell (1992) as follows:

$$Net\ N\ balance = N_f - N_g$$

where N_f is the amount of N fixed (total N in biomass at $R_{3.5}$ × %Ndfa) and N_g represents the total N in grain at harvest.

Grain yield and total N and P exported in grain were measured at harvest maturity stages of the crops. Subsamples of harvested plant materials (shoot and grain) were oven dried at 65 °C for 7 days for dry weight determination. The dried samples were then ground and analyzed for total N and P by hot acid digestion (Novozamsky *et al.* 1983). Colorimetric analysis was done on a Technicon autoanalyzer, using the indophenol blue method (Searle 1984) for N and the ascorbic acid method (Murphy and Riley 1962) for P. Soybean genotypes were classified into P use and response efficiency groups as follows: efficient responder (high yield at both low and high P), inefficient responder (low yield at low P and high yield at high P), efficient nonresponder (high yield at low P but low yield at high P), and inefficient nonresponder (low yield at both low and high P) based on grain yield at low and high P, as described by Gerloff (1977). Low yield refers to grain yields that were significantly lower than the overall mean of low P treatments. High yield refers to grain yields that were significantly higher than the overall mean of high P treatments. Genotypes with grain yields not significantly different from the overall mean were classified as intermediate. Phosphorus accumulation in biomass, P export in grain, VAM colonization of roots, P utilization quotient (grain yield/total P in grain), and relative P response efficiency (grain yield at high P/grain yield at low P) were used to assess the use of grain yield as a suitable criterion for P efficiency and to explain the mechanisms underlying P efficiency in soybean.

Residual effects of the soybean genotypes and P applied in 2001 and 2002 on the subsequent maize crop were measured in 2002 and 2003. In 2003, the previous 0 P plots were divided into two; one half received 15 kg P ha^{-1} (15P) as a fresh addition of TSP while the other half did not. Weeds that had grown in the previous crop cycle during the fallow period were carefully cleared with a cutlass, ensuring that remaining legume residues were not dislodged from their original plots. Soil samples (0–10 cm) from the individual soybean and maize plots were taken before maize was planted and analyzed for pH, Olsen P content, and P fractions. Four seeds of maize (Oba Super I) were sown at 75 cm × 25 cm spacing within the previous soybean and maize plots; the seedlings were later thinned to one/stand at 2 WAP.

At 8 WAP, five plants were randomly harvested from the two middle rows for measurements of VAM infection and total tissue N and P. At physiological maturity, 7 m^2 (in 2002) and 4 m^2 (in 2003) portions of the two middle rows were sampled for grain yield and measurements of total N and P exported in the grain.

Statistical analysis

Data collected on soybean genotypes were combined over 2 years for each location and analyzed using the mixed model ANOVA procedure of SAS (Littel *et al.* 1996). In this model, P treatment and genotype were considered as fixed effects and replications as random effects. Data collected for maize in rotation were analyzed separately for each year, since treatments for the years were not the same. Differences in means were declared significant at $P \leq 0.05$ using the standard error of the mean (Snedecor and Cochran 1980).

Results

Plant growth characteristics

Grain yield of soybean genotypes under low P conditions ranged from 249 to 688 kg ha^{-1} at Shika, from 537 to 1004 kg ha^{-1} at Fashola, and from 205 to 624 kg ha^{-1} at Davié (Table 2). These are low, relative to average yield potentials previously reported (IITA 1981). Application of TSP improved soybean growth at all locations with the highest responses being recorded at Shika while the responses at Davié were smaller. Responses to RP application were, however, less pronounced and grain yields of many genotypes were not increased, especially at Fashola and Davié. Within the TSP treatments, increases in grain yield ranged from 80 to 308% at Shika, from 21 to 57% at Fashola, and from 3 to 63% at Davié. Responses to RP application ranged from 9 to 152% at Shika, from –16 to 22% at Fashola, and from –13 to 28% at Davié. Over the three sites, TGm1566 was among the soybean genotypes with the highest yields without added P. TGm1360, TGm1215, and TGm1540 were among the lowest yielding without P. TGm1566, TGm1196, and TGm1419 were in the highest yielding group when TSP was added. The lowest yielding lines at 0P generally had the highest relative response to TSP. This inverse relationship was particularly marked at Shika, where the average responses to applied P was nearly 200% compared to 40% at the other sites. At Shika, TGm1293, TGm1360, and TGm1540 were the lowest yielding at 0P and showed the largest relative response to TSP. Grain yield at 0P was a predictor of yield with TSP addition (R^2 = 59.0%, $P \leq 0.002$) for the yields averaged over the three sites. Figure 1a shows the relationship between response to TSP and yield at 0P and which was highly significant ($R^2 = 0.63$; $P \leq 0.001$) but with lower, non-significant regression coefficient (R^2 = 0.028; P = 0.58) were obtained

Table 2. Grain yield (kg ha^{-1}) of soybean genotypes grown at three locations under low and high soil P conditions[1].

	Location											
	Shika				Fashola				Davié			
Genotype	0P	RP	TSP	Mean	0P	RP	TSP	Mean	0P	RP	TSP	Mean
TGm1251	332	380	850	521	651	653	983	763	398	449	599	482
TGm1420	385	605	1100	696	717	682	1092	830	358	458	505	440
TGm1511	524	723	1129	792	693	675	951	773	463	528	749	580
TGm0944	683	845	1524	1017	889	748	1177	938	205	248	281	245
TGm1039	403	574	995	657	845	785	1162	931	448	470	648	522
TGm1196	464	783	1451	900	808	775	1068	884	422	429	527	459
TGm1293	249	461	1015	575	858	744	1038	880	409	419	581	469
TGm1360	313	658	1239	737	616	796	1052	821	233	266	314	271
TGm1419	522	798	1608	976	759	808	1140	903	356	431	580	455
TGm1540	262	493	977	577	537	569	701	602	624	537	645	602
TGm1566	688	752	1235	892	808	986	1269	1021	428	471	579	493
TGm1576	461	740	1333	845	833	957	1140	977	401	397	539	446
TGx1456-2E	347	875	1353	858	1004	1009	1288	1100	548	695	804	682
Mean	433	668	1216		771	784	1082		407	446	566	
[2]SEM												
P Source	20				43				20			
Genotype	42				89				45			
P x Genotype	72				154				71			

[1] Data represent means across 2001 and 2002, and [2]SEM, the standard error of the mean.

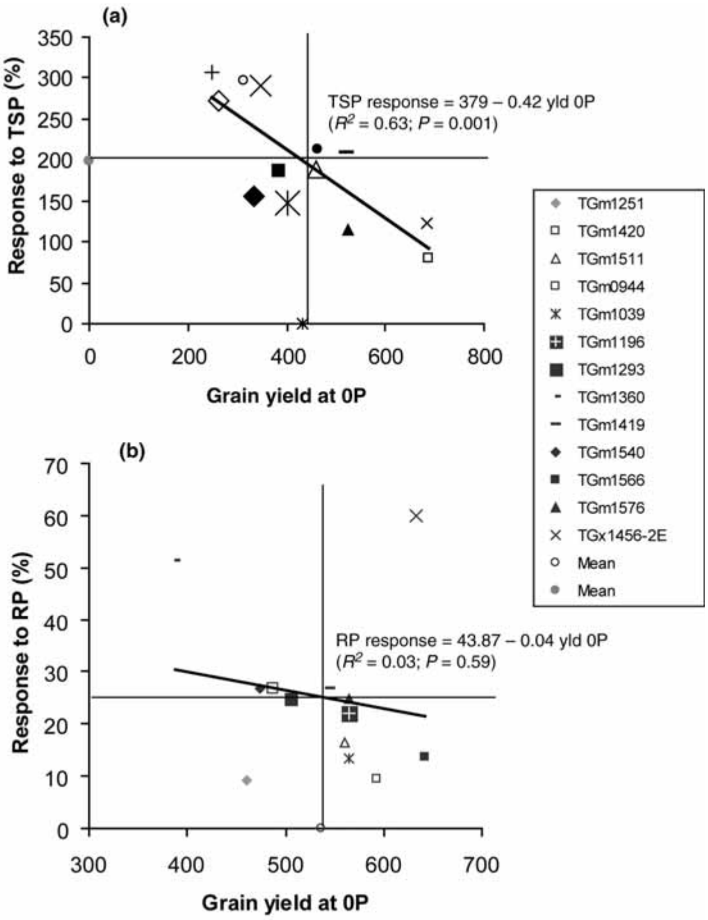

Figure 1. Relationships between relative response to high P and grain yield at low P of soybean genotypes.

with RP application as shown in Figure 1b. Grouping of soybean genotypes based on grain yield under low P conditions gave three major groups of P use efficiency: efficient, inefficient, and intermediate. Similarly, three P response groups (for both TSP and RP) —responders, nonresponders, and intermediate— were established based on grain yield response to P application (Table 3; Fig. 2). The soybean genotype TGm1566 which maintained relatively high yields under low soil P conditions also responded to the application of P fertilizer.

The correlation between grain yield and some P use and response efficiency criteria varied with soybean genotypes under low and high P conditions. Grain yield generally had a highly significant correlation with biomass yield ($P \leq 0.001$; r = 0.20), and with P utilization quotient in grain for 0P (r = –0.33) and RP treatments (r = –0.20). Also the correlation between grain yield and TSP treatment (r = –0.14), though relatively low, was significant at $P \leq 0.05$). Relative response efficiency had a highly significant correlation with grain yield for both RP and TSP treatments. Mycorrhizal infection of roots also had a highly

Table 3. Phosphorus use and response efficiency groups of cowpea and soybean genotypes grown at three locations.

	Group	Soybean genotype
Performance at 0P	Efficient	TGm1566, TGx1456-2E
	Inefficient	TGm1251, TGm1420, TGm1360
	Intermediate	TGm1419, TGm1576, TGm1511, TGm0944, TGm1039, TGm1196, TGm1293, TGM1540
Response to RP application	Responsive	TGm1566, TGx1456-2E
	Nonresponsive	TGm1251, TGm1420, TGm1293
	Intermediate	TGm1419, TGm1576, TGm1511, TGm0944, TGm1039, TGm1196, TGM1540
Response to TSP application	Responsive	TGm1566, TGm1419, TGx1456-2E
	Nonresponsive	TGm1251, TGm1540
	Intermediate	TGm1576, TGm1511, TGm0944, TGm1039, TGm1196, TGM1360, TGm1293, TGm1420

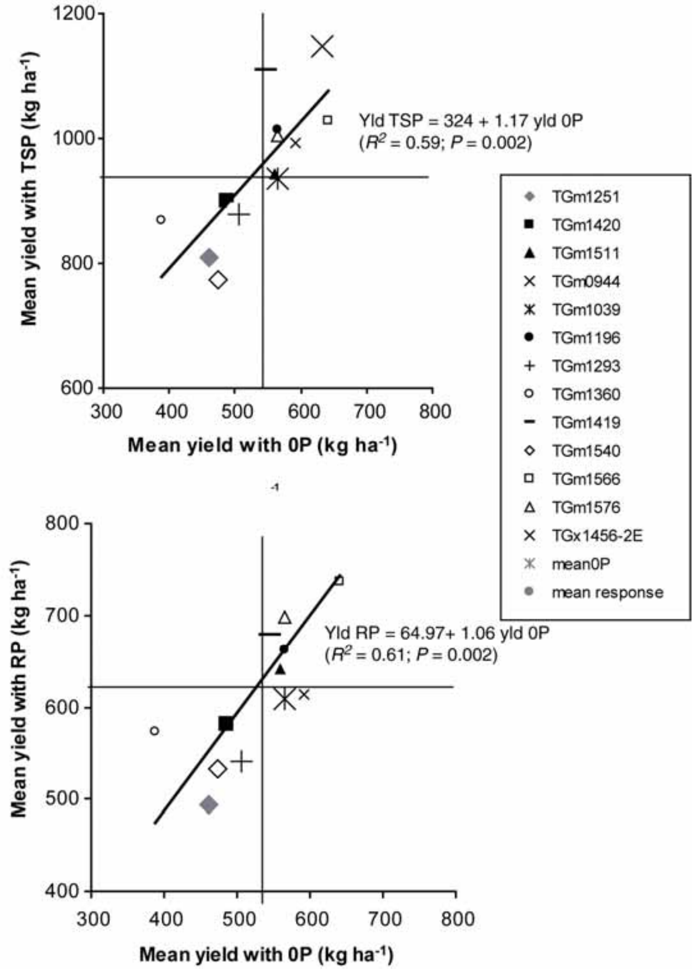

Figure 2. Biplot of grain yield of soybean genotypes at high and low P.

significant correlation ($P \leq 0.001$) with grain yield from PR, although its correlation with that from TSP was significant only at $P \leq 0.05$. All the correlation coefficients, although statistically significant, represented weak relationships between grain yield and P use efficiency.

Nitrogen fixation in soybean genotypes

Nitrogen fixation in soybean varied greatly among the genotypes and was influenced by P source and location (Fig. 3). However, TSP application improved %Ndfa significantly at Shika and Davié but not at Fashola; RP application did not improve %Ndfa significantly at any of the locations. The range of %Ndfa by soybean genotypes was generally wider under low P conditions (27–53%) compared with high P (TSP) conditions (38–58%). The soybean genotypes TGm1420 and TGm1293 consistently derived relatively higher %Ndfa across the locations. Also, differences between the best and poorest N fixers within a P source were significant at all locations but the ranking of genotypes was not at all consistent across the locations. Strikingly, the improved genotype TG×1456–2E had high grain yields at Fashola and Davié under low and high P conditions, and under high P conditions at all locations, but nevertheless had relatively low %Nfda values at all locations.

N nutrition and export in grain

The total N in biomass (at the $R_{3.5}$ growth stages) and in grain across soybean genotypes increased significantly with P fertilizer application. The total N in soybean genotypes under low P conditions ranged from 26.6 to 43.0 kg ha^{-1} at Shika, from 39.2 to 64.9 kg ha^{-1} at Fashola, and from 41.4 to 81.4 kg ha^{-1} at Davié (Table 4). Increases in biomass total N in response to RP and TSP ranged from 51 to 171% at Shika, from –2 to 36% at Fashola, and from 17 to 48% at Davié. Nitrogen uptake in grain of soybean genotypes TGm1566 and TG×1456–2E was significantly higher than in TGm1251 at all P levels at Shika, but a few soybean genotypes (e.g., TG×1456–2E, TGm1566, and TGm0944) demonstrated the capacity to improve their N nutrition with RP as P source at Shika and Davié. None of the genotypes demonstrated this capacity at Fashola.

The total N exported in grain of soybean genotypes was greater than that derived from the atmosphere (Ndfa) in most genotypes, resulting in negative N balances in all soybean plots (Fig. 3) except at Davié. There, three soybean genotypes (TGm1420, TGm0944, and TGm1360) gave positive N balances in all the P treatments. The negative N balances were generally highest at Fashola, with or without P application, but were significantly increased with P application across soybean genotypes at Shika. Surprisingly, the improved soybean genotype TGm1456–2E was among those with the highest negative N balances in all three locations (Fig. 3).

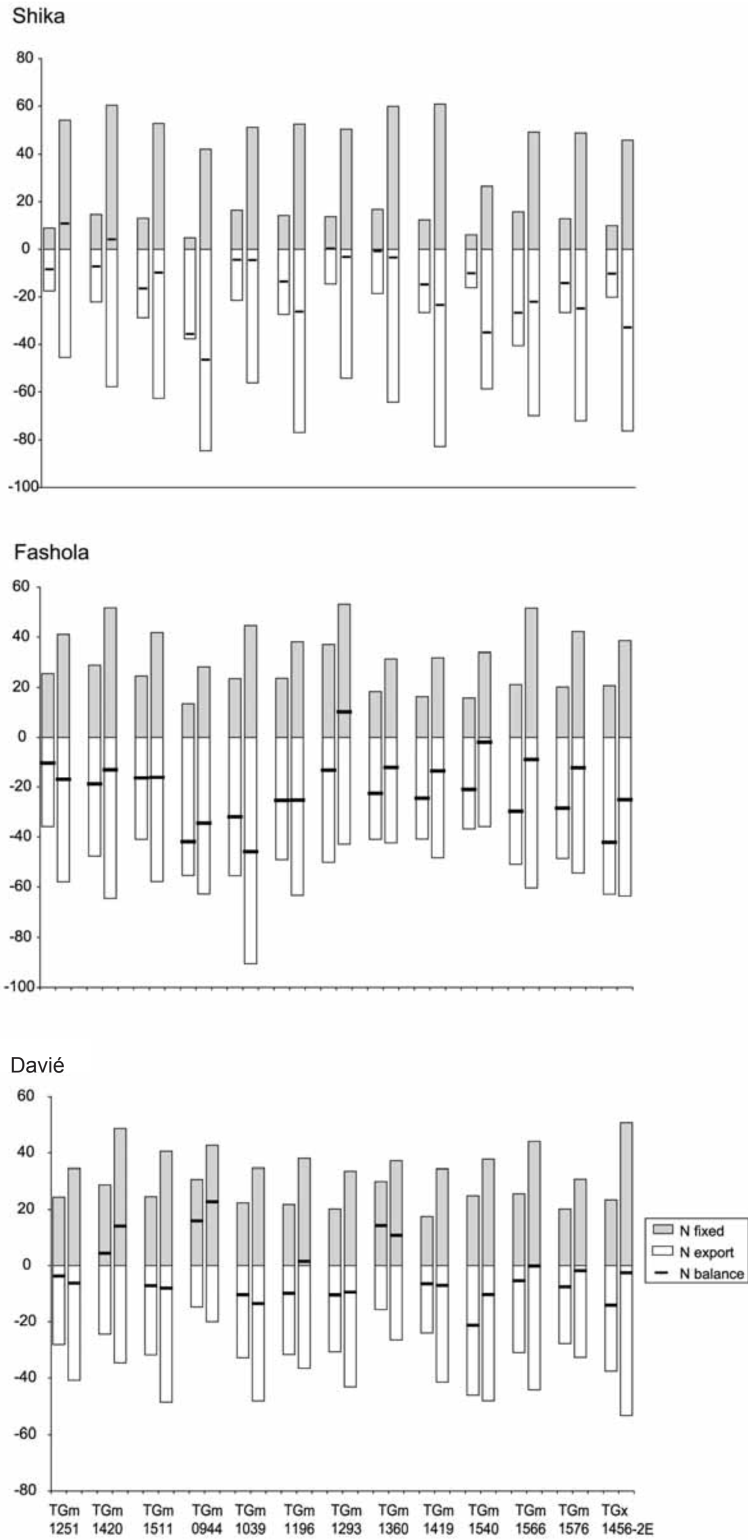

Figure 3. Nitrogen fixation, N exported in grain, and N balance of soybean genotypes grown at three locations under low and high P conditions. For each pair of bars the left bar represents low-P; and the right, the high-P (30 kg P ha^{-1}) condition.

Table 4. Total N accumulation (kg ha^{-1}) in shoot biomass at $R_{3.5}$ growth stage of soybean genotypes grown under low and high P conditions at three locations[1].

	Location											
	Shika				Fashola				Davié			
Genotype	0P	RP	TSP	Mean	0P	RP	TSP	Mean	0P	RP	TSP	Mean
TGm1251	27.3	60.3	108.6	65.4	54.3	53.7	84.7	64.2	55.4	51.5	83.0	63.3
TGm1420	35.4	64.1	115.9	71.8	62.4	56.9	94.3	71.2	67.1	80.9	97.0	81.7
TGm1511	36.9	63.3	119.2	73.2	54.6	54.9	90.4	66.6	48.9	67.4	78.0	64.8
TGm0944	29.9	56.6	118.7	68.4	47.6	46.2	84.2	59.3	81.4	62.1	97.5	80.3
TGm1039	31.1	40.5	101.6	57.7	41.8	44.4	90.1	58.8	56.5	60.4	91.9	69.6
TGm1196	32.6	57.5	105.7	65.2	44.0	44.4	75.4	54.6	62.4	60.4	104.5	75.8
TGm1293	30.1	36.3	93.3	53.2	64.9	46.4	94.9	68.7	48.1	68.1	94.7	70.3
TGm1360	34.2	56.6	126.6	72.5	39.2	51.2	79.7	56.7	64.1	53.3	103.8	73.7
TGm1419	34.6	52.0	130.6	72.4	49.4	49.0	73.6	57.3	41.4	61.8	102.5	68.5
TGm1540	27.2	38.1	70.0	45.1	47.3	54.2	84.9	62.2	77.8	66.7	120.5	88.3
TGm1566	43.0	75.6	123.6	80.7	59.5	54.8	107.9	74.1	61.0	72.8	123.1	85.6
TGm1576	35.3	56.0	94.7	62.0	42.9	46.5	76.8	55.4	54.7	51.5	102.9	69.7
TGx1456-2E	26.6	47.0	85.0	52.9	45.6	51.7	76.5	57.9	66.4	74.4	130.3	90.3
Mean	32.6	54.1	107.2		50.3	50.3	85.6		60.4	63.9	102.3	
[2]SEM												
P Source	2.44				2.21				3.79			
Genotype	5.09				4.60				7.79			
P x Genotype	8.81				7.98				13.46			

[1] Data represent means across 2001 and 2002, and [2]SEM, the standard error of the mean

P uptake in grain

Phosphorus exported in grain of soybean genotypes under low P conditions ranged from 0.88 to 2.39 kg ha^{-1} at Shika, from 3.12 to 5.23 kg ha^{-1} at Fashola, and from 1.03 to 3.68 kg ha^{-1}at Davié (Table 5). These values increased in response to TSP application but the increase was less pronounced with RP application. At Shika, the increase ranged from 16 to 181% for RP, and from 92 to 327% for TSP. The response to RP application was also lower at Davié and the pattern of response was similar to that reported for grain yield. TGm1566 had significantly more P exported in grain at both low and high P conditions at Shika. The response to RP across genotypes was generally negligible at the other two locations, even though TGm1566 gave the highest response of 24% at Fashola.

VAM colonization of soybean roots

Colonization of soybean roots by indigenous VAM fungi propagules were generally low and ranged from 19 to 25% at Shika, from 17 to 28% at Fashola, and from 10 to 17% at Davié, under low P conditions. These generally low levels of colonization were further depressed by TSP but not by RP application. Variation among genotypes in VAM colonization of roots was wide but not statistically significant at any of the P levels and location (data not shown).

Soil Olsen P contents, P fractions and pH at maize planting

In 2002, available P (Olsen P) content (mg P kg^{-1}) of soil from the previous (2001) P treatment plots across soybean genotypes at Fashola was significantly higher in the TSP plots (5.27) than the RP (4.16) and 0P plots (3.57). At Davié, the mean Olsen P was highest in the previous TSP (4.65) and RP (4.18) plots, and these results were significantly higher than in the 0P plots (3.39). Similar trends were observed for the previous (2002) soybean plots in 2003 where Olsen P content (mg P kg^{-1} soil) in TSP plots (8.96) at Shika was significant and higher than those of previous 0P (3.69) and RP plots (4.59). At Fashola, unlike in 2002, the highest mean Olsen P value was obtained from previous RP plots (3.98) across soybean genotypes and was significant over contents in the previous 0P (3.18) and TSP plots (3.32). At Davié, the highest mean Olsen P content of 7.90 mg P kg^{-1} soil from TSP plots was significantly higher than the mean Olsen P contents of the 0P (4.05) and RP plots (5.11). Within a given P treatment, the Olsen P contents were not affected by the cultivation of the previous crop (maize or soybean genotypes). Similarly, compared to maize cultivation, previous cultivation of soybean did not result in significant changes in the mean soil pH and P fractions at the three locations, irrespective of previous P source.

Table 5. Total P in grain (kg ha^{-1}) of soybean genotypes grown at three locations under low and high P conditions[1].

	Location											
	Shika				Fashola				Davié			
Genotype	0P	RP	TSP	Mean	0P	RP	TSP	Mean	0P	RP	TSP	Mean
TGm1251	1.07	1.45	3.27	1.93	3.25	2.90	5.51	3.887	1.14	1.28	2.36	1.59
TGm1420	1.42	2.42	4.64	2.83	3.91	3.35	6.05	4.435	1.49	1.92	2.41	1.94
TGm1511	2.04	2.79	4.69	3.17	3.64	3.46	5.93	4.341	2.18	2.30	3.61	2.70
TGm0944	2.22	3.11	5.74	3.69	4.14	3.47	5.71	4.439	1.04	1.37	1.59	1.33
TGm1039	1.42	2.18	4.29	2.63	4.25	4.08	6.66	4.997	1.55	1.38	2.45	1.80
TGm1196	1.74	3.00	5.92	3.55	4.23	4.02	5.86	4.702	1.80	1.70	2.08	1.86
TGm1293	0.86	1.66	3.61	2.04	3.97	3.21	5.14	4.109	1.77	1.72	2.78	2.09
TGm1360	1.15	2.31	4.68	2.71	3.26	3.49	5.95	4.236	1.04	1.46	2.14	1.55
TGm1419	1.59	2.60	5.48	3.22	3.55	3.86	6.23	4.545	1.03	1.26	2.03	1.44
TGm1540	0.88	1.66	3.69	2.07	3.12	2.83	4.31	3.416	3.68	3.36	4.20	3.74
TGm1566	2.39	2.77	4.61	3.26	3.77	4.68	6.03	4.831	2.20	2.50	3.52	2.74
TGm1576	1.69	2.89	5.35	3.31	4.30	4.63	6.87	5.27	1.57	1.67	2.57	1.94
TGx1456-2E	1.15	3.23	4.91	3.10	5.23	4.75	6.66	5.56	2.74	3.80	4.33	3.62
Mean (P)	1.51	2.47	4.65		3.89	3.75	5.92		1.79	1.98	2.77	
[2]SEM												
P Source	0.09				0.28				0.13			
Genotype	0.18				0.59				0.28			
P x Genotype	0.32				1.03				0.48			

[1] Data represent means across 2001 and 2002, and [2]SEM, the standard error of the mean

Grain yield of maize following soybean genotypes

The pattern of variation in maize grain yield across previous P treatments was similar to that of soybean in the three locations. In 2002, mean grain yields of maize following soybean within 0P plots (1664 kg ha^{-1}) and TSP plots (1634 kg ha^{-1}) were significantly higher than the 1374 kg ha^{-1} obtained from the previous RP plots at Fashola. The grain yield (kg ha^{-1}) from the specific soybean genotype plots ranged from 1236 to 2063 within the previous 0P treatment, from 963 to 1837 within the previous RP treatment, and from 1239 to 1933 within the previous TSP treatment. The corresponding maize grain yield from the maize-after-maize plots was 1501 kg ha^{-1} for 0P, 1025 kg ha^{-1} for RP, and 1268 kg ha^{-1} for TSP. At Davié, maize grain yields across soybean genotype plots were relatively lower with the differences between mean values (kg ha^{-1}) of the previous 0P (1217), RP (1244), and TSP plots (1251) not being statistically significant. Similarly, there were little differences between grain yields of maize following soybean genotypes (data not shown).

The fresh application of 15 kg P ha^{-1} in 2003 to previous (2002) 0P plots at Shika increased mean maize yields across soybean genotypes substantially (up to 178%), whereas the residual effect of the 2002 P application on mean grain yield was only 15% for the RP plots and 25% for the TSP plots. Also, maize yields from previous RP and TSP plots were significantly ($P \leq 0.05$) higher than yields from the previous 0P plots (Table 6). These apparent benefits from previous P application were however reduced at Fashola and Davié. The mean maize grain yields from the 15P plots were significantly higher than those of 0P plots at Fashola, while increases due to previous RP application were not significantly different. At Davié, the mean grain yield from the 15P plots was significantly higher than those of previous 0P plots but not higher than those of the TSP and RP treatments (Table 6).

VAM colonization of root of maize after soybean

In 2002, mean VAM colonization (%) of maize roots across 2001 soybean and maize plots within 0P treatments was significantly higher than mean values obtained in previous RP plots (16), and TSP plots (37) at Fashola. Also, at Davié, the mean VAM colonization (%) of maize from the previous 0P plots (39) was significantly higher than those of the previous RP (9), and TSP (21) plots. Differences among genotypes were, however, not consistent across P treatments and locations (data not shown).

Similarly, the mean VAM of maize roots from the previous 2002 soybean plots were highest (33–40%) in the previous 0P plots and lowest (3 –5%) in the 15P plots and this was consistent at all the locations (Table 7). Surprisingly, VAM colonization was more suppressed within the previous RP plots than in the previous TSP plots. The VAM

Table 6. Grain yield (kg ha^{-1}) of maize in 2003 as affected by the soybean genotype or maize grown in the same plot in 2002, and the P treatment at three locations[1].

	Location											
	Shika				Fashola				Davié			
2002 genotype	0P	15P[2]	RP	TSP	0P	15P	RP	TSP	0P	15P	RP	TSP
TGm1251	1122	2894	1691	1745	658	796	1051	1139	2577	2914	2642	2642
TGm1420	816	2363	2116	1656	905	1544	910	1660	3242	2489	2674	2969
TGm1511	790	2417	2097	1537	1051	1690	1141	1446	2524	2743	2400	3489
TGm0944	1052	3106	2075	1677	692	1331	1306	1278	3911	3089	3113	3063
TGm1039	710	2242	2122	1696	546	877	806	1054	2758	2816	2508	3218
TGm1196	740	2339	2335	1619	773	1129	815	879	3163	3230	2591	3213
TGm1293	819	2335	1959	1601	358	940	903	1210	3363	2844	3201	3256
TGm1360	1044	2098	2001	1547	775	819	791	946	2772	2907	2768	3128
TGm1419	1063	2536	1863	1556	907	1082	742	876	3003	2803	2985	3492
TGm1540	823	2569	1986	1702	790	1100	851	884	4168	2555	3024	3588
TGm1566	967	2405	2394	1674	629	791	946	1217	3196	3401	3155	2957
TGm1576	987	2286	1955	1501	747	1297	856	672	2750	2485	2441	3214
TGx1456-2E	567	2053	2588	1760	631	1134	1186	1104	3125	2369	3327	3230
Mean (Soybean)	885	2434	2091	1636	728	1118	946	1105	3119	2819	2833	3189
Maize	449	1544	1632	1422	729	739	1063	1136	3366	2646	3267	2637
[4]SEM (P x Genotype)	266				258				382			
[3]Mean P (Residual P)	854^{c}	2371^{a}	2058^{b}	1621^{b}	728^{b}	1091^{a}	955^{a}	1107^{a}	3137^{a}	2807^{b}	2864^{ab}	3150^{a}

[1]Data represent means of 2003 maize trial following 2002 soybean genotypes, [2]15 kg P ha^{-1} applied at maize planting, and [3]SEM, the standard error of the mean; Mean values followed by the same letter are not significantly different at $P \leq 0.05$ by SEM of P for the location.

Table 7. VAM colonization of roots of maize following soybean genotypes previously grown under low and high P conditions at three locations[1].

	Shika				Fashola				Davié			
Genotype	0P	15P	RP[2]	TSP	0P	15P	RP	TSP	0P	15P	RP	TSP
TGm1251	37.7	3.2	16.0	28.6	39.4	4.2	6.6	19.5	22.0	0.0	3.9	23.31
TGm1420	55.3	10.8	24.8	46.3	29.4	3.8	20.7	25.3	26.3	3.0	10.6	28.23
TGm1511	57.2	5.4	11.0	28.9	29.3	4.7	17.4	25.2	35.0	3.3	15.4	25.43
TGm0944	35.9	3.8	21.0	39.3	42.2	1.9	11.0	25.0	36.2	3.3	3.8	26.83
TGm1039	38.5	13.8	9.9	41.7	43.2	8.0	7.9	25.2	37.9	0.0	10.8	25.71
TGm1196	37.1	4.4	15.9	21.9	34.4	4.7	6.8	29.0	27.1	2.6	4.2	31.01
TGm1293	32.7	5.4	15.1	39.6	36.1	3.6	26.6	26.6	32.1	1.9	13.1	28.49
TGm1360	37.5	1.8	22.7	40.2	41.5	4.6	14.6	28.3	34.0	3.5	10.2	30.87
TGm1419	39.8	3.5	20.0	29.7	40.8	5.6	6.3	13.8	41.9	3.4	5.6	14.79
TGm1540	36.3	1.1	13.0	27.3	40.9	0.8	15.2	31.3	37.8	2.0	5.9	25.33
TGm1566	29.8	0.9	18.7	42.5	33.0	0.7	12.9	26.4	37.7	2.9	5.6	24.93
TGm1576	35.0	1.8	38.2	23.4	22.4	4.9	5.7	22.4	39.7	6.8	4.9	28.85
TGx1456-2E	45.0	6.2	20.1	33.0	39.2	3.0	15.2	18.5	26.9	3.8	8.8	24.30
Mean (Soybean)	39.8	4.8	19.0	34.0	36.3	3.9	12.8	24.3	33.4	2.8	7.9	26.0
Maize	43.5	3.4	27.7	45.4	43.5	5.0	4.9	27.1	30.5	4.8	16.7	28.58
SEM[3] (P x Genotype)	1.6				1.1				1.3			
Mean (P)	40.1^{a}	4.7^{d}	19.6^{c}	34.9^{b}	36.8^{a}	4.0^{d}	12.3^{d}	24.6^{b}	33.2^{a}	3.0^{d}	8.5^{c}	26.2^{b}

[1] Data represent means of 2003 maize trial following 2002 soybean genotypes, [2] 15 kg P ha^{-1} applied at maize planting, and

[3] SEM, the standard error of the mean; Mean values followed by the same letter are not significantly different at $P \leq 0.05$ by SEM for the location.

colonization in previous RP plots represented about 56% (at Shika), 50% (at Fashola), and 33% (at Davié) of values recorded for TSP plots in the three locations. The mean VAM colonization of root of maize-after-soybean in 2003 was generally not significantly different from that of maize-after-maize (Table 7). However, there were isolated cases where VAM colonization of roots of maize-after-soybean genotypes (such as TGm1420 and TGm1511 within previous 0P plots, and TGm1576 within previous RP plots at Shika) were significantly higher than the colonization in corresponding maize-after-maize plots. At Fashola and Davié, colonization of roots of maize from all previous soybean plots, except those of TGm1251, TGm1039, TGm1196, TGm1419, and TGm1576 within the previous RP plots, was significantly higher than that of maize-after-maize plot. The previous TSP, unlike the application of RP, generally resulted in significantly lower VAM colonization of roots of maize-after-soybean than that of maize-after-maize across the locations. This was the case in 69% of previous soybean genotype plots at Shika, 31% at Fashola, and 23% at Davié.

Nitrogen benefits to maize

Total N exported in grain of maize-after-soybean varied within previous P treatments and across locations. In 2002 at Fashola, mean N exported in maize grain (kg ha^{-1}) in the previous 0P (21.0) and TSP (20.7) plots was significantly higher than the 17.5 kg ha^{-1} from the previous RP plots (data not shown). Within previous soybean plots, however, only total N in grain (kg ha^{-1}) of maize-after-soybean genotype TGm1540 (24.8 kg ha^{-1}) within the 0P plots, TGm1511 (25.3 kg ha^{-1}), TGm1576 (23.8 kg ha^{-1}), and TG×1456-2E plots (25.3 kg ha^{-1}) within TSP plots was significantly higher than those of their respective maize-after-maize plots (17.3 kg ha^{-1} for 0P and 14.8 kg ha^{-1} for TSP treatments). At Davié, however, the mean total N in grain of maize within 0P (17.1 kg ha^{-1}), RP (17.3 kg ha^{-1}), and TSP (16.8 kg ha^{-1}) treatments were not significantly different. Total N in grain of maize following soybean genotypes ranged from 14.1 to 20.8 kg ha^{-1} within previous P treatments, but none of the mean values were significantly higher than those for the corresponding maize-after-maize plots.

In 2003, the fresh addition of 15 kg P ha^{-1} resulted in mean total N exported in grain of maize-after-soybean of 14.04 kg ha^{-1} at Fashola and 30.48 kg ha^{-1} at Shika; these values were significantly larger than the mean total N in grain of maize-after-soybean from the previous 0P and TSP plots at Shika, and also the previous 0P plots at Fashola (Table 8). The total N in grain of maize-after-soybean was influenced by the interaction of soybean genotypes and soil P availability. At Shika, mean total N exported in grain of maize-after-soybean was significantly higher than that of maize-after-maize in all P treatments

Table 8. Total N exported in grain of maize following soybean genotypes previously grown under low and high P conditions at three locations[1].

	Shika				Fashola				Davié			
Genotype	0P	15P	RP[2]	TSP	0P	15P	RP	TSP	0P	15P	RP	TSP
TGm1251	14.82	32.22	25.93	32.00	7.82	12.42	13.06	11.23	35.29	38.72	37.61	35.97
TGm1420	9.38	27.89	31.31	25.46	10.16	16.27	11.05	17.52	33.83	42.00	37.71	40.12
TGm1511	10.10	34.27	30.94	23.42	12.94	24.32	13.93	18.31	35.41	35.40	32.52	48.10
TGm0944	11.53	38.80	27.66	25.48	7.53	13.39	15.77	12.04	42.63	54.51	43.69	43.81
TGm1039	9.14	27.96	29.10	31.80	4.81	10.40	10.35	10.23	36.74	36.46	32.99	43.80
TGm1196	10.26	30.69	37.95	25.21	6.28	10.64	7.10	8.96	44.61	44.23	35.04	42.03
TGm1293	9.67	28.94	27.06	26.70	5.02	14.89	12.13	13.81	48.33	39.39	44.52	45.70
TGm1360	9.54	23.64	27.29	21.06	7.81	9.21	10.48	12.62	38.31	38.79	38.56	44.21
TGm1419	14.17	33.30	23.81	25.34	7.83	9.48	6.97	8.82	40.66	37.92	40.62	49.50
TGm1540	11.76	31.34	28.23	32.57	11.27	14.73	9.23	10.41	36.41	60.13	42.22	45.23
TGm1566	10.52	30.23	34.81	22.17	6.67	11.38	11.35	16.47	46.72	47.49	45.94	41.30
TGm1576	15.82	26.05	25.66	21.55	10.41	18.18	10.45	9.17	38.58	33.55	33.60	45.04
TGx1456-2E	6.85	30.85	32.52	27.70	9.63	17.27	15.32	17.30	33.11	43.48	47.83	45.54
Mean (Soybean)	11.04	30.50	29.41	26.19	8.32	14.04	11.51	12.61	39.28	42.47	39.45	43.87
Maize	6.23	20.88	24.36	19.55	8.27	9.21	13.91	13.94	37.28	43.43	44.18	34.64
SEM[3] (P x Genotype)	3.88				3.77				5.70			
Mean (P)	10.70^c	29.81^a	29.05^a	25.72^b	8.32^b	13.70^a	11.51^a	12.70^a	39.14^a	42.54^a	39.79^a	43.21^a

[1]Data represent means of 2003 maize trial following 2002 soybean genotypes, [2]15 kg P ha^{-1} applied at maize planting, and [3]SEM, the standard error of the mean; Mean values followed by the same letter are not significantly different at $P \le 0.05$ by SEM for the location.

(Table 8). However, within specific P treatments, percentage increases in total N in grain from maize-after-soybean over that of maize-after-maize ranged from 10 to 138% in the previous 0P plots, from 13 to 86% in the 15P plots, from –42 to 56% in the previous TSP plots, and from –2 to 56% in the previous RP plots. These gains in total N in grain were significant only for values obtained from grain of maize-after-soybean genotypes TGm1511, TGm1251, TGm0944, and TGm1419 within the 15P plots, maize-after-soybean genotype TGm1196 within the previous RP plots, and maize-after-soybean genotype TGm1251, TGm1540, and TGm1039 plots within the previous TSP treatments (Table 8). At Fashola, mean N exported in maize-after-soybean was significantly higher than that of maize-after-maize only for the 15P plots. The increase in total grain N of maize-after-soybean over that of maize-after-maize at this location ranged from 0 to 164% within 15P plots, from –42 to 56% within previous 0P plots, from –50 to 13% within previous RP plots, and from –35 to 31% within the previous TSP plots. Only the total N in grain maize-after-soybean genotype TGm1511 within 15P plots was significantly ($P \leq 0.05$) higher than that of maize-after-maize. At Davié, the mean N exported in maize-after-soybean was significantly higher than that of maize-after-maize from the previous 0P and TSP treatments (Table 8). The increases in total N of grain of maize-after-soybean over those of their respective maize-after-maize treatments at this location ranged from –22 to 43%. Unlike the results at Fashola and Shika, none of the differences between specific maize-after-soybean genotype and the corresponding maize-after-maize treatment were significant.

Phosphorus benefits to maize

In 2002, P nutrition as measured by total P exported in maize grain followed a pattern similar to that of N. The mean total P exported in maize grain from previous TSP plots (7.44 kg ha^{-1}) of the 2001 soybean crop cycle, was significantly higher than that from previous RP plots (6.86 kg ha^{-1}) but not that from previous 0P plots (7.68 kg ha^{-1}) at Fashola. Unlike total N exported in maize grain, however, none of the differences between total P export in grain of maize-after-soybean genotypes and their corresponding maize-after-maize treatments were significant at the two locations.

In 2003, the mean total P in grain of maize from previous 0P plots in the 2002 soybean crop cycle, at all the locations, was significantly lower than that of the other P sources. The mean total P of grain of maize-after-soybean plots was significantly higher than that of the corresponding maize-after-maize plots from all P sources at Shika, the previous 0P and 15P plots at Fashola, and the previous RP and TSP plots at Davié (Table 9). Increases in total P of grain from

Table 9. Total P exported in grain of maize following soybean genotypes previously grown under low and high P conditions at three locations[1].

	Location											
	Shika				Fashola				Davié			
Genotype	0P	15P[2]	RP	TSP	0P	15P	RP	TSP	0P	15P	RP	TSP
TGm1251	2.75	4.90	4.47	6.40	1.91	1.83	3.28	3.13	7.83	10.38	9.71	9.30
TGm1420	1.56	4.26	5.28	4.55	2.24	4.71	2.67	4.87	7.35	9.82	17.19	12.84
TGm1511	1.41	4.95	5.82	4.11	3.07	6.86	3.53	4.82	7.94	7.79	6.21	12.76
TGm0944	1.68	7.94	4.53	4.12	1.76	4.04	4.08	3.56	11.33	14.28	11.40	13.13
TGm1039	1.22	4.20	4.43	4.98	1.27	3.25	2.55	3.01	8.45	8.78	7.66	10.98
TGm1196	1.67	4.29	6.39	4.46	1.55	2.54	1.77	2.59	9.79	11.21	9.63	11.83
TGm1293	1.24	4.61	4.59	4.97	1.39	4.34	2.93	3.85	8.28	11.93	10.14	12.70
TGm1360	1.56	2.97	4.72	3.84	1.94	3.02	3.06	3.66	8.78	9.67	8.95	10.83
TGm1419	2.42	5.90	3.69	4.60	2.01	2.82	1.99	2.53	9.51	9.12	9.79	13.53
TGm1540	1.64	3.84	4.46	6.24	3.45	4.96	2.15	2.70	9.53	18.50	11.14	10.72
TGm1566	1.28	4.75	6.73	3.38	1.42	3.45	2.72	5.01	10.33	13.01	9.22	10.93
TGm1576	2.56	3.93	4.00	4.05	2.53	5.06	2.01	2.88	8.22	9.59	8.86	12.62
TGx1456-2E	0.75	6.24	4.26	5.13	2.26	5.19	3.61	4.88	9.04	12.11	13.38	11.46
Mean (Soybean)	1.67	4.83	4.87	4.60	2.06	4.01	2.80	3.65	8.95	11.25	10.25	11.82
Maize	1.06	4.54	4.37	2.66	1.54	2.91	3.15	4.69	8.92	10.60	9.16	8.25
SEM[3] (P x Genotype)	0.85				1.06				2.17			
Mean (P)	1.63^b	4.81^a	4.84^a	4.46^a	2.02^b	3.93^a	2.82^b	3.73^a	8.95^b	11.20^a	10.17^{ab}	11.79^a

[1] Data represent means of 2003 maize trial following 2002 soybean genotypes, [2] 15 kg P ha^{-1} applied at maize planting, and [3] SEM, the standard error of the mean; Mean values followed by the same letter are not significantly different at $P \leq 0.05$ by SEM for the location.

maize-after-soybean plots over those of the corresponding maize-after-maize plots ranged from –29 to 141% across the P treatments in three locations. However, only the total P in grain of maize-after-soybean genotype TGm0944 (7.94 kg ha^{-1}) within the 15P plot, and maize-after-soybean genotypes TGm1251 (6.40 kg ha^{-1}) and TGm1540 (6.24 kg ha^{-1}) within previous TSP plots at Shika were significantly higher than that of maize-after-maize plots. This was also the case for differences between maize-after-soybean genotype TGm1540 (18.50 kg ha^{-1}) within 15P plots, maize-after-soybean TGm1420 (17.19 kg ha^{-1}) within the previous RP plots at Davié, and their corresponding maize-after-maize plots.

Discussion

The results of this study have revealed that the promiscuous soybean genotypes used differ considerably in P nutrition under low and high P conditions and responses to P application could be large, depending on the location and soil biophysical conditions. In a varietal screening study at Fashola, AbdelGadir (1998) observed variations among promiscuous soybean genotypes in selected growth parameters in response to P application. The high grain yields and the corresponding high P uptake of the genotype TG×1456-2E may suggest an improvement in agronomic traits over most of the TGm accessions. Also, previous analysis of the genotypes for P use, and P response efficiency revealed that, unlike the other genotypes, TG×1456-2E and TGm1566 demonstrated a high low-P use and P response efficiency under low and high conditions, which was consistent across the locations (Table 2). This may suggest that an unconscious selection for P efficiency (low or applied P) had occurred during breeding and selection for increased grain yield.

Vanlauwe et al. (2000) reported a site-specific response to RP in two herbaceous legumes in the northern Guinea savanna of Nigeria but the application of RP in our study had limited effects on growth and grain yield enhancement on the soybean genotypes. This may suggest poor use of RP as a P source by the soybean genotypes due to low Ca requirements and uptake (Bekele et al. 1983), or limited soybean rhizosphere-induced dissolution of RP (Kamh et al. 2002). However, certain genotypes demonstrated the capacity to use RP better than the others (Table 2) and this may be related to variations in root morphology among soybean genotypes and architecture (Ohwaki and Hirata 1992) or other mechanisms (Bekele et al. 1983; Kamh et al. 2002) and needs to be further examined.

In West Africa, farmers' adoption of technology is linked to food and cash for the household and the dissemination of grain legumes is more likely to have an impact on farmers' livelihood (Sanginga *et al.* 2001). However, P uptake in grain represents P exported out of the system and, therefore, has implications for P cycling to crops grown in association or following these legume genotypes. In our work, the assessment of P efficiency was based on P accumulation in grain, under low and high P conditions, and indicates that the promiscuous soybean genotypes created greater deficits than maize in soil-available P pools which, unfortunately, are a nonrenewable resource. We were, however, unable to directly determine if the P efficiency was linked to usage from less bioavailable P sources.

The minimum variation among soybean genotypes in percentage VAM infection could be attributed to the narrow genetic base of the breeding lines used in the study, the low and probably less infective VAM propagule populations in savanna soils (Duponnois et al. 2001), the rate of root hair and mycorrhizae development in relation to soybean P demands (Jacobsen *et al.* 1992; Baon *et al.* 1994), and the mycorrhizal dependency of soybean genotypes (Khalil *et al.* 1994) used in the study.

The range of %Ndfa (23–58) measured for the promiscuous soybean genotypes was generally low but within the 21–70% reported by Sanginga et al. (1997; 2002), the 50–60% reported by Okereke and Eaglesham (1993) but lower than the 84–87% reported by Eaglesham *et al.* (1982) and the 77–84% reported by Abaidoo *et al.* (1999). The relatively low %Ndfa under both high and low P conditions recorded in this study indicates that P was probably not the only limiting factor, especially at Fashola and Davié; the effects of the population sizes and effectiveness of indigenous rhizobia nodulating promiscuous soybean and other soil factors could have also been limiting. The low response to RP compared to TSP could be explained by the slow release of P from RP. This could probably not meet the relatively high P demand rate of soybean within the short growth phase of the crop. It is important to note that these wide differences reported above could be traced to the methods of assessment. However, it is generally noted that the full productivity of legume crops, such as soybean, would require %Ndfa values greater than 80 to avoid a net loss of N from the soil environment. Eaglesham *et al.* (1982) observed that a %Ndfa of less than 60% fixation led to a balance of –36 kg N $ha^{-1.}$ Our results also revealed a net negative balance for most of the combinations of soybean genotype, P source, and location as a result of the low %Ndfa and the relatively high N exported as grain and consequently led to a considerable reduction in the potential N benefits of the soybean rotation to maize through N_2 fixation.

The observed trends in grain yield, VAM colonization, total N and P in grain of maize-after-soybean across the locations, under both low and high P conditions, did not demonstrate a consistent and discernible pattern of genotype-specific rotation effects, even though mean increases as high as 97% in grain yield, 77% in grain N, and 57% in grain total P were recorded in certain previous combinations of P source, soybean genotype, and location. The increases measured in parameters of maize-after-soybean support results of previous agronomic work conducted in the Guinea savanna zones of Nigeria. These results revealed that the yield of maize could be improved in rotation systems with soybean (Kaleem 1993; Carsky *et al.* 1997; Sanginga *et al.* 2002) as in other similar cereal–legume rotation systems (Bagayoko *et al.* 2000a,b) where the yields of cereals after legumes were increased by as much as 80% over yields obtained for cereals grown after cereals. Similarly, we recorded reductions in grain yield, and total grain N and P with certain combinations of P source, genotype, and location as reported in some previous work (e.g., Kamh *et al.* 2002) on similar legume–cereal rotation systems.

The increases in growth parameters of cereal following legumes have usually been attributed to N benefits to the cereal through N_2 fixation and N sparing effects (Sanginga *et al.* 2002) and other rotation effects (Alvey *et al.* 2000; Bagayoko *et al.* 2000a, 2000b; Marschner and Baumann 2003). A conservative estimation of the contribution of BNF to the soil N pool for use by the nonlegume, designated as N balance (Peoples and Craswell 1992), was used to predict the contribution of N by soybean to the cereal crop and also partially to account to for yield increases observed in the subsequent cereal crop. The N balances estimated in this study were generally negative, except in few instances (e.g., TGm0944, TGm1420, and TGm1360 at Davié). The negative N balances are due to relative low proportions of N derived from BNF (Fig. 3) and the high N content of the soybean grain. However, this trend did not always result in decreases in grain yield and the total N exported in grain of maize-after-soybean. This may underscore the limitation of using the N balance method of Peoples and Craswell (1992) as an index of N contribution by legumes to cereals in rotation as it does not account for the accumulation of fixed N in the aboveground biomass after the $R_{3.5}$ growth stage and ignores the belowground biomass. It might also be that rotational effects are more important and differ among varieties, independent of their N balance.

We can infer from our results that residual P from the previous application to soybean was not adequate to meet the P demand of maize in rotation at Shika and Fashola, as the addition of 15 kg P ha^{-1} resulted in enhanced maize grain yields at these locations. The low P availability in these savanna soils (Mokwunye *et al.* 1986) coupled with the removal of P through harvested products (Smaling *et al.* 1993) probably explains the response to P application by maize in rotation. It also suggests that in low P environments, such as Shika, where tremendous gains in growth parameters in maize-after-soybean were recorded with a fresh application of P, it may be appropriate to adopt the strategy of frequent small applications of P (Barrow 1980; Cox *et al.* 1981; Linquist *et al.* 1996) to the components of legume–cereal rotation systems to sustain the economic returns of the system.

The contribution of P to maize through soybean rotation could not be directly measured with our experimental approach. We had postulated that soybean lines that performed better at low P supply (classified as 'P-efficient' lines) may have been able to access more soil P than 'P-inefficient' lines and this extra P may have been available to the following maize. There was no evidence of this in the yields of maize after soybean, nor was there any evidence of an effect on the P content of maize grain in the 0P or the RP treatments. Total P export in the grain of maize grown after soybean may reflect the yield of the soybean genotypes, not necessarily their relative P efficiencies. Also, Ohwaki and Hirata (1992) observed that exudation of organic anions in soybean was so small that it was unlikely to account for variations in the P efficiency of the soybean genotypes used in our study.

The relatively high VAM colonization of roots of maize-after-soybean from previous 0P plots may account in part for the high maize yields and P uptake (Smith 1980; Barea 1991), which were sometimes comparable to values recorded for maize that received additional P at the rate of 15 kg ha^{-1} (Table 7). Mean mycorrhizal colonization of maize roots was generally not significantly higher in maize-after-soybean than their corresponding maize-after-maize control, as observed in other legume–cereal rotations systems (e.g., Karlen *et al.* 1994; Sanginga *et al.* 1999; Alvey *et al.* 2000; Bagayoko *et al.* 2000a, 2000b) but the effectiveness of the VAMF population that developed under the different soybean genotypes and subsequent benefits to the P nutrition of maize in rotation cannot be totally ignored. These observations notwithstanding, the apparent enhanced P nutrition and, hence, the grain yield of maize from such previous soybean genotype plots cannot be attributed to a P-sparing effect by soybean, since the P exported in soybean grain was higher than that of the maize control during the soybean crop cycle (data not shown). Further experimental evidence will be required on the P acquisition of the soybean genotypes whose previous cultivation appeared to have improved P nutrition in the following maize crop.

The observed increases in the productivity of the rotation maize, despite relatively low N balances measured and higher P exported in soybean than in maize grain during the soybean crop cycle, may result from the positive, interactive role of P and N resulting from N unaccounted in the N balance estimates, the additional N given to maize at planting, residual P from previously applied RP and TSP, differential VAM colonization within P treatments, and changes in soil physical properties (Horst and Härdter 1994; Obi 1999) and the other rotation effects. The trends observed in the study, however, suggest that the potential exists for the identification of soybean genotypes with the capacity to contribute to N and P nutrition of maize in rotation, but this effort must be directed at developing soybean genotypes with enhanced P uptake from less bioavailable P fractions, maximizing %Ndfa under low P conditions, and reducing N and P harvest indices by maximizing total N and P in stover rather than in grain.

Conclusion

The response of soybean genotypes to P application was moderate and seemed to have been influenced by other biophysical factors. The N balances estimated for the soybean genotypes were generally negative due to the large N exports in the grain but cannot be used to directly account for observed variations in N nutrition and grain yields of maize that followed in rotation. P availability to maize resulting from previous P application of the soybean genotypes was relatively low and could not sustain high maize yield at certain sites. The results have also shown that increases in biomass, and total N and P in maize in rotation with soybean could be influenced by specific interactions among soil N, P, and crop genotype during the two rotation cycles.

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Etude de l'adaptabilité de variétés de maïs pour la culture irriguée en zone Sahélienne

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Résumé

Les rendements grains du maïs (*Zea mays* L.) en zone tropicale de basse altitude sont généralement très faibles par rapport à ceux obtenus en zone de moyenne à haute altitude ou en zone tempérée, même sous culture intensive. Le rendement grain pourrait être amélioré si les variétés sont homologuées sur la base d'adaptation à des localités spécifiques et aussi si les semis sont effectuées à des périodes optimales. Les objectifs de cette étude sont d'identifier (i) des stratégies d'adaptation qui pourraient être recommendées pour les programmes d'amélioration du maïs dans les conditions d'irrigation dans les écologies sahélienne de l'Afrique de l'ouest et du centre (AOC), (ii) des variétés qui sont adaptées aux localités spécifiques et/ou des dates de semis et (iii) des localités ou le progrès de la sélection et le developpement du maïs seraient optimal. Huit génotypes (hybrides et populations) sont sémés par mois dans des essais à deux répétitions pendant 12 mois dans la station expérimentale de Ndiol dans la vallée du fleuve Sénégal. Des méthodes statistiques telles que la régression conjointe ou factorielle combinée avec le model multiplicatif ont été utilisés pour évaluer la stabilité des variétés et décrire les interactions génotype x date de semis, en prenant la température moyenne et la durée de la journée comme covariables. Le rendement grain a varié en moyenne entre 1,5 et 5,6 t/ha pendant les douze mois. Bien que la régression factorielle ait permis d'expliquer en termes biologiques 80 à 98 % de la variation du rendement, la méthode multiplicative était plus efficace dans la detection des adaptations spécifiques des génotypes aux dates de semis spécifiques.

Abstract

Grain yield of maize (*Zea mays* L.) is generally low in the lowland areas of the tropics compared with mid- to high-altitudes and temperate regions, even with comparably high inputs. Grain yield could be improved if varieties are released on the basis of adaptation to specific locations and are planted at the optimum planting dates. The objectives of this study were to identify i) adaptation strategies that could be recommended for maize breeding programmes under irrigated conditions in the Sahel ecology of West and Central Africa (WCA), ii) varieties that are adapted to specific locations and/or planting dates and iii) locations where progress from selection and maize development would be optimal. Eight genotypes (hybrids and populations) were planted monthly in two-replicate experiments for 12 months at Ndiol Research Station in the Senegal river valley. Statistical methods such as joint regression and factorial regression combined with the multiplicative model (AMMI) were used to assess variety stability and to describe genotype x planting date interaction, taking mean temperature and daylength as environmental covariates. Mean grain yield ranged from 1.5 to 5.6 tons/ha for the 12 months. Although the factorial regression explained about 80 to 98% of yield variation, the multiplicative method was more effective in detecting specific adaptability of genotypes to specific planting dates.

Introduction

Les rendements du maïs (*Zea mays* L.) en zone tropicale sont généralement faibles par rapport à ceux obtenus en zone tempérée, même sous culture intensive. En effet, la température affecte directement les rendements biologiques et économiques (c'est-à-dire le poids de matière sèche par unité de surface ou la portion récoltable de la culture) en influençant le taux de croissance (taux d'accumulation de matière sèche), la répartition de la matière sèche, le taux de développement ou la vitesse de changement d'un stade morphologique ou fonctionnel à un autre par exemple de la phase végétative à la phase reproductive et enfin la durée du cycle.

Obtenir ainsi des rendements élevés et réguliers en culture irriguée a toujours été une préoccupation majeure des sélectionneurs et agriculteurs. En zone sahélienne, l'adaptabilité et/ou la stabilité générale des variétés a été toujours d'une importance particulière. Dire cependant que tous les milieux n'ont pas la même aptitude à révéler les même potentialités variétales, c'est conclure à l'existence d'interaction génotype x environnement constituant en elle-même une information riche. De ce fait, la régularité du rendement correspondrait à un de ces aspects nombreux et divers des relations génotype x environnement, lesquelles ont donné lieu à une terminologie abondante. Cela montre que l'analyse de l'adaptabilité et de ses implications pour la définition des stratégies d'adaptation dans le cadre des programmes de sélection et de recommandation variétale pour les services de développement pourrait seulement concerner les réponses des génotypes aux différents milieux, aux zones géographiques, aux pratiques culturales ou autres facteurs qui peuvent être contrôlés ou prédits avant le semis. Plusieurs auteurs ont ainsi développé de nombreuses techniques statistiques pour analyser l'interaction génotype x environnement. La régression linéaire ou conjointe a été développée par Yates et Cochran (1938), Finlay et Wilkinson (1963) et par Eberhart et Russell (1966). Les méthodes multivariées telles que l'analyse en composantes principales, la classification ascendante hiérarchique et les techniques de regroupement des essais variétaux ont été également utilisées pour analyser l'adaptabilité des variétés dans les programmes de sélection. Crossa *et al.* (1990) ont utilisé le modèle multiplicatif (AMMI) dans l'analyse d'essais internationaux de variétés de maïs. Cette étude vise trois objectifs principaux : i) la définition de stratégies d'adaptation du matériel végétal dans le programme de sélection de variétés pour la culture irriguée en zone sahélienne, ii)la recommandation de variétés stables et performantes et enfin iii) l'identification optimale de sites spécifiques pouvant servir de lieux d'évaluation des variétés dans le cadre du programme de développement du maïs pour la culture irriguée en zone sahélienne.

Matériel et Méthodes

Choix du matériel végétal

Huit génotypes d'origines géographiques différentes ont été utilisés pour cette étude. Il s'agit de : Cimmyt Pool 1, tropical altitude précoce; Cimmyt Pool 12, tropical altitude tardif ; IRAT 143 tropical de plaine précoce ; X 304 C tropical de plaine tardif ; LG 11 tempéré de plaine précoce, Hélios (B73 x Mo17), tempéré de plaine tardif ; Early Thaï tropical intermédiaire et témoin station, vulgarisé et enfin IR 3O, hybride double tropical tardif originaire du Brésil.

Dispositif expérimental

Pour comprendre et analyser les effets des variations saisonnières des facteurs climatiques et des dates de semis sur la productivité du maïs, une expérimentation «date de semis mensuels» a été effectuée de Juillet 1990 à Août 1991 à la station expérimentale de Ndiol dans le delta du fleuve Sénégal.

La station est située à 4 m d'altitude et à 15°9 Nord de latitude. Les températures maximales s'observent en août - septembre (37 à 45°C); elles sont minimales en janvier - mars (9 à 10°C). Les variations thermiques sont cependant extrêmes : 9,5 à 45°C en mars - avril. La photopériode varie entre 11,3 h et 13,8 h. La figure 1 donne un aperçu de l'ensemble des conditions climatiques moyennes et mensuelles de la station expérimentale.

L'essai est en blocs complets randomisés avec deux répétitions. La parcelle élémentaire comprend 5 lignes de 3,5 m de long, les écartements sont de 80 cm entre les lignes et 25 cm entre les poquets, soit une densité optimale de 50 000 pieds /ha. Dix plants sont observés sur la ligne centrale de chaque parcelle. Tous les essais ont été semés

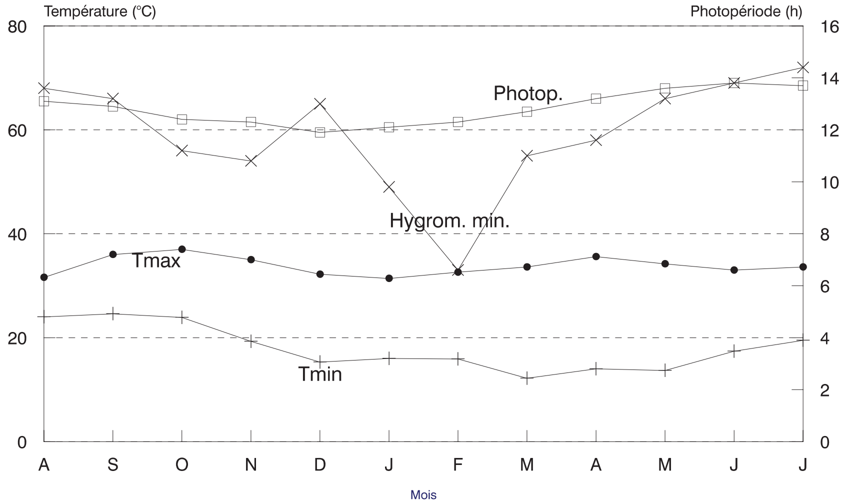


Figure 1: Variation des températures maximales, minimales moyennes et de la longueur du jour.

sur la même bande et ont reçu respectivement 300 kg/ha de N.P.K. (8.18.27) avant le semis, 150 kg/ha d'urée à la montaison et 150 kg/ha d'urée à la floraison. Le choix des caractères a été effectué de façon à ce qu'ils apportent le maximum d'informations sur la plante. Il s'agit des caractères agronomiques comme le rendement et la précocité et de la hauteur moyenne du plant.

Méthodes d'analyse

Analyse de variance selon le modèle interactif complet. Pour toutes les méthodes d'analyse proposées, les effets variétaux sont considérés comme aléatoires et les effets milieux fixes. L'analyse d'un réseau d'essais peut se réaliser, comme pour un essai par une analyse de variance. En effet, si des génotypes sont testés dans plusieurs milieux (dates de semis par exemple), il faut modifier le modèle de décomposition de la variation en introduisant un effet milieu et une interaction génotype x milieu (Comstock et Moll 1963).

Pour une parcelle ijk du génotype i dans le milieu j, nous pouvons alors écrire :

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_{jk} + \theta_{ij} + \varepsilon_{ijk}$$

où

Y_{ijk} est la valeur du génotype i dans le bloc de la date de semis j
μ est la moyenne générale
α_i est l'effet du génotype i, effet aléatoire, de variance
β_j est l'effet de la date de semis (milieu)
γ_{jk} est l'effet bloc k dans la date de semis j ;
θ_{ij} est l'interaction génotype x date de semis;
ε_{ijk} est la résiduelle au niveau de la parcelle ijk de variance σ^2_e .

Méthodes d’étude de la stabilité

La régression conjointe. L’utilisation de la technique de régression a été l’idée de Yates et Cochran (1938) que reprirent Finlay et Wilkinson (1963). L’idée consiste à établir une régression par variété de la performance dans les différents milieux sur la moyenne des variétés dans ces milieux. C’est donc la performance moyenne des variétés dans un milieu qui est prise pour caractériser ce milieu. Cette technique est connue sous le nom de régression linéaire conjointe dont le modèle de base consiste à décomposer l’interaction en une partie prédictible et une partie non-prédictible (Gallais 1990) :

$$(Gm)_{ij} = \beta_i \; m_j + d_{ij}$$

où

m_j est l’effet du milieu j (moyenne centrée de la performance de toutes les variétés).

β_i est le coefficient de régression de l’interaction sur l’effet milieu.

L’écovalence. Dans la situation de modèles à effets fixés pour caractériser le comportement d’un génotype dans différents milieux; Wricke (1962), cité par Gallais (1990), a introduit le paramètre d’écovalence défini au niveau des valeurs phénotypiques. Ce dernier exprime la contribution d’un génotype à la somme des carrés des écarts de l’interaction.

Ainsi pour un génotype i, l’écovalence équivaut à :

$$W_i = b\, \Sigma_j \,(P_{ij.} - P_{i..} - P_{.j.} + P_{...})$$

où

Pijk est la valeur phénotypique d’un individu k du génotype i, dans
la parcelle ij ;
Pi.. est la moyenne et est naturellement le prédicteur de la valeur
génotypique ;
P... remplace μ.

Cette quantité peut être divisée par la somme des carrés des écarts de l'interaction pour obtenir un paramètre "standardisé", variant entre 0 et 1. Un génotype à écovalence faible tend à réagir comme la moyenne des génotypes et donc à être stable.

Le modèle de régression factorielle. Le modèle général de régression factorielle décompose les effets principaux et l’interaction en régressions sur des covariables liées aux deux facteurs. L’objectif étant de comprendre les phénomènes biologiques responsables de l’interaction GE, l’étude se limitant ici à la décomposition de l’interaction.

L'espérance de la matrice de données X de dimensions (I, J) s'écrit (Denis pers. com) :

$$E(X_{ij}) = \Sigma_h \Sigma_k \; Y_{i(k)} \cdot \nu_{(k,h)} \cdot Z_{(h)j} + \Sigma_h \rho_{i(h)} .Z_{(h)j} + \Sigma_k Y_{i(k)} \cdot \tau_{(k)j}$$

Les indices h et k varient respectivement de 1 à H et de 1 à K. Ce modèle englobe les modèles linéaires précédemment décrits, du modèle additif au modèle de régression conjointe. En effet, si une seule covariable constante est associée à chaque facteur (H = K = 1) le modèle de régression factorielle revient au modèle additif (Denis pers. com):

$$E(X_{ij}) = 1.\mu.1 + \alpha_i.1 + 1.\beta_j$$

Le modèle multiplicative. L'application du modèle multiplicatif revient à effectuer une analyse en composantes principales (ACP) sur la matrice résiduelle du modèle additif (Rij) = R. La modélisation multiplicative de l'interaction ne tient pas en fait des paramètres définis par le modèle additif. Le modèle s'écrit :

$$E(X_{ij}) = \mu + \alpha_i + \beta_j + \Sigma_k \gamma_{i(k)} \cdot \theta_{(k)} \cdot \delta_{j(k)}$$

Les indices h et k varient respectivement de 1 à H et de 1 à K.
Les matrices de paramètres inconnues du modèle sont représentées par des lettres grecques tandis que les matrices de valeurs des covariables associées à chacun des facteurs sont connues à priori et représentées par des lettres latines. K et H sont respectivement les nombres de covariables associées au facteur génotype (K <= I) et au facteur environnement (H <= J).

Ce modèle englobe les modèles linéaires précédemment décrits, du modèle additif au modèle de régression conjointe. En effet, si une seule covariable constante est associée à chaque facteur (H = K = 1) le modèle de régression factorielle revient au modèle additif (Denis pers. com):

$$E(X_{ij}) = 1.\mu.1 + \alpha_i.1 + 1.\beta_j$$

Résultats et Discussion

Les résultats du tableau d'analyse de variance (Tableau 1) montrent des effets «génotypes» et des effets «date de semis» très hautement significatifs. L'interaction «génotype x date de semis» est aussi hautement significative pour tous les caractères notamment de la floraison femelle, de la hauteur du plant et du rendement.

L'étude de l'espérance des carrés moyens permet d'estimer la variation expliquée par les effets des génotypes ($\Sigma\alpha_i^2$ / g-1) et des dates de semis ($\Sigma\beta_j^2$ / d-1) d'une part, et par les effets d'interaction

Tableau 1. Analyse de variance selon le modèle interactif complet (Somme des carrés des écarts SCE).

Source	ddl	FF50	HMP	RDT
Génotype	7	9311.7 s***	24645 s***	9948 s***
Date de Semis	11	11309 s***	28712 s***	28641 s***
Bloc(date)	12	68.7 ns	5682 s**	1186 ns
G * D	77	1494.2 s***	21597 s*	13931 s***
Résiduelle	84	543.2	15282	4546

NB : Suite aux données manquantes, les ddl de la variance résiduelle de NRP, LAF, NGR PMGR et RDT sont respectivement égales à 79, 83, 82, et 67

Tableau 2. Variation expliquée par les génotypes et les dates de semis.

Effet	FF50	HMP	RDT
Génotype $[\Sigma\alpha_i^2 / g-1]$	55.1	139.1	56.3
Date semis $[\Sigma\beta_j^2 / t-1]$	63.8	151.7	158.4
Interaction $[\Sigma\theta_{ij} /(g-1)(t-1)$	6.5	49.2	56.5
σ^2	6.4	181.9	67.8

$(\Sigma\theta_{ij}^2 / (g-1)(d-1))$ d'autre part (g est le nombre de génotypes, d le nombre de date de semis). Ainsi les caractères dont l'effet environnemental est important sont très sensibles aux variations du milieu. Il s'agit de la floraison femelle, de la hauteur du plant et du rendement comme le montre le Tableau 2. Cet effet environnemental souvent très important peut être doublé d'une forte interaction génotype x date de semis comme pour les caractères de floraison mais il se trouve que quand l'erreur résiduelle σ^2 est importante par rapport à l'interaction, les effets d'interaction deviennent alors difficilement interprétables.

Effets «dates de semis»

L'analyse de la moyenne au niveau de chaque date de semis permet de caractériser la période et l'influence des facteurs environnementaux qui la caractérisent.

En effet, les dates de semis affectent de façon significative tous les caractères comme le rendement, la floraison femelle et la hauteur du plant. Les plus grandes variations inter-dates de semis sont obtenues avec les variables de précocité (FF50), de la hauteur du plant et du rendement et de ses composantes (cf. Tableau 3). Aussi la différence entre les valeurs extrêmes des caractères est de 29% pour la floraison femelle, de 29% pour la hauteur du plant et de 75% pour le rendement.

Tableau 3. Moyennes des caractères agronomiques.

Caractères Dates	FF50	HMP	RDT (q/ha) (15% Hum)
Août	52.6	129.8	14.5
Septembre	50.6	146.2	33.0
Octobre	58.0	156.2	34.0
Novembre	68.0	144.0	48.0
Décembre	70.2	152.5	56.0
Janvier	72.2	129.2	43.3
Février	68.3	150.3	34.2
Mars	67.7	144.3	49.0
Avril	63.0	155.4	46.0
Mai	58.9	139.3	27.0
Juin	53.2	143.4	23.0
Juillet	51.8	112.2	15.0

La tendance générale est en fait à la baisse des rendements aux semis de juin, juillet et août et à la hausse pour les semis de novembre-décembre et de mars-avril. Ces réductions et/ou ces augmentations sont le résultat des variations du rendement et de la durée du cycle suite aux variations des facteurs climatiques. Les semis de septembre et d'octobre d'une part, de janvier et de février d'autre part ont presque les mêmes potentialités de production : les premiers, favorisant la précocité, voient leurs cultivars fleurir et mûrir dans les conditions de températures favorables de novembre-décembre ; les seconds favorables à la tardivité sont perturbés durant la phase de floraison-maturation par les vents chauds et secs (harmattan) de février-début mars.

Les variétés précoces LG 11, Cimmyt Pool 1, Cimmyt Pool 12 et Early Thaï ont leur rendement maximal inférieur à 60 q/ha, contrairement aux variétés tardives Helios, IRAT 143 et IR 30 dont les rendements maxima sont supérieurs à 70 q/ha. La variété X 304C, à cause de sa tardivité, fleurit plus tard et connaît des problèmes de fécondation à certaines dates de semis, ce qui explique ses rendements souvent très faibles.

Etude de la stabilité des variétés

Avec la régression conjointe, chaque génotype peut être caractérisé, pour sa sensibilité aux conditions environnementales par ses paramètres de stabilité (moyenne, coefficient de régression et la déviation par rapport à la régression) d'une part et par son écovalence d'autre part. Le modèle de régression conjointe (Tableau 4) ne permettant pas d'expliquer de façon significative l'interaction "génotype x date de semis pour la floraison femelle et la hauteur du plant contrairement au rendement (environ 25% de la variation totale), l'écovalence génotypique a été retenue comme autre paramètre de stabilité.

Tableau 4. Tableau d'ANOVA du modèle de régression conjointe sur les différents caractères : $X_{ij} = \mu + \alpha_i + \beta_j + \rho_i . \beta_j + \varepsilon_{ij}$

Source	ddl	FF50	HMP	RDT
Effet génotype	7	4669***	12317**	5966***
Effet date	11	5670***	14369**	16167**
Interaction G*D inter.modélisée	77	748 s***	10788 s***	8096 s***
reste interaction	17	305 s*	2845 s*	3036 ns
	60	441	7942	5060

ns : non significatif à $P < 0.05$ * : significatif à $P < 0.05$
** : significatif à $P < 0.01$ *** : significatif à $P < 0.001$

Tableau 5. Ecovalences génotypiques (W_i) des différents caractères.

Génotype	FF50	HMP	RDT
Caractère			
Cimmyt Pool 1			
Wi	136	1455	777
Cimmyt Pool 12			
Wi	60	1954	837
IRAT 143			
Wi	58	1201	512
X 304 C			
Wi	164	1341	969
LG 11			
Wi	135	1275	751
Hélios			
Wi	73	1246	1489
Early Thaï			
Wi	76	846	667
IR 30			
Wi	79	1579	1215

Selon Finlay - Wilkinson (1963), on peut noter :
Pour le rendement, les génotypes de plaine précoces à intermédiaires Cimmyt Pool 1, LG 11, Early Thaï et IRAT 143 sont les plus stables car ayant des écovalences relativement faibles. On observe en général, que les plus fortes interactions (en valeur absolue) sont positives. Par contre, les génotypes Cimmyt Pool 12, X 304 C, Helios et IR 30 ayant des écovalences souvent importantes sont moins stables que la moyenne et ont une adaptabilité dite spécifique. Ils sont plus productifs quand les conditions environnementales sont favorables (cf. Tableau 5).

Dans l'optique de caractérisation des dates de semis, l'écovalence environnementale W_j représentant la participation de chaque milieu j à la somme des carrés des écarts (SCER) du modèle additif a été calculée. Elle se définit de la manière suivante :

$$W_j = \Sigma i(X_{ij} - X_{i.} - X_{.j} + X_{..})^2$$

Tableau 6. Table d'ANOVA du modèle de régression factorielle faisant intervenir la température et la photopériode comme covariables environnementales sur la variabilité des caractères:

$E(X_{ij}) = \mu + \alpha_i + \Sigma_{h=1,2} \cdot Z_{(h)j} + \beta'_j + \Sigma_{h=1,2}\, \rho_{i(h)} \cdot Z_{(h)j} + \varepsilon_{ij}$

Source	ddl	FF50	HMP	RDT
Effet génotype	7	4669 s***	12317 s***	5966 s***
Effet date semis	11	5670 s***	14368 s***	16166 s***
reg.Température	1	3961 s***	174 ns	5290 s***
reg.Photopériode	1	1096 s***	1155 s***	4614 s***
reste	9	613 s***	13040 s***	6263 s***
Interaction G x D	77	748 s***	10788 s***	8094 s***
résid.Température	7	147 s***	1099 s***	382 ns
résid.Photopériode	7	105 s**	1054 s*	607 ns
reste interaction	63	494	8635	7105

ns : non significatif à $P < 0.05$ * : significatif à $P < 0.05$

** : significatif à $P < 0.01$ *** : significatif à $P < 0.001$

β'_j est le résidu par rapport aux régressions

Pour le rendement, les dates de semis à écovalence importante sont le mois de septembre, de novembre, de mars et d'avril. Ces dates de semis correspondent aux meilleures dates mis à part le semis de septembre dont l'écovalence forte est due au fait que les variétés stables y ont des rendements généralement inférieurs à la moyenne calculée d'une part et d'autre part les variétés à adaptabilité spécifique y trouvent les conditions pour donner souvent de bons rendements. C'est le cas de IRAT143 et de Hélios.

La régression factorielle

Les résultats de l'analyse de régression factorielle faisant intervenir la température et la photopériode comme les covariables environnementales sur la variation des caractères figurent au Tableau 6.

La régression sur la covariable "température" est très hautement significative pour la floraison femelle et le rendement. Egalement, la régression sur la photopériode est aussi très hautement significative pour les mêmes caractères énumérés ci-dessus. Par ailleurs, les résultats de l'analyse de variance du modèle de régression factorielle, faisant intervenir les paramètres additifs du délai semis-floraison βi et βj comme covariables génotypique Y et environnementale Z sur la variabilité du rendement permettent de mettre en évidence l'effet

Tableau 7. Table d'ANOVA du modèle de régression factorielle faisant intervenir les paramètres additifs du délai semis-floraison α_i et β_j comme covariables génotypiques Y et environne-mentale Z sur la variabilité du rendement.

Source	SCE	ddl	C. M	F	P
Effet génotype	5966.0	7	852.2		0.000***
régres.par Y	1503.5	1	1503.5	15.0	0.000***
reste	4462.3	6	743.7	7.4	0.000***
Effet date de semis	16166.0	11	1470.0		0.000***
régres.par Z	10311.2	1	10311.2	102.6	0.000***
reste	5855.5	10	585.5	5.8	0.000***
Interaction	8096.0	77	105.1		0.000***
rég.sur Y	1642.2	10	164.2	1.6	0.11ns
rég..sur Z	425.9	6	70.9	1.2	0.307ns
rég. par Z . Y	0.06	1	0.06	0.0	ns
reste interaction	6027.6	60	100.5		

significatif de la date de semis et de la date de floraison sur la productivité des variétés. Ainsi, les paramètres additifs Y et Z expliquent environ 85 % de la variabilité du rendement (Tableau 7).

En somme, si les covariables "température et photopériode" expliquent de façon significative les variations de l'effet principal "date de semis" pour tous les caractères (89% pour la floraison par exemple), l'interaction G * D est souvent mal expliquée par leurs régressions résiduelles respectives (un maximum de 34% pour la floraison) notamment pour le rendement.

Le modèle multiplicatif

Les résultats du modèle multiplicatif à deux termes (TM1 et TM2) sont représentés dans le Tableau 8.

Le premier terme TM1 est hautement significatif pour tous les caractères notamment pour la floraison et pour le rendement et ses composantes alors que le second terme TM2 est également significatif pour les mêmes caractères. Au total, les deux termes multiplicatifs expliquent 71% de l'interaction pour la floraison, 61% pour la hauteur du plant et enfin 71% pour le rendement.

Le principe de la modélisation multiplicative de l'interaction étant similaire à celui de l'Analyse en Composantes Principales (ACP) appliquée au terme d'interaction R_{ij}, une représentation graphique des génotypes et des dates de semis en fonction des termes multiplicatifs TM1 et TM2 a été effectuée. Trois groupes de variétés peuvent être mis en évidence en fonction de leurs potentialités selon les dates de semis qui seraient assimilables à des domaines de recommandation (Fig. 2) :

Tableau 8. Table d'ANOVA du modèle multiplicatif avec deux termes sur les différents caractères: $X_{ij} = \mu + \alpha_i + \beta_j + \Sigma_{m=1,2}\, \gamma_{i(m)} \cdot \theta_{(m)} \cdot \delta_{j(m)}$

Source	ddl	FF50	HMP	RDT
Effet génotypique (αi)	7	4669 s***	12317 s***	5966 s***
Effet date (βj)	11	5670 s***	14369 s***	16166 s***
Rij	77	748	10788	8096
θ1 . γ1i . δ1j	17	343 s***	3808 s**	3117 s***
θ2 . γ2i . δ2j	15	190 s**	2782 s*	2692 s***
Résid. pure	45	214	4199	2286

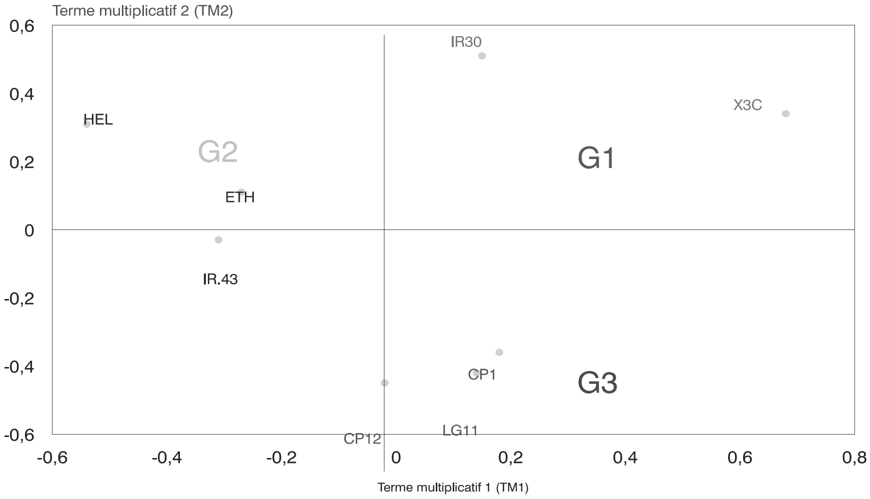
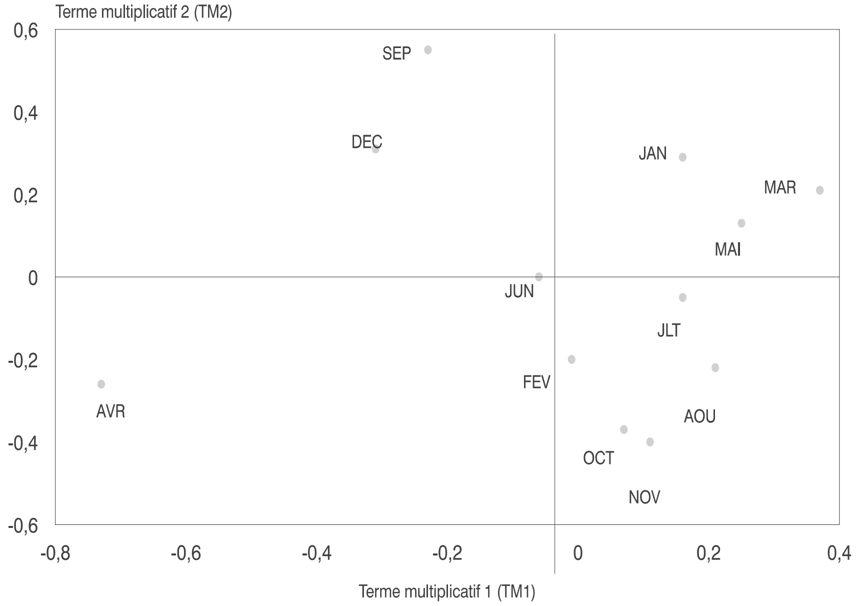


Figure 2: Représentation des génotypes en fonction des paramètres multiplicatifs TM1 et TM2 du rendement.

- le groupe G1 avec les cultivars tropicaux de plaine tardifs X 304 C et IR 30 à très haut potentiel de production ; leurs meilleurs rendements sont obtenus pendant les semis de septembre, de décembre et de janvier.
- le groupe G2, avec un potentiel moyen, comprend les génotypes tropicaux intermédiaires Early Thaï, IRAT 143 et le tempéré tardif Helios ; ces derniers ont donné des rendements élevés au semis d'avril.
- enfin le groupe G3 à faible potentiel de production comprend les génotypes précoces Cimmyt Pool 1, Cimmyt Pool 12 et LG 11 avec des rendements moyens en octobre et en novembre.

La représentation des dates de semis en fonction des termes multiplicatifs (Fig. 3) ne permet pas d'établir une typologie claire des lieux ou domaines de recommandation. Seul l'axe 1 permet de mettre en relation le semis d'avril et le comportement des variétés Hélios, Early Thaï et IRAT 143.



Variable: rendement/ha

Figure 3: Représentation des dates de semis en fonction des termes multiplicatifs.

Conclusion

L'interaction observée sur le rendement serait due à un allongement du cycle des génotypes pendant les périodes relativement fraîches et aux photopériodes courtes.

La représentation graphique des génotypes et des dates de semis en fonction des termes multiplicatifs (cf. Fig. 2 et 3) a permis de distinguer trois groupes de génotypes différentiables par la durée de leur cycle et de leur potentiel de production.

L'interaction génotype x date de semis rendant impossible toute généralisation, deux stratégies apparemment contradictoires sont envisageables :

(1) Rechercher des variétés ayant une bonne adaptation générale, ce qui a pour corollaire une certaine limitation de leur performance. C'est le cas des variétés IRAT 143 LG11, Early Thaï et IR 30 qui ont des écovalences relativement faibles.

(2) Rechercher des variétés spécifiquement adaptées à des saisons particulières, ce qui permet le plus souvent d'obtenir les meilleures performances au prix d'une spécialisation souvent très stricte. Dans cette optique, on peut citer les variétés tropicales IRAT 143, IR30, Early Thaï et la variété tempérée tardive Hélios pour la saison froide (semis de novembre-décembre) et les variétés Early Thaï, X304 C et IR 30 pour la saison chaude (semis de mars-avril). Cependant les potentialités de ces variétés sont plus importantes en saison froide qu'en saison chaude. Cette

seconde stratégie répond bien aux objectifs de systématisation de la double culture dans la vallée des fleuves du Sahel en général et du Sénégal en particulier pour l'augmentation de la productivité dans le cadre de la sécurité alimentaire.

Les modèles obtenus peuvent s'appliquer à différents domaines :

En amélioration variétale

Une application directe et pratique de cette étude pourrait aussi se faire dans les recommandations variétales au niveau des environnements tropicaux. Des hybrides variétaux ou non conventionnels entre populations tropicales et tempérées donnent souvent des rendements meilleurs que le matériel tempéré x tempéré ou tropical x tropical, impliquant la présence d'hétérosis sur le rendement dans différents régimes de température.

Dans l'optimisation du calendrier cultural

Des recommandations en matière de date de semis du maïs pourraient être faites en se référant ainsi aux températures et à la durée du jour :

- les dates de semis favorisant l'allongement du délai semis-floraison, donc la tardivité, seraient responsables de l'essentiel de l'interaction G * D du fait que la variabilité de l'interaction est d'autant plus importante que la floraison est tardive. C'est le cas des semis de novembre, de décembre, de janvier, de février, de mars et d'avril ;

- les dates de semis favorisant la réduction du délai semis-floraison donc la précocité ont des écovalences relativement faibles et des paramètres additifs environnementaux négatifs. C'est le cas des semis de mai, de juin, de juillet, de septembre et d'octobre.

Sur cette base, les dates de semis optimales à recommander dans le cadre de la systématisation de la double maïsiculture correspondent à :

- la période de novembre-décembre pour la saison froide, avec des variétés telles que IRAT 143, Helios, Early Thaï et IR 30 ;
- la période de mars-avril pour la saison chaude avec presque les mêmes cultivars mais avec une baisse de 15 à 20% du rendement moyen selon les variétés par rapport à la saison précédente.

Le développement d'irrigation en zone tropicale faciliterait ainsi l'augmentation de la production grâce au respect des dates de semis recommandées. Une application directe de cette étude pourrait être des recommandations de variétés dans les environnements agroclimatiques tropicaux.

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Section 3

Integrated Pest Management

Present status of maize diseases in the humid forest and western highlands of Cameroon

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Abstract

Maize disease surveys were conducted between 1995 and 2004 in the Republic of Cameroon. A total of 260 farms in 36 villages, ranging from low altitudes with bimodal rainfall distribution to high altitudes with monomodal rainfall, were included in the surveys. In the humid forest, *Bipolaris maydis* and *Puccinia polysora* were the prevalent fungi with a mean incidence of 70% in 1995 and 44% in 2004. *Rhizoctonia solani, Stenocarpella macrospora,* and *Physoderma maydis* occurred at low incidence levels in all the villages. In the western highlands, *Exserohilum turcicum* and *Cercospora zeae-maydis* were the prevalent pathogens, with incidence ranging from 16% to 100% in 1995–1998. In 2004, the mean incidence for the pathogens ranged from 30 to 95%. *Phaeosphaeria maydis*, the most severe pathogen (incidence=70%) in 1995, has been displaced by *Cercospora zeae-maydis* (incidence=60%). The incidences of *Sporisorium reilianum* and *Puccinia sorghi* were about 5% in 1998; in 2004, the incidence of *S. reilianum* had increased to 20%. In many of the farms surveyed, most of these diseases occurred in association. There was a positive correlation between incidence of *Puccinia polysora* and that of *Bipolaris maydis* in the humid forest. *Phaeosphaeria* leaf spot was negatively correlated with *C. zeae-maydis* and *E. turcicum* in the western highlands. Although some diseases were prevalent in specific ecological niches, *E. turcicum* was found in both highlands and lowlands but with low incidence in the latter areas. *Fusarium, Aspergillus* species and *Diplodia maydis* were the most important mycotoxin-producing fungi that caused ear rots in the western highlands in 2004.

Résumé

Des enquêtes sur les maladies du maïs ont été conduites entre 1995 et 2004 en république du Cameroun. Au total 260 champs dans 36 villages de zones à basse altitude et de pluviometrie bimodale à des zones de haute altitude à pluviometrie monomodale sont inclus dans les enquêtes. Dans les zones de forêt humides, *Bipolaris maydis* et *Puccinia polysora* étaient les champignons les plus courants avec une incidence moyenne de 70 et 44% en 1995 et 2004 respectivement. *Rhizoctonia solani, Stenocarpella macrospora,* et *Physoderma maydis,* ont été enregistrés dans tous les villages avec un faible taux d'incidence. Dans les montagnes à l'ouest, *Exserohilum turcicum* et *Cercospora zeae-maydis* étaient les pathogènes les plus courants, avec une incidence variant de 16 à 100 % en 1995-1998. En 2004, l'incidence moyenne enregistrée variait de 30 à 95% pour les pathogènes. *Phaeosphaeria maydis,* la pathogène le plus sévère (incidence=70%) en 1995, a été remplacée par *Cercospora zeae-maydis* (Incidence=60%). L'incidence de *Sporisorium reilianum* et de *Puccinia sorghi* était de près 5% en 1998. En 2004 l'incidence de *Sporisorium reilianum* était de 20%. La plupart de ces maladies surviennent en association dans plusieurs des champs enquêtés. Il y avait une correlation positive des incidences entre *Puccinia polysora* et *Bipolaris maydis* dans la forêt humide. *Phaeosphaeria*, tache des feuilles, était négativement corrélé à *C. zeae-maydis* et *E. turcicum* dans les montagnes de l'ouest. Bien que certaines maladies étaient spécifiques à leurs niches écologiques, *E. turcicum* a été trouvé aussi bien dans les montagnes que sur les plateaux, mais avec une faible incidence sur les plateaux. Les espèces *Fusarium, Aspergillus* et *Diplodia maydis* étaient les champignons les plus importants produisant des mycotoxines qui provoquent des pourritures de racines dans les montagnes de l'ouest en 2004.

Introduction

Maize (*Zea mays* L.) is one of the most important food crops grown in Cameroon. After the Communauté Financière Africaine (CFA) currency was devaluated in 1994, the area under maize cultivation increased from about 700,000 ha in 1996 to 1,000,000 ha in 2004 (MINAGRI 1996; FAO 2004). Maize is cultivated in all five ecological zones of the country but mostly in the Western Highlands (WHL) where it constitutes the staple diet for about 80% of the population. Originally, maize was a subsistence crop but with time, it has become as commercially important as cocoa (*Theobroma cacao* L.) and coffee (*Caffea* sp.), with local industries as the main markets. Although national average yield of maize has been about 1.5 t/ha for many years (NCRE 1994), the total national annual production has increased from 500,000 t in 1991 to over 1,000,000 t in 2004 (FAO 2004) due to expansion of the area under cultivation. The annual production would be higher if the constraints were eliminated or minimized. Some of the constraints militating against full expression of the yield potential of the improved varieties released so far are low soil fertility, poor crop management practices, high cost of production inputs, abiotic stresses, pests and diseases. Cardwell *et al.* (1997) showed that losses due to pests and diseases ranged from 20 to 50% and in the specific case of the grey leaf spot disease, grain yield losses of 90% or more have been reported in several parts of the country (MINAGRI 1996).

In 1995, countrywide baseline field surveys were conducted with more emphasis on the humid forest (HF) and western highlands (WHL) to provide basic data on the time, locations and field conditions under which maize losses caused by pests and diseases occurred.

In 2004, another survey was undertaken in the western highlands of Cameroon (West and North-West). The primary objectives of the study were to (i) obtain a more detailed assessment of the relative importance of the most prevalent diseases in ecological zones with high disease pressures (ear rots) identified during the previous surveys, and (ii) identify the locations with reliably high disease pressure to be used in developing and testing Integrated Pest Management (IPM) technologies.

Materials and Methods

The agroecological zones

In the HF, which is dominated by primary and secondary forests, maize does not constitute the staple food of the population. Shifting cultivation is the predominant farming system and maize is produced in small areas (<0.25 ha) of newly cleared fields. There are two cropping seasons; the main one from March to July, and the minor one from September to November. The two seasons are separated by a short dry spell in August.

The WHL are mostly grassland with altitude ranging from 800 to 2 300 m above sea level. Two maize crops are possible during the long, uninterrupted cropping season from March to November. The length of the rainy season predisposes the WHL to soil fertility decline and heavy build-up of disease inoculum, which lead to primary and secondary infection of diseases. Maize production is intensive in these areas because the population is very dense (230 inhabitants/km^2), with an annual increase of 3.2%. Because of population pressure, farm size has been reducing and continuous cropping is gradually becoming a common farming practice.

Field surveys

Field surveys were conducted in June of 1995, 1996 and 1997. The 1995 survey was conducted in four HF villages (Nkometou, Ngat, Etoud, and Mvoutessi III). In 1996, the survey was repeated in three of the HF villages (Nkometou, Ngat, and Etoud) and three WHL villages (Bamunka, Bali, and Njinikom). In 1997, the survey was repeated in the same WHL villages. Thus, in each of the two ecologies, three villages were surveyed for two consecutive years. In each village 12 farmers were selected at random with the assistance of the extension agent of the locality. The survey team, which consisted of a plant pathologist and an entomologist, visited a total of 108 farmers' fields. In each farm, 15 maize plants at growth stages 6 to 9 as described by Hanway (1966) were chosen at random. Each plant was assessed for growth and damage.

Data on the following variables were recorded: cropping system; organic matter rating on a 1-3 scale (1= low, 2 = medium, 3= high); soil texture rating on a 1-3 scale (1= sandy, 3= clayey); weediness (1-3 scale: 1=clean and 3=very weedy); crop growth stage (1-9 scale: 1= emergence, 5=silking, 7=milk stage, 8=hard dough and 9=physiological maturity); stem diameter (determined by measuring the diameter of the second internode above the ground); percentage grain fill; % cob damage by fungi; width and length of cobs and weight of dehusked cobs. The disease data included the etiology and severity of infection (1-5 scale: 1=clean and 5=heavily infected plant) of at least the two most important diseases per plant. Leaf samples infected with highland blight [*Exserohilum turcicum* (Passerini) Leonard & Suggs], and lowland blight [*Bipolaris maydis* (Nisikado & Miyake) Shoemaker], were incubated on PDA for confirmation of the identity of the causative fungi. Symptoms of *Diplodia* leaf spot (*Stenocarpella macrospora* (Earle) Sutton = *Diplodia macrospora* Earle), common smut (*Ustilago maydis* DC), head smut [*Sporisorium reilianum* (Kühn) Langdon & Fullerton = *Sphacelotheca reiliana* (Kühn) Clint], *Phaeosphaeria* leaf spot [*Phaeosphaeria maydis* (P. Henn) Rane, Payak & Renfro], highland rust (*Puccinia sorghi* Schw.), lowland rust (*Puccinia polysora* Underw.), brown spot (*Physoderma maydis* Miyabe) and sheath blight (*Rhizoctonia solani* Kühn) were compared to those described in the *Compendium of Maize Diseases*. Grey leaf spot was identified according to Latterell & Rossi (1983). The disease incidence of each location consisted of the total number of infected plants per location over 180 plants. Fungal stem infections and proportion of total leaf area infected (% LAI) with diseases were calculated according to Clive (1971). The general phytosanitary condition of the field was also assessed and incidence of diseases that prevailed on maize plants other than those sampled was recorded. In this paper, only the data on disease distribution and the relationships between them, combined and analysed across years, are presented.

In 2004, the survey was planned for all the political Divisions of the two Provinces of the WHL. In each Division, 4 villages were chosen for investigation; in each village 4 fields were selected at random and in each field, about 50 plants were checked for disease infection in a V-turn shape with 25 plants in each branch. Unfortunately, data from only 80 farms in 21 villages were available for analysis.

In the survey, the incidence (%) and severity (1-5 scale) of the four most prevalent diseases were recorded. Data were also obtained on the crop characteristics (improved or local variety), the soil fertility (1-3 scale), soil types, the level of organic manure in the field (1-3 scale), the cropping pattern (mixed or sole crop) and the effects of pests. Diseased plant samples were collected for identification when necessary or for the herbarium.

Data analysis

Analysis was carried out with the Statistical Analysis System (SAS) package. Mean disease severity expressed as percent leaf area infected (%LAI) and individual disease frequency expressed as the number of infected plants/ total number of plants (180) investigated were computed per village. Correlation coefficients were computed to determine the relationships between disease variables. Prior to data analysis all percentage data were subjected to arcsine transformation. Data were analysed separately for each location each year; locations and years were then compared.

Results

Humid Forest

In general, disease incidence (Table 1) varied with location and year. Five major leaf diseases of maize were recorded in 1995 and 2004 in the HF. *Bipolaris maydis* and *P. polysora* (PlateII) were the most frequent in all the villages in both years. In 1995, 2004, incidence of lowland blight caused by *B. maydis* was 38% in Etoud. By 2004, the level of infection had increased to 81.8%. This pattern also occurred in Ngat where 80% incidence of the pathogen was recorded in 2004 compared with 65% in 1995. No significant change in disease incidence was found in Nkometou and the levels were high in both years (>70%). *P. polysora* was recorded mostly in the HF with the highest incidence of 59% recorded in Etoud in 2004 relative to 49% in 1995. *Exserohilum turcicum* was recorded at low incidences ranging from 0 to 18% in all the villages in both years (Table 1). The incidence of sheath blight caused by *Rhizoctonia solani* was moderate across the locations, with the highest incidence (21%) recorded in Ngat in 2004. *Stenocarpella*

Table 1. Mean incidence[+] of individual maize pathogens in the HF of Cameroon in 1995 and 2004.

Pathogens	Locations							
	Nkometou		Etoud		Ngat		Mvoutessi	
	95	04	95	04	95	04	95*	Mean
B. maydis	74.5	71.9	38.0	81.8	65.2	80.0	77.0	69.8
P. polysora	12.7	51.1	49.3	58.8	39.3	50.3	49.1	44.4
R. solani	11.5	2.2	4.7	17.0	11.9	21.2	13.3	11.7
E. turcicum	10.9	0.0	18.0	0.0	0.0	17.6	0.0	6.9
S. macrospora	3.0	18.5	4.7	21.2	13.3	10.9	13.3	12.1

[+] Mean incidence = total number of plants infected out of 180 plants per location.
Data for *Physoderma maydis* and *Ustilago maydis* are not shown because they were rarely recorded.
B = Bipolaris; *P = Puccinia*; *R = Rhizoctonia*; *E = Exserohilum; S. = Stenocarpella*
*Data were collected only in 1995.

Table 2. Mean disease severity ratings (1-5 scale)[+] and leaf area infected (LAI) of maize pathogens in the HF of Cameroon in 1995–2004.

Pathogens	Locations							
	Nkometou		Etoud		Ngat		Mvoutessi	
	95	04	95	04	95	04	95*	Mean
B. maydis	1.2a	1.0b	1.4a	1.2b	1.0a	1.3b	1.0	1.2
P. polysora	1.3a	1.9b	2.2a	1.9a	1.9a	1.8a	1.9	1.8
R. solani	2.6a	2.3a	1.7a	2.7b	2.4a	2.5a	2.8	2.4
E. turcicum	1.3a	1.0a	1.4a	1.1b	1.0a	1.3b	1.0	1.2
S. macrospora	1.1a	1.3b	1.1a	1.4a	1.2a	1.2a	1.3	1.2
LAI	11.7a	10.6b	11.0a	10.1b	7.4a	11.3b	17.7	11.4

[+] Means followed by the same letter in rows within locations are not significantly different ($P > 0.05$)
B=Bipolaris; P=Puccinia; R=Rhizoctonia; E=Exserohilum; S=Stenocarpella LAI=leaf area infected
*Data were collected only in 1995.

macrospora was found in all the locations. The highest incidence (21%) was recorded in Etoud in 2004. *Physoderma maydis* was recorded sporadically in less than 30% of the sites, and incidence in farmers' fields outside the survey area was about 10% (data not shown). Incidence of *Ustilago maydis* was also low, only about 2%.

Disease severity was moderate in all locations with approximately 10% total LAI in most locations (Table 2). The highest LAI of 17.7% was recorded in Mvoutessi in 1995. Significant differences in LAI were found between years in Nkometou, Etoud and Ngat.

Rhizoctonia solani had the highest disease severity (1.2-2.7) in all locations in 1995 and 2004 (Table 2). Significant difference between years was recorded only in Etoud (Table 2). The highest *P. polysora* severity (2.2) was recorded in Etoud in 1995, with no difference between years except in Nkometou. *Stenocarpella macrospora* was recorded in all the locations, with the highest severity (1.4) recorded in Etoud in 1995, but there was no incidence of the disease in 2004.

Significant correlation coefficients were found between individual pathogens and LAI in the HF in 1995. *Exserohilum turcicum* (*P*=0.001), *S. macrospora* (*P*=0.01), *and P. polysora* (*P*=0.01) had significant positive correlation with LAI (Table 3). A weak positive relationship was found between the LAI of *P. polysora* and that of *B. maydis* whereas *B. maydis* and *R. solani* had significant (*P*=0.001) negative correlation with LAI of *E. turcicum* (Table 3). In 2004 in the HF, all the pathogens had significant positive correlation coefficients with LAI (*P*=0.001) (Table 4). LAI of *B. maydis* and *S. macrospora* had significant negative correlation with those of *E. turcicum* (*P*=0.01). The physiological spots, *B. maydis* and *P. polysora,* were positively correlated with maize streak virus (MSV) disease rating. *Exserohilum turcicum* was negatively correlated with *B. maydis, S. macrospora* and *P. polysora* (Table 4).

Western Highlands

In the WHL, six important diseases were recorded in 1995 and 2004 (Table 5). Highland blight incited by *E. turcicum* was found in all the fields. The incidence varied from 16% in Bali to 100% in Bamunka in 2004. Disease severity was high in 2004 (severity >3.5 on a 1-5 scale) in Bali and Njinikom (Table 6). The difference in disease severity rating between years was not significant in Njinikom but the severity declined significantly (*P*<0.05) between 1995 and 2004 in Bali (Table 6).

Grey leaf spot caused by *Cercospora zeae-maydis* occurred only in the WHL with high incidence and severity in both years. Over 33% incidence was recorded in all the villages with 90% incidence in Njinikom in 1995 (Table 5). Across villages and years, mean severity rating was 3.4 (Table 6). *Physoderma maydis* occurred in all locations with highest severity in Bali in the two years. *Stenocarpella macrospora* was rarely observed in Bali in 1995 and Bamunka in 2004. *Phaeosphaeria maydis* was found in >30% of the fields in Bali and Bamunka in 2004. Both years, it had low incidence in Njinikom (Table 5). In all locations, the severity was significantly (*P*<0.05) higher in 2004 than in 1995 (Table 6).

Common smut, incited by *Ustilago maydis,* had very low incidence (1%) in all locations (data not shown), although higher incidences were observed in some roadside fields not included in the survey. Head smut caused by *S. reilianum* had approximately 5% incidence in Njinikom and Bali (data not shown). The highland rust (*Puccinia sorghi*) was found at a very low infection rate mainly in Bamunka and Njinikom (data not shown).

In 1995, only *C. zeae-maydis* and *E. turcicum* prevailed in the fields in the WHL and both had significant (*P*=0.001) positive correlation with LAI (Table 7). *Cercospora zeae-maydis* was also positively correlated with *E. turcicum*.

Table 3. Correlation matrix between leaf area infected (LAI) and individual pathogens in the HF of Cameroon in 1995–2004.

	LAI	Et	Rs	Bm	Sm	Pp
LAI	*1.00*					
E. turcicum	0.21***	1.00				
R. solani	*-0.40****	*-0.04*	*1.00*			
B. maydis	*-0.41****	*-0.21***	*-0.15***	*1.00*		
S. macrospora	0.02**	-0.03**	-0.07	-0.06**	1.00	
P. polysora	0.25**	0.03	-0.03*	0.22*	-0.14**	1.00

Et= *Exserohilum turcicum;* Rs =*Rhizoctonia solani*; Bm =*Bipolaris maydis*;
Sm= *Stenocarpella macrospora;* Pp = *Puccinia polysora*
E= Exserohilum; R= Rhizoctonia; B= Bipolaris; S= Stenocarpella; P= Puccinia
*, **, ***Significant F-test at 0.05, 0.01 and 0.001 levels of probability.

Table 4. Correlation matrix between leaf area infected (LAI) and individual pathogens in the WHL zone of Cameroon, 1995–2004.

	LAI	Et	Rs	Bm	Sm	Pp	MVS	P	Pspt
LAI	1.00								
E. turcicum	0.08***	1.00							
R. solani	0.26***	-0.06	1.00						
B. maydis	0.39***	-0.18**	-0.04***	1.00					
S. macrospora	0.12***	-0.03**	0.01*	-0.15	1.00				
P. polysora	0.52***	-0.04	0.06***	-0.06	-0.13***	1.00			
MSV	0.42***	0.12**	0.08	0.11***	0.11**	0.19***	1.00		
Phy. maydis	0.03**	-0.04	-0.02***	0.06***	-0.09***	-0.04**	-0.07**	1.00	
Pspt	0.28**	-0.03**	0.06***	0.09***	-0.05**	0.13	0.09***	0.07**	1.0

Et =Exserohilum turcicum; Rs =Rhizoctonia solani; *Bm =Bipolaris maydis*; *Sm =Stenocarpella macrospora;*
Pp = Puccinia polysora; MSV= maize streak virus; Pspt =physiological spot.
E= Exserohilum; R= Rhizoctonia; B= Bipolaris; S= Stenocarpella
P= Puccinia; Phy= Physoderma
*, **, ***Significant at 0.05, 0.01 and 0.001 levels of probability.

Table 5. Incidences* of individual maize pathogens in the WHL of Cameroon in 1995–2004.

	Bali		Njinikom		Bamunka		
	95	04	95	04	95	04	Mean
E. turcicum	3.8	16.7	64.3	65.0	51.4	100.00	50.2
C. zeae maydis	4.3	33.6	71.4	90.5	68.6	84.0	58.7
Phy. maydis	0.0	27.8	0.0	27.8	0.0	33.00	14.8
Stem disease	*3.8*	*1.5*	*4.3*	*7.5*	*10.0*	*5.00*	*5.4*
Pha. maydis	0.0	33.3	1.6	3.6	0.0	33.00	11.9
S. maydis	0.0	0.0	0.0	0.0	0.0	13.90	2.3

*Mean incidence = total number of plants infected out of 180 plants per location
E= Exserohilum; C= Cercospora; Phy. = Physoderma; Pha. = Phaeosphaeria;
S= Stenocarpella.

Table 6. Mean disease severity ratings (1-5 scale)* and leaf area infected (LAI) by maize pathogens in the WHL of Cameroon in 1995 and 2004.

Pathogens	Locations						
	Bali		Njinikom		Bamunka		
	95	04	95	04	95	04	Mean
E. turcicum	*3.5a*	*2.3b*	*3.6a*	*3.3a*	*3.0a*	*2.8a*	*3.1*
C. zeae-maydis	*3.5a*	*3.5a*	*3.1a*	*3.9b*	*3.6a*	*2.6b*	*3.4*
Phy. maydis	1.9a	2.9b	1.0a	2.2b	1.0a	2.6a	1.9
Stem disease	*1.0a*	*1.6b*	*1.1a*	*1.6b*	*1.2a*	*1.9a*	*1.4*
Pha. maydis	1.0a	2.1b	1.0a	2.5b	1.0a	2.1a	1.6
S.macrospora	0.7	-	-	-	-	0.6	-
LAI	18.9a	3.5b	18.2a	33.2b	12.8a	8.3b	15.8

*Means followed by the same letter in rows within location are not significantly different (*P*< 0.05).
E = Exserohilum; C = Cercospora; Phy. = Physoderma; Pha. = Phaeosphaeria S= Stenocarpella.
\- = not recorded.

Table 7. Correlation matrix between leaf area infected (LAI) and individual pathogens in the WHL of Cameroon in 1995.

	LAI	Cz	Et
LAI	1.00		
C. zeae-maydis	0.65***	1.00	
E. turcicum	0.39***	0.2***	1.00

Cz= *Cercospora zeae-maydis*; Et = *Exserohilum turcicum; C= Cercospora; E= Exserohilum*
*significant at *P*=0.05; ** significant at *P*=0.01, *** significant at *P*=0.001

In 2004, in the WHL, *E. turcicum*, *Phaeosphaeria maydis*, and *C. zeae-maydis* had significant (*P*=0.001) positive, and *S. macrospora* significant (*P*=0.01) negative correlation coefficients with LAI (Table 8). Negative correlations existed between *E. turcicum* and *S. macrospora* and *C. zeae-maydis*, as well as between *C. zeae-maydis* and physiological spot and *Physoderma maydis,* but the former increased with *Phaeosphaeria maydis*. Ear rots (*Fusarium* ssp. and *Diplodia* spp.) were a serious threat to maize harvested late in the WHL in 2004 (Table 9).

Diseases recorded in 2004, were similar to those recorded the previous years with high incidence of ear and stalk rots due to *Fusarium* spp. and *Diplodia* spp., particularly in Noun (20%), Mifi (10%), and Menoua Division (10%).

Discussion

Detailed disease surveys conducted in different parts of Cameroon for selected years between 1995 and 2004 showed that *P. polysora, B. maydis* and *S. macrospora* were the most prevalent diseases in the HF while *C. zeae-maydis* and *E. turcicum* were the predominant maize diseases in the WHL. Generally, *P. polysora* was found more frequently

Table 8. Correlation matrix between leaf area infected (LAI) and individual pathogens in the WHL of Cameroon in 2004.

	LAI	*Et*	*Pha*	*Cz*	*Phy*	Pspt	*Sm*
LAI	1.00						
E. turcicum	0.63***	1.00					
Pha.maydis	0.44***	0.27***	1.00				
C. zeae-maydis	0.28***	-0.22*	0.16*	1.00			
Phy. maydis	0.11*	0.17	0.21	-0.34**	1.00		
Pspt	-0.08*	0.08	-0.11	-0.34**	0.23	1.00	
S. macrospora	-0.34**	-0.33***	-0.16	0.14	0.15	0.36	1.00

Et= Exserohilum turcicum; Pha = Phaeosphaeria maydis; Cz= *Cercospora zeae-maydis*
Phy =*Physoderma maydis; Pspt* =physiological spot; *Sm* =*Stenocarpella macrospora*
E= Exserohilum; Pha= Phaeosphaeria; C= Cercospora; Phy= Physoderma
S= Stenocarpella
* significant at *P*=0.05, **significant at *P*=0.01, and ***significant at *P*=0.001

Table 9. Distribution of maize ear rots in the WHL of Cameroon in 2004.

Diseases	Incidences (%)			
	Mifi	Noun	Mbiyeh	Bali
Fusarium *rots*	*25*	*20*	*15*	*10*
Diplodia rots	15	10	5	10

on mature leaves in all the locations of the HF. Although several earlier studies (Foko 1973; Praquin 1976; Timti 1980; Ngoko 1994; Cardwell *et al.* 1997) had reported the occurrence of many maize diseases in Cameroon, only a few were found with high incidence and severity in localized areas.

The severity of these diseases varied with years and locations. *Phaeosphaeria maydis*, which was reported to be important in 1993 with 80% prevalence in previous maize disease surveys (Ngoko 1994), was no longer found in 2004. This leaf spot was displaced almost entirely by grey leaf spot in the WHL. Though many diseases remained zone specific, highland blight was found in the HF, as had been noted previously in the zone (Buddenhagen 1985). This disease organism, therefore, appears to have spread out of its optimum environment, which, traditionally, is believed to be relatively cool, humid mid- and high altitudes. However, the disease was found at a low incidence and severity in the HF, unlike in the WHL.

Differences in the results of the maize disease surveys carried out in Cameroon may have been due to several factors. Several maize disease surveys conducted in the early stages utilized survey techniques that were different from one team to the other. Some were systematic with stops at regular intervals, others were carried out in randomly selected fields, or in localized fields and experimental research sites. Surveys carried out in the 1970s and 1980s were on a very small scale, while surveys carried out in the 1990s covered almost the entire country. Sample sizes and method of estimation of extent of damage also varied from one survey team to another.

Despite the differences associated with the surveys, certain definite trends in the dynamics of maize diseases have emerged for the country. From 1970 to 1997, several leaf, stem and ear diseases of maize were identified in Cameroon. The number of diseases and their levels of incidence and severity have varied during this period. *E. turcicum, S. reilianum*, and *P. polysora* have been found to occur consistently during this period, although their relative severity and importance have varied. In the WHL, *E. turcicum* appeared to be displaced by *Pha. maydis* in the early-to-mid 1990s (Ngoko 1991). After that period, Ngoko (1994) noted that *Pha. maydis* was displaced by grey leaf spot. *Helminthosporium carbonum* Ullstrupp reported by Foko (1973) was not found in the 1990s (Ngoko 1991; 1994; Cardwell *et al.* 1997). While the incidence of highland blight is decreasing in the WHL, Ngoko (1994) found that head smut was becoming more important in the region. These phenomena could be the result of the introduction of maize varieties resistant to blight, whereas breeding for resistance to *S. reilianum* has not been conducted since the disappearance of cv. Z155, which was the only resistant variety available in the mid-1970s (Ayuk-Takem *et al.* 1982).

Grey leaf spot was one of the most important maize diseases in the WHL in both years. In earlier studies, the disease was not found at all in the WHL (Foko 1973; Timti 1980). Subsequently, Ngoko (1994) reported a low incidence of grey leaf spot while Cardwell *et al.* (1997) noted that in the western areas, it became more prevalent as organic matter decreased. This disease is displacing other foliar diseases such as *E. turcicum* and *Pha. maydis* in these areas. Considering the increasing importance of the disease, it has become a necessity to initiate a screening program for grey leaf spot in WHL.

Phaeosphaeria maydis, known in 1985 as a minor disease, was highly virulent in 1992–1993 (NCRE 1994). This disease, which was first reported in 1963 in the highlands of Mexico (Rane *et al.* 1965), was considered as a disease of highland maize. However, the disease has now been observed in Cameroon both in the highlands of Donga-Mantung Division (altitude > 1800 m a.s.l) and in the low altitude areas of Bali (<1000 m a.s.l). Rane *et al.* (1965) had earlier found this pathogen to be prevalent only in highland zones with altitudes of 2000 m a.s.l. and higher. Results of the surveys reported herein contradict these previous findings. This may be due to the evolution of new biotypes or races of the pathogens, which are adapted to different environmental conditions. More epidemiological and etiological investigations are needed to gain a thorough understanding of the dynamics of this organism on maize in the WHL of Cameroon.

Significant correlations were found between some diseases and LAI. In 1995 in the HF and 2004 in the WHL, the negative correlations of LAI with *R. solani* and *B. maydis, S. macrospora* and physiological spot suggested that despite the presence of these pathogens on the leaf surface, their effects may have been diluted by *E. turcicum,* which was negatively correlated with the pathogens. *E turcicum* and *P. polysora* were associated with leaf destruction. This pattern was not apparent in 2004, but *B. maydis, S. macrospora* and *P. polysora* were inversely correlated to *E. turcicum*. This relation suggested that while some disease organisms coexist in the same ecological areas, there are situations where better-adapted ones displace some others. Understanding the type of relationship may be beneficial for planning the most effective control strategies.

From the observations in 2004, it is clear that the incidence and severity of leaf diseases of maize have decreased significantly from the early 1990s. The National Cereals Research and Extension Project, a USAID-funded project, has released several maize varieties with resistance to these pathogens. Grey leaf spot, which was a minor problem in 1995, has taken the lead over *Phaeosphaeria* leaf spot and highland blight and today is a major leaf problem in all the maize producing areas of the WHL. These diseases have not been researched to any appreciable extent in Cameroon. In addition, ear rots have become a major problem to maize producers. The climatic changes (especially unpredictable rainfall), the post-harvest agricultural techniques (harvesting takes place during the peak rain period in the WHL), and the poor drying and storage conditions favour the infection of grains by several fungi and possible contamination by mycotoxins. These secondary metabolites are known to be public health problems in localities where maize is consumed as staple food.

Annual maize production in Cameroon has not increased at the expected rate. This is attributable to the technological packages released so far, which are probably inadequate, and the cost of inputs (Fajemisin 1985; NCRE 1994; Ngoko *et al.* 2002). Intensified food production has led to ineffective crop rotation or fallowing. Continuous maize cultivation in areas where several diseases are endemic contributes to pathogen build-up. Though the type of synergy that occurs among the different maize pathogens is not yet well elucidated, individual pathogens may cause less destruction on plants and plant parts compared to the association of several fungi (Cardwell *et al.* 1997). The association of several maize pathogens in the field needs to be further investigated to determine whether these fungi cause disease in succession and to what extent synergism occurs. Results of the present study, and those of earlier studies (Cardwell *et al.* 1997), have identified hot spots for major diseases where screening for resistance could take place without artificial inoculation. The use of resistant varieties and the IPM techniques are the most appropriate control strategies for resource-poor farmers.

With the high incidence and outbreaks of ear rots, and *C. zeae-maydis,* it has become necessary for plant breeders, in collaboration with plant pathologists, to initiate screening programs to identify resistance sources to these two pathogens in the WHL, the ecology with the greatest potential for increased maize production in Cameroon.

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Colonization of resistant and susceptible maize genotypes by the pink stem borer, *Sesamia calamistis* (Lepidoptera: Noctuidae)

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Abstract

The role of four colonizing responses (oviposition, larval arrest, larval establishment and larval feeding) of *Sesamia calamistis* (Lepidoptera: Noctuidae) in determining the resistance or susceptibility of eight genotypes of maize (*Zea mays* L.) was elucidated. Four resistant (S5 9-1, S5 11-1, S5 27-1 and S5 27-3), two moderately resistant (Tzmi 103 and Tzi 4001), and two susceptible (S5 20-2 and Tzmi 407) genotypes were used in the study. *S. calamistis* exhibited variable colonizing responses on the maize genotypes. The interaction of the responses was also considered in order to estimate the net resistance (determined by low responses reflecting non-preference or antixenosis) or susceptibility (characterized by higher responses that promote colonization) of one genotype in comparison to another. The profiles developed from the study showed that S5 9-1 had five responses in the very low to medium range, thus confirming its resistance to *S. calamistis*. On the contrary, S5 20-2 had a total of four responses in the medium to very high range, while Tzmi 407 had three responses in the medium to high range and were, therefore, truly susceptible. The profiles of the other genotypes fell between these two extremes.

Résumé

Cette étude a mis en évidence les mécanismes responsables de la résistance et la susceptibilité de huit génotypes de maïs par rapport au comportement de ponte des femelles, d'orientation (arrêt), d'établissement et d'alimentation des larves de *Sesamia calamistis*. Les trois groupes de génotypes suivants ont été étudiés: les résistants S5 9-1, S511-1, S5 27-1 et S5 27-3, les modérément résistants Tzmi 103 et Tzi 4001, et les susceptibles S5 20-2 et Tzmi 407. La réponse de l'insecte vis-à-vis d'un génotype était variable selon que tel comportement ou tel autre était concerné. Par ailleurs, la réponse de l'insecte pour un même comportement a varié d'un génotype à l'autre. Aussi, les interactions des différentes réponses ont-elles été prises en compte, afin de déterminer la résistance relative (caractérisée par des

faibles réactions qui indiquent la non-préférence ou l'antibiose) ou la susceptibilité relative (caractérisée par des fortes réactions qui facilitent la colonisation) d'un génotype comparativement à un autre. Un profil de l'ensemble des réactions à chaque génotype a été établi afin de permettre une meilleure compréhension des différents aspects de ces interactions. Les différents profiles ont montré que S5 9-1 a eu cing réponses allant de faibles à moyenne, ce qui indique une résistance de sa part vis-à-vis de *S. calamistis*. S5 20-2 au contraire, a eu une réponse très élevée, et trois réponses moyennes, tandis que Tzmi 407 en avait deux réponses moyenne, ce qui les rend très susceptibles vis-à-vis de cet insecte. Les profiles des autres génotypes se trouvaient entre ces deux extrêmes.

Introduction

Stem borers are one of the major constraints to maize (*Zea mays* L.) production in Africa. The most important and predominant borer species are *Chilo partellus* (Swinhoe), *Busseola fusca* (Fuller), *Sesamia calamistis* (Hmps.) and *Eldana saccharina* (Walker) (Usua 1968; Girling 1978; Kumar and Sampson 1982; Aroga 1987a, b; PNUD/FAO 1989; Cardwell *et al.* 1997). Strategies to reduce damage due to these pests have, in the past, relied mainly on the use of insecticides, which are usually expensive (Seshu Reddy 1983; Kfir 1990). In Africa, a large proportion of maize producers are small-scale subsistence farmers. For such farmers, it is not economically or logistically feasible to use synthetic insecticides. In addition, synthetic insecticides have harmful effects on human beings and cause environmental pollution. Air and water contamination, postharvest residues, lack of selectivity, and resurgence of resistant species are examples of adverse effects of using synthetic insecticides (CCE 1974). Therefore, more economically sustainable strategies to pest management, such as the use of insect resistant or tolerant genotypes, are being researched and developed.

Host-plant resistance is one of the most important components of the integrated pest management of the maize stem borers. Several genotypes resistant or tolerant to *C. partellus, E. saccharina* and *S. calamistis* have been developed (Bosque-Pérez *et al*. 1989; Bosque-Pérez and Mareck 1990; Kumar 1991; Ajala *et al*. 1995; IITA 2000). For instance, eight S5 lines have been reported as resistant and two others as susceptible to *S. calamistis* (IITA 2000). The criteria used for these classifications were leaf-feeding scores, dead hearts, stem tunnelling and the overall plant damage (Ajala and Saxena 1994; Ajala *et al*. 1995).

According to Saxena (1969, 1985) the insect's colonizing responses are part of the factors determining the level of genotypic resistance

Table 1. **Maize genotypes used to evaluate the colonizing responses of the pink borer, *Sesamia calamistis* to resistant and susceptible cultivars.**

S/No.	Lines	Status	Origin
1	S5 9-1	Resistant	IITA Ibadan
2	S5 11-1	Resistant	IITA Ibadan
3	S5 27-1	Resistant	IITA Ibadan
4	S5 27-3	Resistant	IITA Ibadan
5	Tzmi 103	Moderately resistant	IITA Ibadan
6	Tzi 4001	Moderately resistant	IITA Ibadan
7	S5 20-2	Susceptible	IITA Ibadan
8	Tzmi 407	Susceptible	IITA Ibadan

or susceptibility to the insect. The present study was an attempt to elucidate the role of certain colonizing responses in determining resistance or susceptibility of eight maize genotypes to *S. calamistis*. The colonizing responses measured included oviposition by the moths, larval 'arrest', larval establishment, larval feeding and nutrition (utilization of ingested food). Results of profiles developed for each genotype confirmed the resistance of S5 9-1 and the susceptibility of S5 20-2 and Tzmi 407.

Materials and Methods

The study was conducted at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria from September 2001 to February 2002. Insects for the study were obtained from a laboratory culture of *S. calamistis* maintained on an artificial diet. Eight maize genotypes were studied (Table 1) and the following parameters were measured:

Oviposition

(a) A choice situation. The genotypes were grown in a radial planting design to give each plant an equal chance to be selected for oviposition by the moths. The plants were enclosed in a cage (2 m x 2 m x 2.5 m) of nylon net to exclude volunteer ovipositing moths. Twenty ovipositing moths (mated on the night of emergence) put in an open can placed in the center of the cage (the following night), were allowed to move out and lay eggs freely in the cage. The insects were provided with water on a wet paper towel in a 60 x 15 mm Petri dish. The number of eggs laid on each leaf (counting from the base of the plant) of each plant was recorded twice a week. The 20 moths were replenished each week with fresh ovipositing females. The test period was 2-6 weeks after plant emergence (WAE). The ovipisitional preference for the different leaves was compared among the eight genotypes. The test was repeated 10 times.

(b) A no-choice situation. In this experiment, the eight maize genotypes were planted in 2 replicates of 5 plants per genotype. The plants were covered with a wire-mesh cage (150 x 150 x 150 cm) to exclude volunteer ovipositing moths. Ten ovipositing moths (treated as described in the choice situation experiment) were released in each cage. The number of eggs laid on each leaf of each plant (counting from the base of the plant) was determined twice a week; the moths were replenished each week; the test period was 2-6 WAE and the ovipositional preference for different leaves of the genotypes was compared.

Larval 'arrest'

At 4 WAE, five test plants of each genotype were each artificially infested with 20 neonates first instar larvae. The plants were covered with a wire-mesh cage (80 x 80 x 80 cm). The test was repeated 4 times. The infested plants were dissected after 72 hours, and the percentages of the larvae recovered from the plants were recorded.

At 7 WAE, one plant of each genotype was infested with single, freshly molted third instar larvae on the outermost leaves of the whorl. The plants were covered with a wire-mesh cage (100 x 80 x 80 cm). The test was repeated in 2 replicates of 10 plants each. The infested plants were dissected after 24 hours, and the percentages of the larvae recovered from the plants and the site of recovery were recorded.

Larval establishment

Seed of each of the eight maize genotypes were planted in two 3 m row plots, spaced 75 cm apart with the plants spaced 25 cm apart within the row. Immediately after sowing, each plot was covered with a cage made of nylon net (12 meshes/cm). The cages, each being 6 m long x 4.2 m wide x 3 m high, were to protect plants from natural infestation. Fertilizer was applied to the plots at the rate of 60 kg P ha^{-1} at the time of planting and 60 kg N ha^{-1} 3 WAE of the plants. Plots were hand-weeded and irrigated as necessary.

At 3 WAE, each plant of a given genotype was infested with an egg mass containing 60 eggs at the black head stage. All the plants in a plot were infested. The egg masses were carefully placed between the leaf sheath of the second leaf and the stem. Ten days after infestation, 10 plants in each plot were dissected and the number of larvae recovered from each plant was recorded. Similarly, at harvest, 10 plants from each plot were dissected and the number of larvae and pupae recovered from each plant were recorded.

Larval feeding

(a) On leaves. 20 first instar larvae kept in an incubator maintained at 25°C, 50-60% r.h. and 12 h photoperiod were provided with a 7-cm segment of maize leaf whorl. After 72 h, the remaining portions of the leaf were examined and the area of the lesions (reflecting the feeding response) due to larval feeding was measured, using a paper sheet marked with squares (1square = 1sq. cm). The test was repeated 10 times.

(b) On stem segment. A single weighed third instar larva was given a 7 cm weighed stem segment in a glass vial (7.5 x 2.5 cm) and was kept in an incubator maintained at 25°C, 50-60% r.h. and 12 h photoperiod. The segment was removed after 24 h, split open and the length and width of the cavities resulting from the larval feeding were measured. The weights of the larvae, the stem cutting and the feces were measured separately. The approximate volume of the consumed stem was calculated to serve as an index for stem feeding. The test was repeated 10 times.

Nutrition (utilization of food)

A single weighed third instar larva was given a 7 cm weighed stem segment in a glass vial (7.5 x 2.5 cm) and kept in an incubator maintained at 25°C, 50-60% r.h. and 12 h photoperiod. The segment was removed after 24 h, split open and the larvae removed. The weights of the larvae, the stem cutting and the feces were measured separately. Genotypes were compared in respect of the following parameters using the formulae suggested by Waldbauer (1968) and modified by Alghali and Saxena (1988):

(i) ***Relative weight of food consumed*** = weight gained + weight of the feces.

(ii) ***Consumption index*** (CI) = F/TA, where F = fresh or dry weight of food consumed, T = duration of feeding period (days); A = mean fresh or dry weight of insect during feeding period, which is obtained as [1/2 (initial weight before feeding + final weight after feeding)].

(iii) ***Relative growth rate*** (GR) = G/TA, where G = weight gain of larvae during feeding, T = duration of feeding period (days), A = mean fresh or dry weight of insect during feeding period.

(iv) ***Approximate digestibility*** (AD) – an expression of the percentage of ingested food that is absorbed:
(AD = (weight of food ingested – weight of feces)/weight of ingested food) x 100.

(v) ***Efficiency of conversion of digested food*** (ECD), which is an expression of the percentage of absorbed food converted into body tissue: ECD = [(weight gained)/(weight of food ingested – weight of feces)] x 100.

(vi) ***Efficiency of conversion of ingested food*** (ECI), an expression of the percentage of ingested food that is converted into body tissue: ECI = GR/CI.

Table 2. Ovipositional responses of *S. calamistis* to eight maize genotypes.

Genotypes	Resistance status	Number of eggs/week (mean ± s.e.)*	
		No-choice situation	Choice situation
S5 9-1	Resistant	347.8 ± 110.2 a	836.4 ± 367.0 a
S5 11-1	Resistant	366.2 ± 171.1 a	731.4 ± 371.7 ab
S5 27-1	Resistant	228.0 ± 108.3 a	800.6 ± 358.6 ab
S5 27-3	Resistant	320.0 ± 85.0 a	726.0 ± 364.7 ab
Tzmi 103	Mod. resistant	197.0 ± 54.8 a	701.6 ± 334.5 b
Tzi 4001	Mod. resistant	248.2 ± 44.2 a	746.8 ± 368.8 ab
S5 20-2	Susceptible	290.4 ± 105.6 a	750.8 ± 383.3 ab
Tzmi 407	Susceptible	208.2 ± 78.4 a	719.6 ± 348.0 ab

*Means within a column followed by the same letter(s) are not significantly different (*P*>0.05, LSD)

Profiles

Profiles of colonizing responses of *S. calamistis* were developed using the method developed by ICIPE (1990) on the susceptible genotypes, S5 20-2 and Tzmi 407, as references. Values of each type of response were obtained by calculating the ratio of the mean value of each type of response to that of a susceptible. Responses were categorized using the ICIPE (1990) classification as follows: very low (VL) for ratios >|0<0.4|; low (L) for ratios >| 0.4<0.8|; medium (M) for ratios >|0.8<1.2|; high (H) for ratios >|1.2<1.6|; and very high (VH) for ratios >|1.6|.

Data analysis

A one-way analysis of variance (ANOVA) was computed followed by separation of means, using the least significant difference (LSD) test.

Results

Oviposition

Despite the large range of mean number of eggs/week under the no-choice test (197 to 366 eggs/week), there were no significant differences among the maize genotypes (Table 2). In the choice situation, significantly more eggs were laid on the resistant maize genotype S5 9-1 (836.4 eggs/week), followed by S5 27-1 (800.6 eggs/week), which is also resistant to *S. calamistis*. The susceptible S5 20 was third in the choice situation. The moderately resistant Tzmi 103 had the least number of eggs in the choice situation, with significantly fewer eggs than S5 9-1. In addition, females of *S. calamistis* laid significantly more eggs in a choice scenario than in a no-choice situation (Table 2). Females laid the majority of their eggs on the second and third leaf sheaths of the plant under both situations.

Table 3. ***S. calamistis*** **larval arrest on eight maize genotypes.**

Genotypes	Larval recovery (Mean ± s.e.)* Number of first instar arrested	% of third instar arrested	% of third instar entering the stem
S5 9-1	2.8 ± 0.8 a	80 ± 00 a	0
S5 11-1	4.6 ± 1.8 a	65 ± 15 a	0
S5 27-1	7.6 ± 3.8 a	86 ± 05 a	0
S5 27-3	2.2 ± 1.1 a	90 ± 10 a	0
Tzmi 103	5.6 ± 1.8 a	95 ± 05 a	5
Tzi 4001	7.2 ± 2.9 a	75 ± 05 a	0
S5 20-2	7.2 ± 1.1 a	86 ± 05 a	5
Tzmi 407	6.6 ± 1.9 a	86 ± 05 a	5

*Means within a column followed by the same letter are not significantly different (*P*>0.05, LSD)

Table 4. ***S. calamistis*** **larval establishment on eight maize genotypes.**

Maize genotypes	Mean ± s.e. larvae/plant recovered 10 days after infestation*	Number of borers recovered at harvest time Total	% of larvae	% of pupae	Mean % of stem tunnelling at harvest time
S5 9-1	1.3 ± 0.5 b	0	0	0	0
S5 11-1	3.3 ± 1.3 b	2	100	0	11.4
S5 27-1	5.5 ± 0.8 b	1	0	100	29.6
S5 27-3	4.1 ± 1.8 b	-	-	-	-
Tzmi 103	1.1 ± 0.4 b	0	0	0	0
Tzi 4001	3.5 ± 1.8 b	3	0	100	17.2
S5 20-2	20.2 ± 2.9 a	0	0	0	10.4
Tzmi 407	4.2 ± 1.2 b	-	-	-	-

*Means within a column followed by the same letter are not significantly different (*P*>0.05, LSD)

Larval arrest

There were no significant differences among genotypes for first instar larval recovery (Table 3). In general, the percentages of first instar larvae recovered were very low for all the eight maize genotypes. In contrast, the percentages of third instar larvae recovered were very high (>60%) for all the genotypes. There were no significant genotypic differences in the third instar larvae recovered. However, 5% of these larvae were already established inside the stem of the two susceptible genotypes (S5 20-2 and Tzmi 407) two days after the infestation (Table 3), while 5% of those recovered on the resistant S5 9-1 caused no damage to their host plants after the same period of time.

Larval establishment

A highly significant number of larvae per plant were recovered ten days after infestation from the susceptible S5 20-2 but not from the resistant S5 9-1 (20 vs. 1.3 larvae/plant) (Table 4). Significant differences were also observed between the susceptible S5 20-2 and the others in terms of the number of larvae that had settled down ten days after infestation (Table 4). At harvest time, very few borers were

Table 5. Larval feeding responses of *S.calamistis* to eight maize genotypes.

Maize genotypes	Leaf area (sq. cm) eaten by 10 first instar larvae (Mean ± s.e.)*	Volume (cu.cm) of stem eaten by a single third instar larva (Mean ± s.e.)	Mean weight of stem tissues consumed by a single third instar larva (Mean ± s.e.)
S5 9-1	2.18 ± 0.35 ab	3.49 ± 0.62 ab	0.64 ± 0.16 cd
S5 11-1	1.86 ± 0.19 ab	4.72 ± 1.05ab	0.83 ± 0.08 bcd
S5 27-1	2.52 ± 0.38 a	3.40 ± 0.96 ab	0.47 ± 0.10 d
S5 27-3	2.07 ± 0.40 ab	4.92 ± 1.63a	0.89 ± 0.19 bcd
Tzmi 103	1.47 ± 0.27b	3.70 ± 0.75ab	0.79 ± 0.17 bcd
Tzi 4001	2.34 ± 0.29 ab	3.03 ± 0.83 ab	1.25 ± 0.13 ab
S5 20-2	1.97 ± 0.29ab	2.16 ± 0.43 b	1.00 ± 0.07 bc
Tzmi 407	1.87 ± 0.29ab	4.70 ± 0.60 ab	1.68 ± 0.32 a

* Means within a column followed by the same letter are not significantly different (*P*>0.05, LSD)

recovered from the plants, and majority of those recovered were in the pupal stage (Table 4). The mean percentage of tunnelling estimated was also low for all genotypes.

Larval feeding on leaf and stem segments

The leaf area consumed by the first instar larvae was significantly higher on the resistant S5 27-1 than on the moderately resistant Tzmi 103 (Table 5). No significant differences were observed in leaf area consumed between the other genotypes. The volume of stem consumed by the third instar larvae was significantly higher on the resistant S5 27-3 than on the susceptible S5 20-2 (Table 5). No significant differences were recorded between the other genotypes. The mean weight of the stem tissues consumed by third instar larvae was significantly higher on the susceptible Tzmi 407 than on all the resistant and moderately resistant genotypes, and the susceptible S5 20-2 (Table 5). However, the relative weight of food consumed by these larvae was higher on the resistant S5 11-1 than on the other genotypes (Table 6). In addition, a significant difference in terms of the weight of feces collected from the third instar larvae fed on the different genotypes was found between the resistant S5 11-1 and the resistant S5 27-1(Table 6).

Food utilization

The stem consumption indices of the third instar larvae were lower on the resistant genotypes than on the susceptible ones, although their growth rates were not different (Table 7). A higher approximate digestibility (AD), indicating the percentage of ingested food that was digested, was obtained on susceptible than resistant genotypes (Table 7). On the contrary, values obtained for the efficiency of conversion of digested food to body substance (ECD) and the efficiency of conversion of ingested food to body substance (ECI) were lower on the susceptible than the resistant genotypes (Table 7).

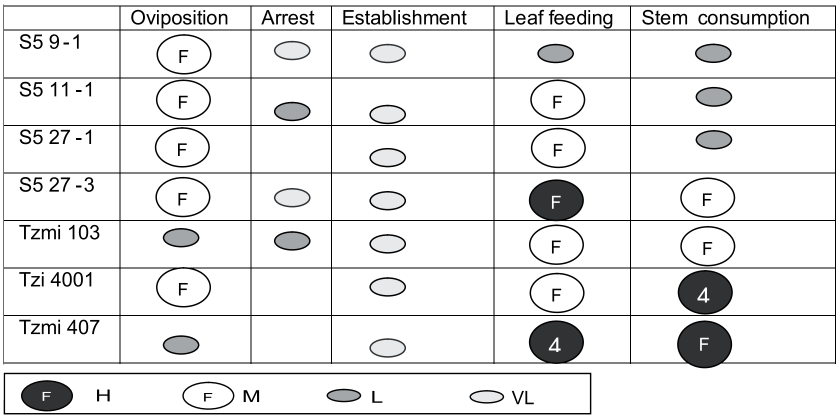
Table 6. Feeding of third instar larvae of *S. calamistis* on eight maize genotypes.

Maize genotypes	Weight of larvae (g) (Mean ± s.e.)			Weight of the feces (g) (Mean ± s.e.)	Relative weight of food consumed (g)
	Before feeding	After feeding	Weight gained		
S5 9-1	0.095 ± 0.006 a*	0.185 ± 0.018 ab	0.090	0.287 ± 0.059 ab	0.377
S5 11-1	0.101 ± 0.004 a	0.210 ± 0.0018 a	0.109	0.480 ± 0.068 a	0.589
S5 27-1	0.088 ± 0.008 ab	0.160 ± 0.016 bc	0.072	0.256 ± 0.075 b	0.328
S5 27-3	0.093 ± 0.008 a	0.174 ± 0.020abc	0.081	0.380 ± 0.083 ab	0.461
Tzmi 103	0.073 ± 0.002 b	0.108 ± 0.005 d	0.035	0.310 ± 0.103 ab	0.345
Tzi 4001	0.075 ± 0.005 b	0.141 ± 0.012 cd	0.066	0.290 ± 0.071 ab	0.356
S5 20-2	0.098 ± 0.004 a	0.163 ± 0.011 bc	0.063	0.280 ± 0.047 ab	0.343
Tzmi 407	0.096 ± 0.006a	0.187 ± 0.018 ab	0.091	0.350 ± 0.067 ab	0.441

* Means within a column followed by the same letter are not significantly different (*P*>0.05)

Table 7. Consumption, growth and utilization indices of third instar larvae of *S. calamistis* on eight maize genotypes.

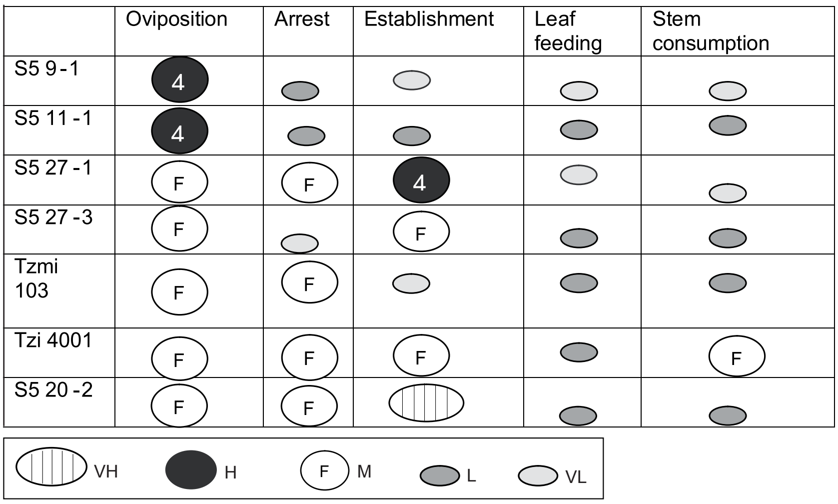
Maize genotypes	Consumption index	Growth rate	AD (%)	ECD (%)	ECI (%)
S5 9-1	2.2	0.32	55	25	14
S5 11-1	2.7	0.32	41	31	11
S5 27-1	2.0	0.29	42	36	14
S5 27-3	3.9	0.19	57	16	5
Tzmi 103	4.4	0.30	61	7	7
Tzi 4001	5.8	0.30	77	7	5
S5 20-2	4.0	0.24	72	9	4
Tzmi 407	5.9	0.32	79	7	5



	Oviposition	Arrest	Establishment	Leaf feeding	Stem consumption
S5 9-1	○ F	⬭	⬭	⬬	⬬
S5 11-1	○ F	⬬	⬭	○ F	⬬
S5 27-1	○ F		⬭	○ F	⬬
S5 27-3	○ F	⬭	⬭	● F	○ F
Tzmi 103	⬬	⬬	⬭	○ F	○ F
Tzi 4001	○ F		⬭	○ F	● 4
Tzmi 407	⬬		⬭	● 4	● F

● F H ○ F M ⬬ L ⬭ VL

Figure 1. Profiles of colonizing responses of *S. calamistis* to different maize genotypes, using S5 20-2 as a reference [H = High; M = Medium; L = Low; VL = Very low (ICIPE, 1990)].



	Oviposition	Arrest	Establishment	Leaf feeding	Stem consumption
S5 9-1	● 4	⬬	⬭	⬭	⬭
S5 11-1	● 4	⬬	⬬	⬬	⬬
S5 27-1	○ F	○ F	● 4	⬭	⬭
S5 27-3	○ F	⬭	○ F	⬬	⬬
Tzmi 103	○ F	○ F	⬭	⬬	⬬
Tzi 4001	○ F	○ F	○ F	⬬	○ F
S5 20-2	○ F	○ F	▥	⬬	⬬

▥ VH ● H ○ F M ⬬ L ⬭ VL

Figure 2. Profiles of colonizing responses of *S. calamistis* to different maize genotypes, using Tzmi 407 as a reference [VH = Very high; H = High; M = Medium; L = Low; VL = Very low (ICIPE, 1990)].

Profiles

Figures 1 and 2 present the profiles developed by calculating the ratios of the mean values of each type of response in a tested genotype to those of the susceptible S5 20-2 and Tzmi 407, respectively. Greater numbers of responses in the low grade indicate greater resistance of a genotype to colonization by *S. calamistis*. Out of five responses in the low grade, S5 9-1 had four responses and S5 11-1 had three (Fig. 1), which may account for their resistance. On the other hand, Tzmi 407 had two responses in the high, and one in the medium grade, resulting in its susceptibility. Results presented in Figure 2 showed that when Tzmi 407 was used as reference genotype, S5 9-1 had 3 responses in the very low grade, while S5 11-1 had 4 responses in the low grade, which would account for their high level of resistance.

Discussion

Oviposition intensity in the no-choice tests followed the same trend as in the choice tests, with genotype S5 9-1 being consistently the most preferred and Tzmi 103 the least preferred (Table 2). These results contradict those of Ampofo (1985) and Kumar (1992), who observed that for oviposition, *C. partellus* had a high preference for the susceptible check in comparison to the resistant maize genotypes. Results of the present study suggest that the leaves of the resistant genotype S5 9-1 may contain volatile chemicals that make ovipositing moths prefer it for egg laying. If so, the chemicals need to be identified and tested to determine those that attract ovipositing moths or that stimulate egg laying. Furthermore, it appears from the results of the present study that oviposition response may not be involved in the resistance of this genotype to *S. calamistis*. Similar observations have been made on some sorghum lines resistant to *Chilo partellus* (Saxena 1990).

It was observed that the number of eggs deposited on the moderately resistant Tzmi 103 in the two scenarios was less than the one laid on the other genotypes. Based on these results, it seems that the leaves of this genotype either lack or contain low levels of the volatile chemicals that attract moths or stimulate egg laying. It could also be that the volatile chemicals of the leaves repel *S. calamistis* moths. Therefore, the insect's ovipositional non-preference for Tzmi 103 provides an explanation for its antixenosis. The quantity of eggs laid on S5 20-2 confirmed its susceptibility to *S. calamistis*.

The number of first instar larvae recovered on the plants of S5 9-1 and S5 27-3 after 48 hr of infestation was very low thus confirming the resistance of these genotypes to the larval stage (especially larval arrest) of the insect. The first instar larval arrest was very high on the resistant S5 27-1; therefore, this phenomenon may not be involved in the resistance of this genotype to *S. calamistis*.

Although oviposition preference for S5 9-1 was high, larval establishment on it was very low and thus confirms its resistance to *S. calamistis*. A very low larval establishment on S5 9-1 on which a large number of eggs was laid suggests that the suitability to neonate larvae is not the only determining factor in the choice of oviposition sites. Ampofo and Saxena (1986) came to a similar conclusion with *C. partellus*. If and when identified, the plant characters responsible for the failure of larval establishment on S5 9-1 and leading to antibiosis may be used for the improvement of maize resistance to *S. calamistis*. Contrary to S5 9-1, larval establishment was high on Tzmi 407 and very high on S5 20-2. These two lines, therefore, may be classified as susceptible and highly susceptible to *S. calamistis*.

The consumption index of the third instar larvae of *S. calamistis* on stem tissues was lower on resistant genotypes S5 9-1 and S5 27-1 than on moderately resistant and susceptible genotypes. These observations indicated a high non-preference for the genotypes thus further confirming their high level of resistance to *S. calamistis*. Low consumption index is an indication that less food was consumed or that the insect did not use the consumed food properly. According to Alghali and Osisanya (1982), the degree of utilization of food consumed depends upon the digestibility of the food and the efficiency of conversion of the ingested food into body substances. In the present study, although there were no significant differences among genotypes with respect to growth rate, the digestibility of food ingested was low on resistant genotypes S5 11-1, S5 27-1 and S5 9-1, leading to antibiosis. However, the efficiency of conversion of the ingested food into body substances was higher in these genotypes. This indicates that the digestible portion of ingested food from susceptible genotypes that was metabolised for energy to maintain life was low. It may be concluded that the susceptible S5 20-2 and Tzmi 407 were not necessarily suitable for the growth of *S. calamistis*. Similar observations have been made on other species (Alghali and Osisanya, 1982; Alghali and Saxena, 1988). Thus, there is an urgent need to carry out detailed nutritional analyses of these resistant and susceptible genotypes to determine the plant characters influencing the consumption of *S. calamistis* third instar larvae on stem tissues. In addition, the characters involved in the conversion of ingested food into body substances need to be identified. Proper identification and understanding of these two sets of plant characters could be a powerful tool for the management of *S. calamistis*.

The different profiles obtained in this study showed genotypic variation for the level of responses, which, in turn, suggests genotypic variation in the plant characters responsible for a response. Therefore, if the plant characters are heritable, they may be manipulated through appropriate breeding techniques to increase resistance in the genotypes evaluated in this study, or in populations developed from the genotypes with high resistance and other suitable characters. Among the genotypes evaluated in the study, only S5 9-1 showed very low grades in the profiles obtained from both choice and no-choice scenarios. These results explain its high resistance to *S. calamistis*. On the contrary, S5 20-2 and Tzmi 407 elicited three responses in the medium to very high grade in one scenario, and four responses in the medium to high grade in the second. It may, therefore, be concluded that S5 9-1 is resistant, while S5 20-2 and Tzmi 407 are susceptible to *S. calamistis*.

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Assessment of *Striga* infestation in crop fields in the savanna zones of northeast Nigeria

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Abstract

Striga is a major constraint to crop productivity in the savanna zones of northeast Nigeria. In a community livelihood survey, farmers in the region ranked *Striga* infestation as the topmost priority constraint. A field survey was, therefore, conducted to assess the level of field infestation by *Striga* species in crop and fallow fields in the three ecological zones of the region. The survey, which was conducted in 2004, covered 935 fields comprising 459 compound and 476 bush fields from 30 communities, which were selected from four Local Government Areas (LGA) in the southern part of Borno State. Four major *Striga* species were found to be associated with specific hosts: *Striga hermonthica* (Del.) Benth in sorghum and maize; *Striga aspera* (Willd.) Benth in rice; *Striga densiflora* Benth in pearl millet and fallow and *Striga gesnerioides* (Willd.) Vatke in cowpea. Across ecologies and fields (compound or bush), 68% of the 935 fields were infested by *Striga*. Similarly, 75% of compound fields and 62% of bush fields were infested with the four *Striga* species. The order of prevalence of the *Striga* species was *S. hermonthica*>*S. gesnerioides*>*S. aspera*>*S. densiflora*. For *S. hermonthica,* the level of infestation in the ecologies was in the order: Sudan savanna>northern Guinea savanna>southern Guinea savanna while infestation by *S. gesnerioides* was in the order of northern Guinea savanna>Sudan savanna>southern Guinea savanna. Across the three ecologies, 86% of the maize and sorghum fields were infested with *S. hermonthica*, while 83% of cowpea fields were infested with *S. gesnerioides*. About 44% of the rice fields in the zones were infested with *S. aspera*, while 36% of fallows were infested with *S. densiflora*. In all ecologies, the number of emerged *Striga* plants in sorghum fields was higher than in maize fields, suggesting that *Striga* is more adapted to sorghum. Generally, *Striga* infestation was higher in compound fields than bush fields across the three ecologies. The results of this study showed that *Striga* is a major factor in environmental degradation and a significant constraint to crop production in all the ecologies. Therefore to improve crop production and increase income of farmers, efforts should be made to combat *Striga* through multidimensional or integrated approach in these areas.

Résumé

Le *Striga* est une contrainte majeure à la productivité des cultures au nord-est du Nigéria. Dans une enquête communautaire sur le bien être, les paysans de la région ont sélectionné le *Striga* comme la principale contrainte prioritaire. Une étude au champ a été conduite pour évaluer le niveau d'infestation des cultures au champs et dans les jachères par les espèces de *Striga* dans les 3 zones ecologiques de la région. L'enquête qui a été menée en 2004 a couvert 935 champs s'étandant sur 459 concessions dans 30 communautés de quatre gouvernements locaux dans la partie sud de l'etat de Borno. Les plants de *Striga* émergés ont été comptés à partir d'au moins quatre points cardinaux dans chacun des 30 communautés impliquées. Quatre principales espèces de *Striga* ont été identifiées, comme étant associées à certains hôtes: *Striga hermonthica* [Del.] Benth associé au sorgho ou au maïs; *Striga aspera* [Willd.] Benth associé au riz; *Striga densiflora* Benth trouvé dans la jachère et dans le petit mil et *Striga gesnerioides* [Willd.] Vatke, trouvé dans le niébé. A travers les écologies et les champs de case et de brousse, 68% des 935 champs sont infestés par quatre espèces de *Striga*. L'ordre de prévalence des différentes espèces de *Striga* est le suivant : *S. hermonthica>S. gesnerioides>S. aspera>S.densiflora*. Le niveau d'infestation des champs de céréales par *S. hermonthica* dans les différentes écologies était dans l'ordre Savane soudanienne >Nord savane guinéenne>Sud savane guinéenne tandis que l'infestation du niébé par *S. gesneroides* était dans l'ordre de Nord savane guinéenne>Savane soudanienne>Sud savane guinéenne. A travers toutes les 3 ecologies, 86% des champs de maïs et de sorgho étaient infestés de *S. hermonthica* alors que 83% des champs de niébé étaient infestés de *S. gesnerioides*. Environ 44% des champs de riz étaient infestés par *S. aspera* tandis que 36% des jachères étaient infestés par *S. densiflora*. Dans toutes les écologies le nombre de plants émergés de *Striga* était plus élevé dans les champs de sorgho que dans les champs de maïs, suggérant que le *Striga* est plus adapté au sorgho. L'infestation de *Striga* était plus importante dans les champs de case que dans les champs de brousse , à travers les trois écologies. Les résultats montrent ici que *Striga* est une contrainte majeure à la production des cultures dans toutes les écologies de la zone d'étude. Ainsi donc, pour améliorer la production des cultures et accroître les revenus des agriculteurs, des efforts devraient être faits pour lutter contre le *Striga* à travers des approches multidimensionnelles ou integrées.

Introduction

Striga, the root-parasitic weed species in the Scrophulariaceae family, is a major constraint to crop production and food security in the Savanna ecologies of West and Central Africa (Lagoke *et al.* 1991). The intensification of cropping systems, which is characterized by reduction or absence of rotation and bush fallow, has exacerbated land degradation and *Striga* infestation in the sub-region. *Striga* infestation is associated with low soil fertility, continuous monocropping, increased land use intensification, and poor weed management (Ransom 1999).

Sauerborn (1991) reported that 21 million ha of land were infested with *Striga* in Africa, while estimates obtained by Lagoke *et al.* (1991) showed that about 50 million out of the 73 million ha of arable cropland in Africa were already severely or moderately infested. The extent of infestation of the savanna ecologies in Nigeria may be higher as shown by Lagoke *et al.* (1991) who reported infestation of over 40% of the arable land by several *Striga* species. They further forecast infestation of another 40% during the 10 subsequent years, bringing the level of infestation to 80% by 2001. Crop losses ranging between 10 and 100% due to the menace of the parasitic weeds have been reported (Lagoke *et. al.* 1991). *Striga* impairs photosynthetic efficiency (Stewart *et al.* 1991) and exerts phytotoxic effects (Ransom *et al.* 1996) on the host.

Striga infestation and host damage are usually more severe under abiotic stresses. Manyong *et al.* (1996) reported that *S. hermonthica* (Del.) Benth had become a serious problem in areas of poor market access where farmers do not apply fertilizer adequately to maize in northern Guinea savanna of Nigeria. Emechebe *et al.* (1991) also reported that *S. gesnerioides* (Willd.) Vatke completely blighted cowpea [*Vigna unguiculata* (L.) Walp] on farmers' fields in the northern Guinea savanna, resulting in crop losses as high as 100%.

The problem of *Striga* infestation is sometimes compounded by the occurrence of more than one *species* on the same farmland and especially in cereal-legume intercrops. In a study conducted by the Promoting Sustainable Agriculture in Borno State (PROSAB) Project, farmers rated *Striga* infestation as the most important constraint together with low soil fertility during a community livelihood analysis in the study area (PROSAB 2004). However, no empirical study has been conducted to determine the level or extent of infestation in the study area apart from preliminary reports made by Gworgwor *et al.* (2001). They reported that 98% of the fields sampled in the northeast region of Nigeria were infested with *Striga hermonthica* while *Striga densiflora* was a minor species in the zone. Ogborn (1987) reported that *Striga* infestation in farmers' fields varied according to farming practices such as rotations, manure and/or fertilizer application, and weed management.

Soil type, field management, distance of farms from settlements and rainfall regime may also influence the extent of *Striga* infestation. The present study was conducted to determine the level and extent of infestation of crop and fallow fields by *Striga* species in the PROSAB area. Information obtained from the study would serve as the baseline for environmental monitoring and would be used to develop sustainable interventions to combat the *Striga* menace, arrest environmental degradation and increase food production in the project area in particular and north east Nigeria in general.

Materials and Methods

Characteristics of the study area

The study area consisted of 30 communities selected from four Local Government Areas (LGA) in the southern part of Borno State (11 ^{0} 50′E and 10 ^{0} 25′N) of northeastern Nigeria. The study covered an estimated area of 16,100 km^2, which is inhabited by 700,000 people based on the 1991 National population census (Anon. 1996). The area lies in the Sudan savanna (SS), northern Guinea savanna (NGS) and southern Guinea savanna (SGS) zones (Bukar *et al.* 1997). Average annual rainfall range from about 700 mm in the SS to over 1,200 mm in the SGS. The period of rainfall is from June to September in the SS, May to September in the NGS and May to October in the SGS. The soil type ranges from sandy loam in the SS to sandy clay in the NGS and clay loam in the SGS (Anon. 1996). Due to the presence of undulating hills in the NGN and SGS, there is a larger expanse of arable land in the SS. Rainfed farming is the mainstay of the people and diverse crops and cropping systems are used by farmers in the zones.

Emerged *Striga* plant counts

Field surveys of *Striga species* in the 30 communities (10 communities per ecological zone) were carried out in the study using simple random sampling technique. The fields were randomly selected from the four cardinal points of each community. For each community, at least four fields were selected for each available crop and fallow. Compound fields were sampled within 1 km, while bush fields were sampled at a distance of 1-5 km from the community. Ecological zones and field location (i.e., compound and bush) were considered the factors of the survey.

Striga species were identified based on the developmental and morphological features described by Ramaiah *et al.* (1983) and Parker and Riches (1993). *Striga* plant counts were made in maize (*Zea mays* L.), sorghum (*Sorghum bicolor* (L.) Moench), pearl millet (*Pennisetum glaucum* (L.) R. Br.) rice (*Oryza sativa* L.), cowpea (*Vigna unguiculata* (L.) Walp.) and fallow fields between September and November 2004. Emerged *Striga* plants were counted from 1.0 m x 1.0 m quadrat at 15-20 m intervals from five points diagonally chosen from each field as described by Kim (1994) and Dugje *et al.* (2003). At the time of the survey, the crops were either flowering or had reached physiological maturity while the *Striga* plants were also flowering or had reached advanced seeding stage. In all, 935 fields (476 bush and 459 compound farms) were sampled in the three ecological zones.

Statistical analysis

Striga emergence counts were transformed with the formula $\sqrt{y+0.50}$, where y = *Striga* counts/m^2. All grain yield data were converted to hectare basis and subjected to the analysis of variance (ANOVA) using the General Linear Model (GLM) procedure of the Statistical Analysis Systems (SAS) Package (SAS Institute Inc. 1990). Means were separated using Duncan Multiple Range Test (DMRT) at $P<0.05$.

Results

Extent of field infestation by Striga *species*

Four *Striga species* were identified in the field: *S. hermonthica* (Del.) Benth. *S. aspera* (Willd.) Benth. *S. gesnerioides* (Willd.) Vatke and *S. densiflora,* Benth., thus corroborating the results of the survey conducted by Gworgwor *et al.* (2001). Over 98% of the *Striga* species identified in maize and sorghum fields was *S. hermonthica,* the rest being *S. aspera,* which was observed only in only few fields. Rice fields were mainly infested by *S. aspera*. *Striga densiflora* was found mainly on late maturing pearl millet, some weedy rice fields and grass species in fallow fields. *S. gesnerioides* was the dominant parasitic weed species present in sole cowpea and few cereal-cowpea intercrops.

About 68% of the 935 fields sampled in the three zones were infested by the *Striga* species (Table 1). For the field location, 60% of the 476 bush fields and 75% of the 459 compound fields were infested. Among the ecological zones, the NGS had the highest infestation of 74%; SGS and SS had infestation levels of 60 and 68%. The levels of infestation of the crops were 36, 44, 77, 83, 84 and 94% for fallow, rice, maize, cowpea, pearl millet and sorghum, respectively.

The compound fields of sorghum, maize, rice, pearl millet and fallow had higher levels of infestation than bush fields, while bush fields had higher infestation than compound fields of cowpeas. This could be attributed to the continuous cultivation of compound fields, which results in faster depletion of their natural fertility than bush fields.

Across ecological zones and locations, 85.5% of the fields sampled were infested with *S. hermonthica,* while 44.1, 58.8 and 82.8% were infested by *S. aspera, S. densiflora* and *S. gesnerioides.*

Table 1. Percentage of crop and fallow fields infested by *Striga* species in Sudan, northern Guinea and southern Guinea savannas from 935 fields sampled in Nigeria, 2004.

	Type of field						
Ecological Zone	Sorghum[1]	Maize[1]	Rice[2]	Millet[3]	Cowpea[4]	Fallow[3]	Mean
	% Compound fields infested (n = 459)						
Sudan savanna	100.0	96.0	-	100.0	71.0	45.0	82.4
Northern Guinea savanna	96.0	87.0	61.0	-	95.0	48.0	77.4
Southern Guinea savanna	93.0	56.0	58.0	-	78.0	37.0	64.4
Mean	96.3	79.6	59.5	100.0	81.3	43.3	74.7
	% Bush fields infested (n = 476)						
Sudan savanna	97.0	96.0	9.0	67.0	53.0	27.0	53.7
Northern Guinea savanna	100.0	67.0	56.0	-	100.0	30.0	70.6
Southern Guinea savanna	80.0	58.0	21.0	-	100.0	17.0	54.8
Mean	92.3	73.6	28.6	67.0	84.3	24.7	61.8
Overall mean	94.3	76.6	44.1	83.5	82.8	35.5	68.3

Associated *Striga* species were 1= *Striga hermonthica*, 2 = *Striga aspera*, 3 = *Striga densiflora*, 4 = *Striga gesnerioides*

Table 2. Plant counts/ha (x1000) of *Striga* species in crop and fallow fields in three ecological zones of northeast Nigeria.

Ecological zone and field location	Type of field				
	Sorghum[1]	Maize[1]	Rice[2]	Fallow[3]	Cowpea[4]
Ecological Zone					
Sudan savanna	123.8 a	97.4 a	1.7 b	8.6 a	24.8 b
Northern Guinea savanna	98.3 ab	44.0 b	13.3 a	4.5 ab	37.4 a
Southern Guinea savanna	72.2 b	43.6 b	7.5 a	2.7 b	13.3 b
Mean	94.5	64.8	8.8	5.3	26.9
SE	61.4	50.8	6.8	3.6	9.3
Field Location					
Compound	116.7 a	56.1a	13.2 a	6.1 a	30.7 a
Bush	76.2 a	72.9 a	5.1 b	4.4 a	23.3 a
SE	25.6	36.7	4.8	3.7	9.0

Associated *Striga* species were 1= *Striga hermonthica*, 2 = *Striga aspera* 3 = *Striga densiflora*, 4 = *Striga gesnerioides*

Means followed by the same letter in a row are not significantly different at $P<0.05$ (DMRT).

Emerged Striga plant counts

Emerged *Striga* plant counts/ha in sorghum were 41.7% higher in the SS than the SGS (Table 2), and this difference was significant at $P<0.01$. The sorghum compound fields were slightly more infested (34.7%) than the bush fields. The result for maize was similar; greater ($P<0.05$) *Striga* counts were recorded in the SS than the other two ecologies. *Striga* counts in maize were greater by 54.8 and 55.2% in SS compared to NGS and SGS. Maize bush fields had higher *Striga* infestation than compound fields.

Striga emergence counts in rice were significantly ($P<0.05$) higher in the NGS (by 43.6%) and SGS (87.2%) than SS; that is, NGS=SGS>SS. Rice compound fields had more ($P<0.05$)> *Striga*.

Discussion

The high level of infestation of sorghum, cowpea and maize fields recorded in this survey may have resulted from the continuous cropping of these three crops by farmers, as the crops constitute the major staple foods in the region (PROSAB 2004). The higher infestation of sorghum fields is an indication of a relatively low adaptation of *S. hermonthica* to maize, a more recently introduced crop than sorghum in the savanna of Africa (Efron 1993). Kim *et al.* (1994) also found that maize was the most susceptible host to *S. hermonthica* damage, compared to sorghum and pearl millet. *Striga* has evolved with sorghum for a long period, which probably makes sorghum more tolerant of *Striga* than maize. Although farmers practice cereal-legume intercropping, the continuous intercropping with cowpea and sole cropping of cowpea

(Emechebe *et al.* 1991) may have increased *S. gesnerioides* buildup as both *S. hermonthica* and *S. gesnerioides* were prevalent in some cereal-cowpea intercrops. This suggests that the two species can co-exist even under intercropping. The rotation systems used by farmers may not be effective for *Striga* control because not all legumes are capable of inducing suicidal germination of *Striga*. Different strategies should, therefore, be developed to control the two *Striga* species. There was high incidence of *S. densiflora* in pearl millet fields though grass species in fallow and weedy rice fields were alternative hosts of the species. The implication is that growing late maturing varieties of pearl millet after fallow may increase the *Striga* buildup in the soil. *S. aspera* was found mainly attacking upland rice. Its economic importance will increase with the expansion of rice production in these areas.

The higher level of *S. hermonthica* infestation in the SS may be attributed to the dominance of sorghum-based cropping system, lower total rainfall, poor weed management and low application of nutrients such as nitrogen and organic manure (PROSAB 2004). The predominance of the maize-based cropping system in the more humid ecologies probably reduced the level of *Striga* infestation. Efron (1993) reported that *Striga* emergence counts were generally lower in maize than sorghum fields. Weber *et al.* (1995) also suggested that maize could be used to reduce *Striga* seed bank in the soil. Better crop management practices, such as fertilizer application and timely weeding that are recommended for maize probably helped in reducing *Striga* seed bank in the soil. The prolonged growth duration, inadequate fertilization and after-harvest sprouts that support seed production by *Striga* plants may have contributed to a greater *Striga* buildup in sorghum-based than maize-based cropping systems.

The relatively higher infestation of cowpea fields by *S. gesnerioides* in the NGS and SS may be attributed to continuous cropping of cowpea and increased land use intensification. The fact that most *Striga* sp. hot spots were recorded in compound farms gives further support to the notion that increased land use intensification due to increased pressure on land increases *Striga* infestation. This is because cowpea, which is mainly grown in these two ecologies increased *Striga* seed bank over time. Most compound fields are therefore depleted of their natural fertility due to continuous cropping and low fertilizer application. The acute shortage of land as a result of increased population and the presence of undulating hills in the humid savannas may exacerbate land use intensification. Manyong *et al.* (1996) reported that land use intensification is driven more by the increasing population than by market opportunities. Smith and Weber (1994) cautioned that soil fertility would be a serious problem in areas where land use intensification was on the increase due to population pressure. This could be because population pressure may limit access to yield enhancing inputs such as fertilizers and fallow land.

Striga infestation of crop and fallow fields were generally lower in the southern Guinea than in the other zones. The relatively early onset, higher and longer rainfall duration, heavier soils and more diverse cropping systems may reduce the level of infestation compared to the other zones. Ogborn (1987) reported that when the onset and establishment of the rains occurred early in the cropping season, infestation by *S. hermonthica* was delayed and excessively wet soils were not favourable for *Striga* host damage.

Despite the differences in the level of infestation, *Striga* was found to be a major constraint to crop production in all the savanna ecologies surveyed. Both *S. hermonthica* and *S. gesnerioides* were more prevalent in the SS than in the other two ecologies. While *S. gesnerioides* was a major threat to cowpea production in the NGS, sorghum supported the highest *Striga* population in all the fields sampled.

Conclusion

Striga is a major problem in all crops across the three savanna ecological zones in the northeast of Nigeria. To improve crop production, ensure food security and increase income of farmers, efforts should be made to combat the *Striga* menace and reverse land degradation in the savanna. Community mobilization and awareness creation on *Striga* damage and control strategies through publicity campaigns at community levels, farmer group training on integrated control measures and on-farm demonstrations of integrated control options are recommended for effective and sustainable *Striga* control in these ecologies. Strategic interventions should be developed to target both the compound and bush fields in the project area. However further assessment of factors affecting *Striga* infestation, such as cropping history, traditional and improved farming practices and farmer coping strategies to control *Striga* infestation will be necessary for the development of effective and sustainable interventions.

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The use of spicy plant oils against *Sitophilus zeamais* (Coleoptera, Curculionidae) in stored maize in Cameroon

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Abstract

Ocimum gratissimum, Piper nigrum and *Xylopia aethiopica* are common spicy plant species in Cameroon. Essential oil extracts from their fruits were tested for insecticidal activity against *Sitophilus zeamais* Motsch. (Coleoptera, Curculionidae), the principal weevil of stored maize and grain products in the tropics. After the extraction of the essential oils by hydrodistillation, formulations as dustable powder were prepared at 5 and 10% concentrations and applied to maize in which adult *S. zeamais* were exposed for 0 to 96 hr. All the treatments showed effective insecticidal activity by ingestion and contact after 96 hours compared to the untreated control and pirimiphos–methyl formulations. For all the formulations tested, a significant difference ($P<0.05$) was observed between contact and ingestion assays, the contact test being more effective. The mortality rate of *S. zeamais* increased with increased concentration of the essential oil of the three plants and the duration of exposure of the weevils on the treated substrates. By contact, *P. nigrum* (97.2 ± 4.6%) was the most effective insecticide whereas *X. aethiopica* (97.3 ± 3.7%) was the most effective by ingestion. The essential oils from the fruits of these plant species may be useful as maize grain preservatives against *S. zeamais* during storage.

Résumé

Ocimum gratissimum, Piper nigrum et *Xylopia aethiopica* sont des espèces communes d'épices au Cameroun. Les extraits des huiles essentielles de leurs fruits ont été testés pour leur efficacité contre *Sitophilus zeamais* (Coleoptera, Circulionidae), le principal charançon de stockage du maïs et des produits issus des grains sous les tropiques. Après l'extraction des huiles essentielles par hydrodistillation, des formulations donnant des produits ayant l'aspect de poudre ont été préparées à 5 et 10% et appliqué au maïs où des adultes de S. zeamais ont été exposés de 0 a 96 heures.. Tous les traitements ont montré une activité insecticide efficace par l'ingestion et par le contact après 96 heures en comparaison avec le contrôle non traité et avec les formulations de pirimiphos - méthyle. Pour toutes les formulations essayées, une différence significative ($p<0.05$) était observée pour les essais de contact et d'ingestion, et l'essai de contact étant le plus actif. La mortalité de *S. zeamais* augmentait avec la concentration d'huiles essentielles de ces trois plants et la durée d'exposition des charançons aux substrats traités. Par le contact, *P. nigrum* (97,2+-4,6) était l'insecticide le plus efficace tandis que *X. aethiopica (97,3+-3,7)* était le plus efficace par ingestion. Les huiles essentielles des fruits de ces espèces épicées peuvent être utiles dans la protection des graines de maïs contre *S. zeamais* au cours du stockage.

Introduction

Insects are major storage pests of cereal grains. It has been reported that storage pests can cause complete deterioration of a whole stock of maize (*Zea mays* L.) in 8-10 months (Bell 1994a). Insects such as the weevils, especially *Sitophilus zeamais* (Motsch) (Coleoptera, Curculionidae), are serious pests almost always found in stored maize causing considerable losses (Prempeh 1971; Okoro *et al.* 1992; Hidalgo *et al.* 1998; Obeng-Ofori and Amiteye 2005). One way to avoid or minimize postharvest losses due to *S. zeamais* is the use of synthetic insecticides. The associated detrimental effects on the environment and health, development of resistant strains of the insect, erratic supply and prohibitive costs of the insecticide are of major concern to agricultural scientists. These have given scientists the impetus to conduct research into alternative methods of pest control that would reduce the use of synthetic insecticides (Schmutterer and Ascher 1986). An alternative is the use of natural plant products (Szafranski *et al.* 1991). Plant products have played an important role in the traditional methods of protection against crop pests and disease vectors in Africa (Stoll 1988; Poswal and Akpa 1991). Some of the natural products protect grain without any observable side effect on their germination and organoleptic properties (Kethar 1986; Bell 1994a and b).

The use of locally available vegetable oils as grain protectants has been practiced for a long time (Pereira 1983). In recent years, research on the efficacy of the use of vegetable oils as stored-grain protectants against insects has been intensified (Don-Pedro 1987, 1989; Kumar and Okoronkwo 1991; Jackai 1993; Pacheco *et al.* 1995; Obeng-Ofori 1995; Obeng-Ofori and Reichmuth 1999). Most of the essential oils used in crop protection are extracts from plants known to have insecticidal activity. Examples of such plants are neem (*Azadirachta indica*) and cotton (*Gossypium arboreum*), whose seed oils have been used as insecticides (Schmutterer and Ascher 1986).

The objectives of the present study were to (i) evaluate the insecticidal effects of the essential oils extracted from three spicy plants of Cameroon: *Ocimum gratissimum* L. (Lamiaceae), *Piper nigrum* L. (Piperaceae) and *Xylopia aethiopica* (Annonaceae); and (ii) investigate the possibility of using the essential oils from these plants in the protection of stored maize grains.

Materials and Methods

Insect rearing

Sitophilus zeamais used in this study was cultured in the laboratory and maintained at 26 ± 2°C and 65-70% R.H in the dark. One hundred adults of mixed sex were obtained from a laboratory stock culture and reared on 500 g of maize in glass jars. After 3 weeks of oviposition, the parents and adults of the insect were removed by sieving the grains with a 2.0 mm mesh in order to obtain a homogeneous insect population. The beetles that subsequently emerged were transferred to another jar for further rearing. Seven days after the transfer, the insects in the jars were again sorted to obtain adult insects, at most, seven days old, which were used for different bioassays.

Extraction of essential oils

Plant materials used in the study were previously washed and drained (leaves) or sorted and finely ground to powder (fruits). The plants were *Ocimum gratissimum* (L), *Piper nigrum* (L) and *Xylopia aethiopica* fruits. The essential oils of these plants were extracted by steam distillation in a Clevenger type apparatus for 4 hours. The oil extracts were dehydrated with anhydrous sodium sulphate and then stored at 4°C in a refrigerator until used. The concentration process yielded 0.44% (v/wt) for *O. gratissimum,* 3.61% (v/wt) for *P. nigrum* and 1.35% (v/wt) for *X. aethiopica.*

Preparation of insecticide formulations

The insecticidal formulations were prepared according to Keita *et al.* (1999). The formulation was a powder from a mixture of the essential oil with kaolin in the ratio of 10^{-4} g of essential oil to 1 g of kaolin dust. For the different tests, two doses of the oils (5 and 10%) were formulated as powder. These concentrations were calculated as the ratio between the relative amount of the quantity of the mixture and the quantity of maize to treat.

Treatment procedure

Two types of tests were conducted on 20 g samples of clean maize grain put in 25 ml plastic flasks. The tests were (i) ingestion or consumption test and (ii) contact or direct application test.

Evaluation of the insecticidal activity of the oils by ingestion. Maize grains in the 25 ml flasks were treated with the insecticide. Thereafter, the insects to be used for the tests were introduced into the flasks and kept in the laboratory for 7 days. Data on the mortality rate of the insects were recorded at 0, 24, 48, 72 and 96 hours of exposure to the treated grains from which cumulative mortality was determined. Actelic, an organophosphorous synthetic insecticide commonly used in Cameroon to control *S. zeamais* in stored maize, was used as reference insecticide for the control.

Evaluation of the insecticidal activity of the oils by contact. Toxicity by contact was assessed by direct application or the knock down effect of the oils. A mixture was put in a plastic flask and the insects were allowed to be in direct contact with the product for five minutes. After this period, insects were removed and transferred on clean maize in flasks. Insect mortality rate was noted after 48 and 96 hours of exposure to the treated grains. Actelic was also used as the control in this experiment.

In each of the two experiments, 20 adult weevils were introduced into the plastic flask, which was covered with a piece of cloth and held with a rubber band. Five replicates were set up for each oil and control tratment. Insect mortality rate (in %) was calculated for each flask. Mortality was corrected for the natural mortality using the formula proposed by Abbot (1925).

Data analysis

Data collected on mortality rate were transformed by probit analysis for the determination of LD_{50} (Finney 1971). The data were then subjected to the analysis of variance (ANOVA), using SAS (SAS 1990). Mean mortality rate was used for the comparison of the treatments. The cumulative mean mortality rates were adjusted using Abbot's formula.

Results and Discussion

Figures 1 and 2 represent the mortality rates after consumption of *S. zeamais* with respect to the concentrations (5 and 10 %) of the essential oils and pirimiphos–methyl. The mortality rate of the insects increased with the exposure time and with increased concentration of the essential oils from the three plants and pirimiphos–methyl.

At the 5% oil extract concentration, *X. aethiopica* and *O. gratissimum* had higher mortality rates (63 and 53%) than the control (37%). This was not the case with the essential oil from *P. nigrum* that had only 16% mortality (Fig. 1). The essential oil from *X. aethiopica* exhibited the best insecticidal activity by consumption test, with a mortality rate of 97.3% recorded after 96 hours of exposure at 10% concentration (Fig. 2).

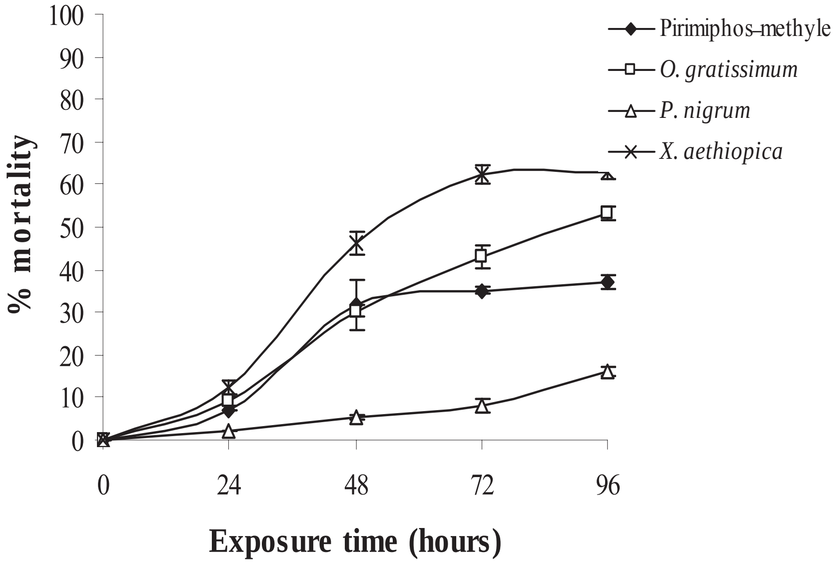

Figure 1. Mortality rate (%) of *S. zeamais* adults on maize grains treated with 5% concentration of oil extracts from three spicy plants and actelic (pirimiphos–methyl) at different periods of exposure.

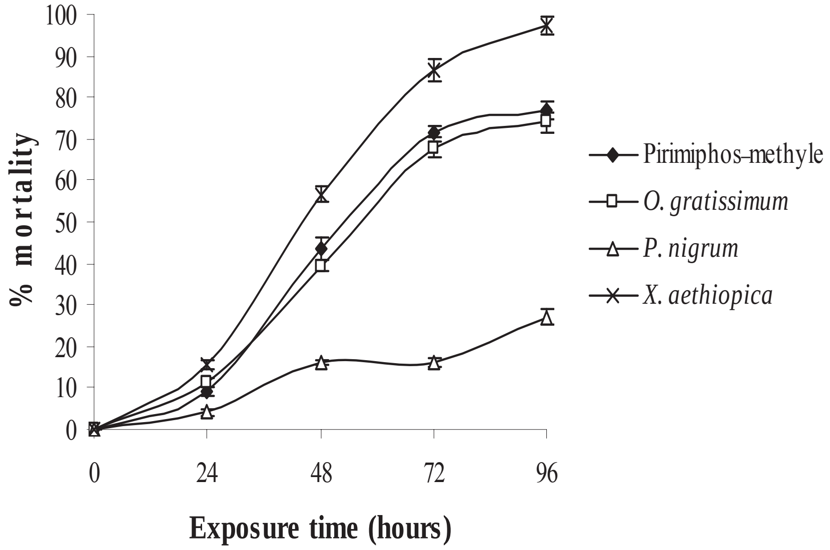

Figure 2. Mortality rate (%) of *S. zeamais* adults on maize grains treated with 10% concentration of oil extracts from three spicy plants and actelic (pirimiphos–methyl) at different periods of exposure.

The mortality rate of *S. zeamais* by contact also increased with the exposure time and the concentrations of the essential oils (Table 1).

Unlike the case of consumption, the essential oil from *P. nigrum* showed the highest insecticidal activity with a maximum mortality rate of 97.2% recorded after 96 hours of exposure at 10% concentration. Furthermore, all the essential oils tested exhibited higher insecticidal activity by contact than the control (actelic).

Table 1. Insecticidal effects by contact of essential oils from *O. gratissimum, P. nigrum* and *X. aethiopica* on *S. zeamais* at concentrations of 5 and 10%.

	Exposure time (hours)			
	48		96	
	Concentrations (%)			
Essential oils	5	10	5	10
O. gratissimum	66.1 ± 5.8	76.9 ± 5.0	85.9 ± 6.9	85.7 ± 5.3
P. nigrum	88.5 ± 6.8	95.6 ± 5.0	92.7 ± 5.8	97.2 ± 4.6
X. aethiopica	71.4 ± 6.4	86.8 ± 5.9	85.0 ± 4.7	90.1 ± 6.7
Control (actelic)	59.7 ± 3.1	69.8 ± 2.9	75.5 ± 2,2	83.1 ± 1.9

Table 2. LD_{50} calculated for mortality after 96 hours of exposure of *S. zeamais* Motsch to essential oils of *O. gratissimum, X. aethiopica* and *P. nigrum*.

Essential oils	Ingestion	Contact
O. gratissimum	75.15	48.55
X. aethiopica	83.19	45.59
P. nigrum	16.95	22.89

For all the plant materials tested, the results of probit analysis (Table 2), which determined LD_{50}, showed that the mortality rates obtained by consumption were higher than those obtained by direct application. The implication of this is that lower concentrations of essential oil will be more effective by contact than by ingestion. The contact test is, therefore, more efficient than the ingestion test in the control of *S. zeamais*. Moreover, statistical analysis showed that there was a significant difference ($P<0.05$) between the two types of tests (data not shown).

Insecticidal activities of essential oils from various plants have been demonstrated in several previous studies (Jirovetz *et al.* 1997; 1998; Bouda *et al.* 2001; Tapondjou *et al.* 2005). Although their mode of action is not clearly understood, it has been suggested in the case of vegetable oils that insect mortality is due to anoxia or interference in normal respiration resulting in suffocation (Schoonhoven 1978; Don–Pedro 1989). Some oils act as grain surface protectants, preventing stored products from any insect attack (Schmutterer and Ascher 1986). The toxic effects of phytochemicals on *S. zeamais* depend on several factors, which include the chemical composition of the crude oil and insect susceptibility (Tapondjou *et al.* 2005).

The chemical composition of the three essential oils evaluated in the present study had been analysed and found to include monoterpens and terpinenes (1,8-cineol, pinenes and limonene), which have toxic activity in insects (Gopalakrisnan *et al.* 1993; Jirovetz *et al.* 1997, 1998). Essential oils, however, have certain drawbacks when used as insecticides. When being preserved, it is important to keep them in a saturated atmosphere in the dark to avoid oxidation, which occurs in the light (Valnet, 1998).

The fruits of *X. aethiopica* and *P nigrum,* and the leaves of *O. gratissimum* are common household spices (used in domestic cooking) and medicines in many traditional African communities (Bauer *et al.* 1990). To prepare them as pesticide dust by simple drying and grinding is relatively cheap and practical. They can, therefore, be easily adopted by rural communities as cheaper and safer alternatives to the more expensive and often hazardous conventional grain protectants. They also have the potential for the manufacture of ecologically friendly pesticides for the pollution-conscious industrialized world (Okoro *et al.* 1992). In other words, these oils could be utilized in the management of insects feeding on grains or insects present within the stored grain stocks.

Conclusion

The application of essential oil insecticide mixtures may reduce the use of synthetic insecticides and hence reduce health hazards to applicators and consumers. The present study showed that *X. aethiopica* and *P. nigrum* had significant insecticide activity by consumption and contact, respectively. If readily available, treatment of grains with these essential oil mixtures could have important practical applications in areas of the world where insecticides are expensive, in short supply and hazardous to handle. This has an important practical implication in the search for and use of plant extracts for pest control. Further studies should be carried out to assess the insecticidal activity of the dust of plants of all these species.

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Amélioration du rendement et de la rentabilité de la culture de maïs sur des terres infestées par *Striga hermonthica* au nord du Bénin

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Résumé

Le *Striga hermonthica* continue d'être un fléau redoutable à la production du maïs dans la partie septentrionale du Bénin. Pour lutter contre ce parasite, des tests ont été conduits en deux années (2002-2003) sur 29 parcelles expérimentales en milieu paysan dans trois villages du Département de l'Alibori afin d'évaluer les capacités de *Aeschynomene histrix* à réduire l'infestation du *Striga* et à stabiliser le rendement du maïs. Les traitements appliqués dans chaque parcelle paysanne étaient :(i) la culture pure de maïs sans fumure minérale, (ii) la culture pure de maïs avec fumure minérale, (iii) la culture de maïs avec fumure minérale associée à l'arachide et (iv) la culture de maïs avec fumure minérale associée à l'*Aeschynomene histrix*. La culture pure de maïs sans fumure minérale a été la plus infestée. L'association maïs + fumure minérale avec les légumineuses réduit l'infestation du *Striga* sur la variété de maïs EVDT 97 STR C_1. La technologie améliorée associant l'arachide avec apport de fumure minérale est la meilleure alternative avec un taux marginal de rentabilité de 278 % contre 140 % pour la technologie améliorée associant *l'Aeschynomene histrix* avec apport de fumure minérale. L'utilisation de légumineuses joue un rôle important dans l'amélioration des potentialités productives du maïs dans la zone d'étude.

Abstract

Striga hermonthica has been a serious constraint to maize (*Zea mays* L.) production in northern Bénin. Twenty nine on-farm trials were conducted in 2002 and 2003 to evaluate the ability of *Aeschynomene histrix* to reduce infestation by this parasite and stabilize maize yield in three villages of the district of Alibori. The treatments applied in each farmer's fields were (i) sole maize without fertilizer application, (ii) sole maize with fertilizer application, (iii) maize with fertilizer application intercropped with groundnut, and (iv) maize with fertilizer application intercropped with *Aeschynomene histrix*. Sole maize without fertilizer application had the highest infestation by the parasite. Maize with fertilizer application, intercropped with legumes reduced *Striga* infestation on EVDT 97 STR C_1. The improved technology of intercropping maize with groundnut with fertilizer application to the maize crop, was the best alternative, with a marginal income rate of 278% compared with 140% for the improved technology based on intercropping maize with *Aeschynomene histrix* and fertilizer application. It was concluded that maize grain yield in the study area would improve by intercropping maize with legumes, especially groundnut.

Introduction

Les céréales les plus affectées par l'espèce *Striga hermonthica* sont le sorgho (Sorghum bicolor) le millet (*Pennisetum glandi*) et le maïs (*Zea mays* L) avec une perte annuelle qui s'élève à plus de sept milliards de dollars en Afrique (M'boob, 1989). Jadis faiblement consommé dans le nord, le maïs grâce au projet de développement de semences communautaires de variétés améliorées de maïs initié par WECAMAN, est aujourd'hui la principale céréale des populations au nord du Bénin. Par l'importance de la production maïsicole, les Départements de Borgou-Alibori occupent la 2^e place après les Départements de l'Ouémé-Plateau. Or, le département de l'Alibori situé au nord du Bénin est envahi par cette mauvaise herbe parasite qui attaque le maïs. L'augmentation de la production de maïs dans cette zone pourrait être limitée à cause des pertes énormes causées par le Striga.

Pour lutter contre ses effets, des variétés de maïs tolérantes/résistantes au *Striga* ont été mise au point dans les centres internationaux de recherche et testées en milieu paysan au nord du Bénin. Les résultats de ces tests n'ont pas comblé l'espoir des producteurs car la résistance des variétés en question n'est pas durable. En dépit de l'appréciation de la technologie faite par les paysans, leur adoption est frainée par la perte de résistance dans le temps et la baisse du rendement qui s'en suit et qui est aggravée par la pauvreté des sols.

Des essais effectués par le Centre National d'Agro-Pédologie (CENAP) et l'Unité de Recherche Zootechnique et Vétérinaire (URZV), de nouvelles légumineuses sont proposées pour élargir la gamme des légumineuses cultivées en milieu paysan (Actes du CNRA, 1997). Les observations effectuées par l'URZV en 1999 ont montré que *Aeschynomene histrix* est facile à enfouir lorsque le paysan procède au labour aussitôt après arrachage. L'*Aeschynomene histrix* s'insère donc mieux dans une approche de lutte intégrée pour amoindrir le niveau d'infestation. C'est pourquoi l'*Aeschynomene histrix* avec les possibilités qu'elle offre de régénérer les sols après recepage a été utilisé comme alternative de production de biomasse pour assurer la stabilité du rendement du maïs dans les parcelles infestées de *Striga* au nord Bénin.

Matériels et Méthodes

Les essais sont conduits dans vingt neuf champs paysans en 2002 –2003 à Angaradébou, Bagou et Bensékou dans l'Alibori au nord du Bénin. Quatre traitements dont le traitement avec l'arachide sont suivis auprès de chaque paysan. L'arachide contrairement à l'*Aeschynomene histrix* produit des graines commercialisables, est capable d'induire la germination suicidaire des semences de *S. hermonthica* et contribue à l'augmentation de l'azote dans le sol.

T0: Culture pure de maïs sans fumure minérale (témoin absolu). Ce traitement est relatif à la première pratique paysanne où le système de culture est plus extensif. La quantité de semence utilisée est donc plus faible.

T1: Culture pure de maïs avec fumure minérale. Il constitue la deuxième pratique paysanne du milieu avec une quantité de semences utilisée moindre que celles des deux traitements qui suivent.

T2: Association maïs avec fumure minérale + arachide. Il est basé sur l'application des recommandations techniques de la recherche.

T3: Association maïs avec fumure minérale + *Aeschynomene histrix.* Ce traitement implique également un mode de culture basé sur les recommandations techniques de la recherche.

Le dispositif expérimental utilisé est un bloc où chaque champ paysan constitue une répétition. Les parcelles d'essai sont de 200 m². *Aeschynomene histrix* est semé en continu entre les lignes de maïs à raison de 10 kg/ha soit 200 g par parcelle d'essai. Les graines de *Aeschynomene* sont mélangées à de la terre fine pour faciliter le semis. L'arachide (TS 32-1) est associée au maïs en bandes successives, trois lignes d'arachide pour deux lignes de maïs pratique bien connue des paysans. Le semis est fait à 0,60 m x 0,20 m à un plant/poquet. La variété de maïs utilisée est la EV DT 97 STR C_1 tolérante / résistante et est semée à 0,80 m x 0,40 m à 2 plants/poquet soit 25 kg/ha. Les semis ont été protégés par alphachloralose contre les rongeurs. La dose de fumure apportée au maïs en 2002 est de 33 kg/ha de triple super phosphate, 25 kg/ha de chlorure de potassium et 20 kg/ha d'urée. En 2003 seule l'urée est apportée au maïs à la dose de 50 kg/ha. Les parcelles sont sarclées jusqu'à l'apparition du *Striga*. Puis le désherbage a continué par arrachage manuel des mauvaises herbes à l'exception du *Striga*. Les observations ont porté sur la sévérité de l'attaque de *Striga* évaluée indirectement par le comptage du nombre de plants de *Striga hermonthica* ayant émergé six, neuf et douze semaines (à la récolte) après semis. Les paramètres mesurés sont la marge brute et le rendement du maïs dans chaque système. L'opinion paysanne a été recueillie pour évaluer la performance des différents traitements.

L'analyse financière a porté sur le calcul du budget partiel. Le budget partiel intègre les coûts variables qui diffèrent d'une technologie à une autre (Alimi et Manyong, 2000 ; CIMMYT, 1989). Le budget partiel compare les coûts additionnels (ou marginaux) et les bénéfices nets additionnels (ou marginaux). Ces coûts s'expriment par la formule suivante :

$$CVM(BNM) = \textit{Variation entre deux traitements consécutifs}$$

CVM = Coûts Variables Marginaux
BNM = Bénéfices Nets Marginaux

Dans ce budget partiel, la comparaison est faite entre les technologies consécutives. Certains niveaux d'analyse sont ainsi déterminés dans ce budget partiel. Il s'agit entre autres de l'analyse de dominance, du taux marginal de rentabilité et de l'analyse par la méthode arithmétique. L'analyse de dominance permet d'éliminer la technologie dont les bénéfices nets qu'elle procure sont insuffisants. Le taux marginal de rentabilité représente le gain que le paysan peut espérer obtenir en moyenne de son investissement quand il souhaite changer une pratique ou une variété par une autre. Il est déterminé par la formule suivante :

Ce taux se compare au Taux Minimum Acceptable de Rentabilité (TMAR) dont la formule est la suivante.

$$TMAR = \textit{Coût du capital} + \textit{revenu de gestion}$$

Le coût du capital est le bénéfice que le producteur s'abstient d'obtenir quand il investit son capital dans une activité pendant une certaine période. Ce coût représente en fait le taux d'intérêt d'un emprunt. Dans le cas précis, on considérera dans les calculs le taux d'intérêt de la Caisse Locale de Crédit Agricole Mutuel (CLCAM) qui est de 2 % par mois. Le revenu de gestion est le bénéfice que le paysan espère récupérer dans la gestion de son champ de maïs. S'il s'agit d'une nouvelle technologie, il représente le bénéfice que le paysan espère récupérer du temps utilisé et des efforts fournis pour apprendre et pratiquer cette technologie. Alimi et Manyong (2000) suggèrent un revenu de gestion de 100% dans le cas de la culture du maïs.

Résultats

Evaluation des plants de Striga

La culture pure de maïs sans fumure est la plus infestée (Tableau 1). Les résultats obtenus en 2003 confirment le bon niveau des traitements maïs + légumineuses. La réduction du nombre de plants de *Striga* montre que ces traitements sont importants dans la lutte contre le parasite, car ils permettent de limiter l'expansion du *Striga*.

Performances agronomiques des traitements

Les traitements sont significativement différents par rapport au rendement grain du maïs (Tableau 2). Les résultats obtenus en 2003 confirment l'effet de la fumure minérale et de la matière organique sur le rendement grain maïs. Le rendement du maïs non fumé cultivé sur maïs non fumé baisse progressivement alors que celui du maïs fume ou du maïs fumé associé aux légumineuses augmente. La différence de rendement observée entre le traitement sans fumure et le traitement avec fumure d'une part, et le traitement avec légumineuses d'autre part, est due à l'apport de la matière organique au sol qui a entraîné une amélioration de la fertilité du sol par conséquent une augmentation du rendement grain maïs (Tableau 2). Ces résultats sont similaires à ceux obtenus par Gbèhounou et Toukourou, 1998.

Les surplus en rendement grain maïs assurés par la fumure minérale appliquée seule, les deux légumineuses confondues et l'*Aeschynomene* par rapport à l'arachide sont respectivement de 990 ; 1020 et 290 kg/ha (Tableau 3)

Analyse par Budget partiel

Le tableau 4 présente le budget partiel des différents traitements. Le Tableau 4 montre que les bénéfices nets croissent en fonction des coûts qui varient de la pratique paysanne (T0) à celle améliorée en association avec l'arachide (T2). Cette croissance est plus prononcée au niveau de l'association Maïs-Arachide-Fumure minérale. Ces observations traduisent le caractère positif de l'association de l'arachide au maïs comme source de fertilisation.

Analyse de dominance

Le Tableau 5 présente le total des coûts variables qui diffèrent et les bénéfices nets correspondant à chaque technologie. A ce niveau, l'analyse devant porter sur les différentes technologies, les coûts afférents au semis, à l'utilisation de fumure (achat de fumure et épandage), au sarclage et à la récolte du produit issu de la production sont considérés comme des coûts variables. Ils sont pour ce fait intégrés dans l'analyse de dominance.

Tableau 1. Incidence des plants de *Striga* (nombre) par plant de maïs dans 29 champs paysans en 2002-2003 au nord du Bénin.

Traitement	2002			2003		
	6 SAS	9 SAS	12 SAS	6 SAS	9 SAS	12 SAS
Maïs pur sans engrais	2,56	4,21	6,18	2,23	3,63	5,57
Maïs pur avec engrais	1,95	3,26	6,02	1,20	1,86	2,88
Maïs avec engrais + arachide	1,08	1,92	4,33	0,75	1,36	2,21
Maïs avec engrais + *Aeschynomene*	0,96	1,83	2,88	0,58	1,23	1,92
Ecart type moyen	0,146	0,204	0,218	0,146	0,204	0,218

Variété de maïs utilisée = EV DT 97 STR C_1

Tableau 2. Rendement grain (kg/ha) dans 29 champs paysans en 2002–2003 au nord du Bénin.

Traitement	Rendement	
	2002	2003
Maïs pur sans engrais	840	680
Maïs pur avec engrais	1690	1810
Maïs avec engrais + arachide	1260	1980
Maïs avec engrais + *Aeschynomene*	1620	2210
Ecart type moyenne	61	

Tableau 3. Effets comparatifs induits par les traitements sur le rendement grains maïs dans 29 champs paysans au nord du Bénin.

kg/ha			Ecart type
Fumure	Légumineuses	Arachide/*Aeschynomene*	moyenne
990	1020	290	61

Tableau 4. Budget partiel par technologie.

Libellés	Unités	Technologies			
		Maïs (T0)	Maïs + fumure (T1)	Maïs+ Arachide+ fumure minérale (T2)	Maïs+*Aes-chynomene* + fumure minérale (T3)
A. Revenu de vente					
A.1. Revenu Maïs	*FCFA/ha*				
1.Rendement moyen Maïs	kg/ha	741	1710	1555	1893
2.Prix unitaire Maïs	FCFA/ha	60	60	60	60
Sous-Total revenu Maïs	*FCFA/ha*	*44460*	*102600*	*93300*	*113580*
A.2. Revenu Arachide/ Aeschynomene					
1.Rendement moyen en graine d' Arachide ou en fourrage d'*Aeschynomene*	kg/ha	0	0	776	1750
2.Prix unitaire Arachide graine ou Fourrage *Aeschynomene*	FCFA/ha	0	0	210	50
Sous-Total revenu Arachide/Aeschynomene	*FCFA/ha*	*0*	*0*	*162960*	*87500*
Revenu Total		*44460*	*102600*	*256260*	*201080*
B. Coûts variables					
1.Semence Maïs (achat, transport)	FCFA/ha	2695	3250	2113	3250
2.Semence *Aeschynomene* (achat, transport)	FCFA/ha	0	0	0	18000
3.Semence Arachide (achat, transport)	FCFA/ha	0	0	17167	0
4.Main-d'œuvre Semis (Maïs, Arachide/ *Aeschynomene*)	FCFA/ha	5000	5000	9000	7000

Tableau 4. Contd.

Libellés	Unités	Technologies			
		Maïs (T0)	Maïs + fumure (T1)	Maïs+ Arachide+ fumure minérale (T2)	Maïs+*Aeschynomene* + fumure minérale (T3)
5.Main-d'œuvre Sarclage	FCFA/ha	7093	9760	14000	18160
6.Fumure (achat, transport et main-d'œuvre d'épandage)	FCFA/ha	0	36775	36775	36775
7.Main-d'œuvre Récolte Maïs	FCFA/ha	8000	12500	12775	12775
8.Main-d'œuvre Ramassage Maïs	FCFA/ha	3000	5925	5675	5675
9.Main-d'œuvre Egrenage Maïs	FCFA/ha	1500	5550	5663	5663
10.Main-d'œuvre Récolte *Aeschynomene*	FCFA/ha	0	0	0	12500
11. Main-d'œuvre Récolte Arachide	FCFA/ha	0	0	8797	0
12. Main-d'œuvre Ramassage Arachide	FCFA/ha	0	0	8400	0
13. Main-d'œuvre Egoussage Arachide	FCFA/ha	0	0	14047	0
Total coûts variables	FCFA/ha	*27288*	*78760*	*134412*	*119798*
Bénéfices nets	*FCFA/ha*	*17171,8*	*23840*	*121848,5*	*81282*

Tableau 5. Analyse de dominance par technologie.

Paramètres	Technologies			
	Maïs (T0)	Maïs + fumure (T1)	Maïs+*Aeschynomene* + fumure minérale (T3)	Maïs+ Arachide + fumure minérale (T2)
Total des coûts qui varient (FCFA/ ha)	27 288	78 760	119 798	134 412
Bénéfices nets (FCFA/ha)	17 171,75	23 840	81 282	121 848,5

On remarque de ce tableau que les technologies se succèdent en progression ascendante en fonction de la totalité des coûts qui varient. Les bénéfices nets s'élèvent également dans le même sens de progression.

Aucune technologie n'est donc dominée. La pratique paysanne qui consiste à la production de maïs sans autre apport présente le plus faible bénéfice net. La technologie associant la fumure et l'Arachide donne un bénéfice net supérieur à toutes les technologies mais engendre également des coûts plus élevés. Cette technologie (association Maïs+Arachide+Fumure) est donc plus rentable que toutes les autres technologies.

Il ressort de cette analyse que la technologie associant la fumure et l'arachide au maïs est celle qui présente la meilleure performance

Tableau 6. Analyse marginale des technologies nondominées.

Paramètres	Unité	Technologies			
		Maïs (T0)	Maïs + fumure (T1)	Maïs+*Aeschynomene*+ fumure minérale (T3)	Maïs+ Arachide + fumure minérale (T2)
Bénéfices marginaux	FCFA/ha	-	6 668,25	57 442	40 566,5
Coûts marginaux	FCFA/ha	-	51 472	41 038	14 614
Taux marginal de rentabilité	%	-	13	140	278
Taux minimum acceptable de rentabilité	%	-	107	107	107

économique. Elle est donc la meilleure alternative et peut être adoptée par le producteur. Toutefois, la technologie associant la fumure et l'*Aeschynomene* présente également une meilleure performance économique mais elle ne saurait égaler celle de la fumure avec arachide.

Taux Marginal de Rentabilité (TMR)

Ce taux traduit le bénéfice additionnel que le paysan peut récupérer sur un investissement donné. Le Tableau 6 présente l'analyse marginale de toutes les technologies car aucune n'est dominée.

L'observation de ce tableau montre que le Taux Minimum de Rentabilité (TMR) est supérieur au Taux Minimum Acceptable de rentabilité (TMAR) pour la technologie associant au maïs, l'*Aeschynomene* et la fumure minérale et celle combinant au maïs, l'arachide et la fumure minérale. Ces deux technologies peuvent donc être recommandées. Pour chaque unité monétaire (FCFA) investie dans la technologie utilisant l'*Aeschynomene* avec apport de fumure minérale, le paysan peut investir 1 FCFA et obtenir 1,4 FCFA de bénéfice additionnel. Dans le cas de la fumure avec l'arachide, lorsque le paysan investit 1 FCFA, il gagne 2,78 FCFA comme bénéfice additionnel. Par contre, la technologie associant uniquement la fumure minérale au maïs présente un TMR très inférieur au TMAR. Cette technologie n'est donc pas à recommander aux paysans de ces zones.

Opinion des paysans

Les paysans accueillent très favorablement la technologie, car elle leur permet de réduire l'infestation du *Striga* qui constitue la bête noire de leurs céréales. Les traitements maïs + arachide et maïs + *Aeschynomene* retiennent leur attention. Tous deux réduisent l'effet du *Striga,* selon plusieurs d'entre eux *Aeschynomene* est un fertilisant du sol, mais difficile à gérer. Le surcroît de rendement obtenu par l'utilisation de l'*Aeschynomene histrix* par rapport à l'arachide est de 290 kg/ha. Cependant son avantage est qu'ils possèdent des fourrages pour leurs animaux en temps de soudure. Le traitement maïs associé à l'arachide joue le même rôle et deux récoltes peuvent être faites sur la même parcelle.

Discussion

L'incidence du *Striga hermonthica* varie selon le traitement. Le plus infesté a une incidence de 5,57 plants *Striga hermonthica* par plant de maïs. Ce niveau d'infestation est raisonnable. Il indique que les parcelles d'expérimentation étaient relativement infestées et que les essais ont été installés sur les sites appropriés par rapport à l'objectif de l'essai. L'association maïs + légumineuses diminue le nombre de plants de *Striga hermonthica* émergés. Par conséquent elle diminue la production de graines de *S. hermonthica* au cours de la saison. Cela confirme les résultats publiés par Carsky et al. (1999). Le faible rendement obtenu avec le maïs + arachide malgré l'application de la fumure s'explique par l'utilisation d'une partie des éléments nutritifs du sol au profit de l'arachide pour la formation des graines. L'augmentation de l'infestation observée à la 12ème semaine (à la récolte) après semis dans la culture de maïs + fumure n'a aucun effet sur le rendement grains maïs car les plants sont déjà enfin de cycle et les épis bien formés.

Les analyses financières indiquent que les pratiques associant les légumineuses et la fumure minérale au maïs sont plus rentables. La comparaison du Taux Marginal de Rentabilité (TMR) avec le Taux Minimum Acceptable de Rentabilité (TMAR) montre que la technologie améliorée associant l'arachide avec apport de fumure minérale est la meilleure alternative. En effet, elle présente un TMR (278%) nettement supérieur au TMAR (107 %). La fumure minérale n'influence pas fortement l'amélioration de la productivité du maïs dans la zone d'étude. En effet, l'utilisation de la fumure seule ne permet pas de dégager un bénéfice net additionnel.

Conclusion

L'association maïs-légumineuse concourt à réduire le nombre de plants de *Striga* émergeant au-dessus du sol, favorisant ainsi la diminution de stock de graines *de Striga* dans le sol, l'intensité d'infestation des champs par le *Striga* et l'amélioration de rendement du maïs. L'analyse de dominance montre qu'aucune technologie n'est dominée. L'analyse marginale indique que les technologies relatives à l'association des légumineuses (*Aeschynomene histrix* ou Arachide) avec fumure sont celles qui donnent la meilleure rentabilité pour les producteurs. L'arachide constitue la légumineuse qui réagit très favorablement à la production du maïs dans cette zone. Il ressort de ces observations que dans la phase actuelle de la conduite de l'essai dans la zone d'étude, l'utilisation des légumineuses joue un rôle important dans l'amélioration des potentialités productives du maïs.

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Herbicide resistant maize: a novel method to control *Striga* in Africa

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Abstract

Grain yield of maize (*Zea mays* L.) in Africa is greatly constrained by the parasitic weed *Striga hermonthoica* (Del.) Benth. The weed infests maize on an estimated 20 million ha, making it a major cause of maize yield reduction from near the world average of about 4.2 t/ha a few decades ago, to the present level of 1.3 t/ha. Doubling yields from 1.0 t/ha would produce enough food for 400 million people in Africa. One way to increase maize productivity and production that would have immediate impact in sub-Saharan Africa is to control the weed. CIMMYT and its partners have developed a unique technology for *Striga* control in maize. The technology combines low doses of imazapyr (<30 g/ha) herbicide applied as a seed coating to non-transgenic imidazolinone resistant (IR) maize seed to effect early *Striga* control before or during attachment to the maize roots. The technology has no adverse effects on intercropped legumes if sown more than 12-cm from the treated maize seed, and it costs only 4 USD/ha, in addition to about 8% increase in seed costs. CIMMYT has developed and tested IR early and late OPVs adapted to the mid-altitude ecology of western Kenya. Twenty-two early IR OPVs were evaluated across 7 sites under both *Striga*-free and *Striga*- infested conditions in Western Kenya. Five cultivars out yielded the best commercial *Striga* tolerant check (KSTP94) under both *Striga*- free (5.7 vs. 5.1 t/ha for the check) and *Striga*-infested (3.4 vs. 1.7 t/ha for the check) conditions. The number of *Striga* plants was three times lower under IR OPVs compared to the check. This technology and germplasm could increase maize production in sub-Saharan Africa.

Résumé

Le rendement grain du maïs (*Zea mays* L.) est sérieusement affecté par la plante parasite *Striga hermonthica*. L'herbe parasite *Striga* affecte le maïs sur des superficies estimées à 20 millions d'hectares, faisant de celui-ci, une des causes majeures de la réduction des rendements de maïs de près de la moyenne mondiale de 4.2 T/ha dans les dernières décennies, à 1.3 T/ha à présent. En doublant les rendements de 1.0 T/ha, il y aurait assez de nourriture pour 400 millions de personnes en Afrique. La lutte contre le striga est une option pour augmenter la productivité et la production du maïs en Afrique sub-sahariene. Une technologie exceptionnelle pour la lutte contre le *Striga* sur le maïs a été développée par le CIMMYT et ses partenaires. La technologie combine des doses faibles de l'herbicide imazapyr (<30 g/ha), appliqué en enrobé aux semences de maïs non–transgéniques et résistantes à l'Imidazolinone (RI). Cela contribue à un contrôle précoce du *Striga* avant ou pendant la fixation du parasite aux racines du maïs. Il n'y a pas d'effets nefaste sur l'association avec les légumineuses, lorsque celles-ci sont semées à plus de 12 cm des semences traitées de maïs. Cela coûte 4 USD/ha, en plus d'un surcoût de la semence d'environ 8%. Le CIMMYT a développé et testé des variétés à pollinisation libre précoces et tardives, resistantes à Imazapyr (RI) adaptées à la moyenne–altitude de l'écologie de l'ouest du Kenya. Vingt deux variétés à pollinisation libre précoces et RI , ont été évaluées à travers 7 sites aussi bien sous infestation de *Striga,* que dans des conditions de non-infestation à l'ouest du Kenya. Cinq cultivars ont eu des rendements supérieurs au meilleur témoin commercial tolérant à *Striga* (KSTP94) aussi bien en conditions de non infestation de *Striga* (5.7 contre 5.1 T/ha pour le témoin) et sous infestation de *Striga* (3.4 contre 1.7 T/ha pour le témoin). Le nombre de plants de *Striga* était trois fois plus faible avec les variétés à pollinisation libre RI qu'avec le témoin. Cette technologie et le germplasme pourraient faire augmenter la production de maïs en Afrique sub-Saharienne.

Background

Striga hermonthica (Del.) Benth. and *S. asiatica* adversely affect grain production of cereal crops; including maize (*Zea mays* L.), pearl millet (*Eleusine corocana* L.), sorghum [*Sorghum bicolor* (L.) Moench] and upland rice (*Oryza sativa* L.) throughout Africa where, according to FAO statistics, over 100 million people lose at least 50% of their crop yield to this parasite annually (Berner *et al.* 1995). Much of the maize producing areas of Kenya is highly *Striga*-prone (Fig.1). Grain yield of maize in sub-Saharan Africa for the last two decades or more has remained about 1.5 t/ha, well below the world average of 4.2 t/ha due to infestation by *S. hermonthica,* along with low soil nitrogen, drought and foliar diseases such as the maize streak virus (MSV). *Striga* spp. are obligate parasitic plants commonly found in cereal-based agricultural systems of the poor subsistence farmers in Africa. *Striga* produces large amounts of seed that are triggered into germination when they are close to the roots of potential host plants. Otherwise, the seed can stay dormant in the soil for over 20 years. Most *Striga*-infested areas in Africa have very high levels of the *Striga* seeds in the soil due to years of neglect and mismanagement. Although crop rotation and

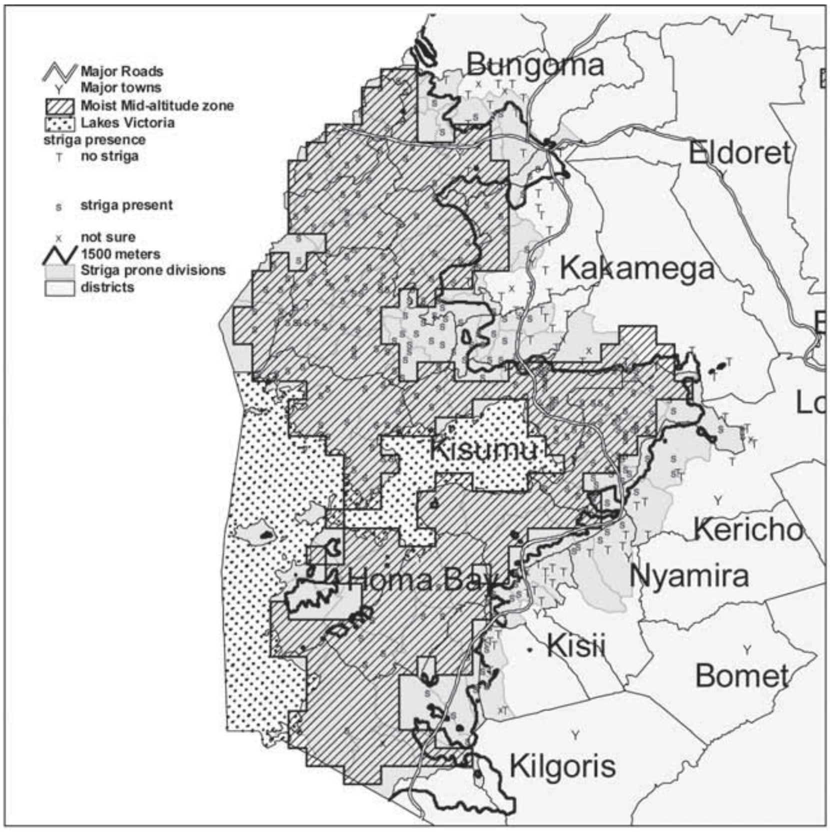

Figure 1. *Striga*-prone areas in Western Kenya.

intercropping involving grain legumes (Carsky *et al*. 1994; Carsky *et al*. 2000; Khan *et al*. 2000; Oswald and Ransom 2001), application of organic and inorganic fertilizers (Combari *et al*. 1990; Mumera and Below 1993; Gacheru and Rao 2001), and the use of *Striga* tolerant cultivars (Kim *et al*. 2003; Diallo *et al*. 1997) can partially reduce the problem, no short-term control measure has been developed that subsistence farmers could use within their limited financial resources, or that fits well into their traditional cropping systems. Thus there is an immediate need for cost-effective control measures that meet at least two criteria: (i) controlling *Striga* itself, so that maximum crop yields can be achieved each cropping season; and (ii) depleting the *Striga* seed bank in the soil. Such technologies are needed as stopgap control measures until crop varieties with adequate level of genetic resistance become available (Kanampiu *et al*. 2001a).

The International Maize and Wheat Improvement Center (CIMMYT), Mexico, and its partners have developed a unique technology for *Striga* control in maize. The technology involves the application of low doses of a herbicide, imazapyr (<30g/ha), as a seed coating chemical to non-transgenic imidazolinone resistant (IR) maize seed for early *Striga* control before or during attachment to the maize roots. Kanampiu *et al.* (2002) reported that imazapyr reduced the *Striga* seed bank by 80–100% in the 0–30 cm soil layer. There are no effects on intercropped legumes, if they are sown at least 12 cm apart from the treated maize seed (Kanampiu *et al.* 2002). Since the herbicide can be added to the standard seed treatment, the extra cost of this technology is limited to the cost of the herbicide, estimated at about 4 US$/ha, which corresponds to an increase of 8% of the seed cost (Kanampiu *et al.* 2001a). From 1996 to 2004, the herbicide resistance gene was bred into newly developed stress tolerant tropical maize varieties. During 2004, several new IR-maize OPVs were tested on-station and on-farm in sub-Saharan Africa.

In this paper, (i) the methods used for the development of herbicide resistant maize are described in some detail; (ii) results of the 2004 variety evaluation trials carried out in East Africa are presented with emphasis on the effect of the herbicide treatment on *Striga* control and grain yield; (iii) an economic analysis of the trials are presented; (iv) the potential impact of the technology is assessed and (v) the effect on producers, consumers, and the resource-poor farmers are discussed.

Materials and Methods

Imidazolinone resistant (IR) germplasm development

The initial testing of the low-dose herbicide seed treatment technology was on the IR maize hybrid, PH 3245-IR, developed by Pioneer Seeds. This hybrid is a temperate material that is highly susceptible to maize diseases prevalent in the tropics. In 1996, PH 3245-IR was crossed with ZM503 (INTA/INTB) population at CIMMYT-Zimbabwe to incorporate the IR gene into a tropical maize germplasm background. Inbred lines with tolerance to drought, low nitrogen and MSV were later crossed with the IR-maize germplasm. This resulted in an IR synthetic maize population, with about 75% tropical genetic background. Starting from 1996, this population was used in herbicide trials (Kanampiu *et al.* 2001a). However, in addition to low grain-yield potential, the population was highly susceptible to *Turcicum* leaf blight (caused by *Exerohilum turcicum*) and gray leaf spot (caused by *Cercospora zeae-maydis*). Inbred lines that are resistant to these diseases were then developed from a conversion program initiated in CIMMYT–Kenya in 2000, involving ECAVL17STR, a *Striga* tolerant population (Kanampiu *et al.* 2001b). The inbred lines have been used to develop some of the varieties evaluated in the trials presented in this paper.

Another approach used involved the conversion of elite CIMMYT Maize Lines (CMLs) and stress tolerant open-pollinated varieties (OPVs) to IR. To start with, CIMMYT's Applied Biotechnology Center developed herbicide resistant lines, CML202-IR and CML204-IR. Using these sources of herbicide resistance as donor parents, a conventional backcross program was initiated in CIMMYT-Kenya. Early and intermediate stress tolerant OPVs developed under the Africa Maize Stress (AMS) and the Southern Africa Drought and Low Soil Fertility Projects (SADLF) were crossed with the IR single cross CML202IR x CML204IR. The BC_0F_1 crosses were planted along with the recurrent parents and four weeks after planting or after the first irrigation, the BC_0F_1 plants were sprayed with imazapyr (15 g a.i. ha^{-1}) as 25% Arsenal™. Higher doses of imazapyr at the early backcrossing stage led to male sterility of the plants, especially when applied close to the tasseling stage. Plants without the IR-gene died while those that were heterozygous were severely deformed. At flowering, bulked pollen of the recurrent parents was used to pollinate the resistant plants of BC_0F_1 crosses. The BC_1F_1 crosses and the recurrent parents were planted to form the BC_2 F_1 using the same procedure. During the formation of the BC_3F_1, 30 g imazapyr a.i./ha of herbicide was applied. The BC_3F_1 were recombined twice; however, the seeds were coated with imazapyr at the rate of 30 g a.i. /ha instead of the plants being sprayed.

Herbicide use

Spraying. Ten liters of water was mixed with 6 ml of 25% Arsenal™ in a 20-liter backpack sprayer and applied to maize plants at 8-10 leaf stage for selecting homozygous plants in an area of 500 m^{-2}. Thus the imazapyr rate was equivalent to 30 g a.i. /ha.

Coating procedure. Seeds were coated with the herbicide by mixing 54 gm of 20% a.i. lindane and 26% a.i. thiram-containing commercial seed-dressing powder (Murtano) with 600 ml water and 30 g imazapyr (per ha) to make a slurry. The seeds that served as control were treated with the insecticide/fungicide powder only. The slurry was added to 18 kg of IR-maize seed (enough for planting one hectare), to give about 0.56 mg a.i. imazapyr/seed, respectively (i.e. 45 g a.i./ha, at 53,300 maize plants/ha), assuming equal distribution of the chemical on the seeds. The treated seeds were then dried and planted in the field.

IR-OPVs Evaluation

In 2004 growing season A (2004A; long rainy season), 22 IR early OPVs along with 2 standard checks and one local *Striga* tolerant OPV check (KSTP94) were evaluated under *Striga*-free and artificial *Striga*-infested environments in East Africa. A 5 x 5 lattice design was used in 2-row plots, 5 m long, with 0.50 m between hills and 3 seeds/hill, which was later thinned to 2 plants/hill. The trial was replicated twice. During 2004 B season (short rains) the best early IR-OPV was selected and planted into 10-row plots, each row being 10 m long. The most popular commercial hybrid H513 was included in the trial, which was conducted in 15 farmers' fields under natural *Striga* infestation in western Kenya.

Artificial Striga *infestation*

For the artificial infestation, an inoculum was prepared by mixing about 5 g *Striga* seeds (25% purity and 25% viability) thoroughly with 5 kg fine sand. The inoculum was then added to an enlarged planting hole at a depth of 7-10 cm (directly below the maize) to ensure that each maize plant was exposed to a minimum of 5,000 viable *Striga* seeds in addition to those already in the field [applied in an area of 75 m^{-2} (121 hills: 11 rows, each 10 m-long, 11 hills per row)]. About 50 kg N and 128 kg P_2O_5/ha were applied at the time of planting in form of di-ammonium phosphate (18-46-0) to ensure vigorous maize development.

Data collection and analysis

Grain yield at 15% moisture under both *Striga*-free and *Striga*-infested conditions were recorded as well as the most important agronomic characters and foliar diseases. Analysis of variance was performed using combination of the following softwares: Microsoft ® Office Excel 2003, SAS® 9.1, and Fieldbk 5.1/7.1(CIMMYT 1999).

Economic analysis

For the economic analysis of agronomic trials of a new technology, the results are usually compared with the control, which is usually the current farmers' practice. In this study, two methods were used: partial budget analysis and marginal analysis. In partial budget analysis, different options or technologies were compared in terms of their net benefits (*NB*), defined as the gross margin (yield times output price) minus the variable costs (*VC*). In marginal analysis, the extra net benefit ΔNB (the yield gain times the output price) was compared to the extra variable costs ΔVC (in this case, the cost of the herbicide), by calculating the marginal rate of return (*MRR*); that is:

$$MRR = \frac{\Delta NB}{\Delta VC}$$

This ratio represents the return a farmer receives from his investment on a new technology. During the last 5 years in East Africa, maize prices have more or less followed international prices; an average of 160 US$/ton was, therefore, used for the economic analysis.

Impact assessment

To estimate the potential impact of the herbicide resistant maize in Western Kenya, the area infested by *Striga* was determined using geo-referenced data from a farm-level survey conducted from 1993 (Frost 1995). Using a survey conducted from 1992 (Hassan *et al.* 1995), crop loss was calculated from farmer estimates. Agricultural statistics obtained from the Ministry of Agriculture, mostly district level data, and agricultural statistics at the division level, compiled by the International Livestock Research Institute (ILRI), were intersected with the map to calculate the maize production area and the expected crop loss. Similarly, population data from the 1999 population census (Central Bureau of Statistics 2001) were added to the map to calculate the number of households affected. Finally, data from a 2001 survey of 123 farmers, randomly selected using a two-stage sampling design, were used to determine farmers' interest and willingness–to–pay.

Results and Discussion

Effect of IR-maize on Striga

As expected, the number of *Striga* plants/m^2 was significantly higher in the sites with artificial infestation, with a higher *Striga* emergence in Alupe than in Kibos. On average, susceptible checks produced 198 *Striga* plants/m^2 in Alupe whereas most of the IR-OPVs produced only 0-3 *Striga* plants/m^2, with 2 exceptions that produced 8 and 18 *Striga* plants/m^2 (data not presented). Averaged across 7 sites, the IR-OPVs produced 3 *Striga* plants/m^2 versus 71 plants/m^2 produced by the checks (Table 1). The slight variation in the number of *Striga* plants produced by the IR-maize cultivars could be attributed to the heterogeneity of the field which led to water logging in some parts. In such spots, some of the herbicide could have been leached or washed away before it killed all the *Striga* seeds around the planted maize seeds. In some cases, very low grain yield was observed even where the number of *Striga* plants was zero, indicating that yield reduction was due to other factors such as drought and low soil fertility, or phytotoxicity of the *Striga* attack (Kanampiu *et al.* 2001a,b; Ransom *et al.* 1996).

Yield gains from IR-maize

Data on grain yield and some other agronomic traits are presented in Table 1. Across sites, 6 IR-OPVs yielded 5.3-5.8 t/ha under optimum conditions, whereas the best check, hybrid H623 yielded 5.9 t/ha. The 2 other checks, KSTP94 (*Striga* tolerant OPV) and WS202 (normal OPV) yielded 5.1 and 4.6 t/ha. Under artificial infestation, the selected IR-OPVs yielded 2.5-3.4 t/ha whereas the checks yielded 0.8-1.7 t/ha. The *Striga* tolerant check yielded as much as the *Striga* susceptible OPV (1.7 t/ha), 100% less than the best IR-OPV (3.4 t/ha). The average yield of the selected IR-OPV was 93% higher (2.7 t/ha) than the average yield of the checks (1.4 t/ha). The IR-OPVs and the checks

Table 1: Grain yield (t/ha), agronomic characters and *Striga* plants/m^2 of early IR OPVs tested under both *Striga-infested* and *Striga-free* conditions in 7 East African locations during the 2004A season.

		Grain Yield									
Entry	Pedigree	OPT* Across	STR** Across	Anth Date	ASI	Husk Cover	Ear Rot	GLS	Eturc	Ear Aspect	Striga
		t/ha	t/ha	d	d	%	%	1-5	1-5	1-5	#/sq m
17	ECA-STRIGOFF-VE-216	5.7	3.4	65	5	8	2	1.7	1.3	2.0	1.8
9	ECA-STRIGOFF-VE-208	5.4	2.9	70	7	7	3	1.6	2.5	2.4	2.6
7	ECA-STRIGOFF-VE-206	5.8	2.5	68	8	12	1	2.0	2.3	2.3	7.8
18	ECA-STRIGOFF-VE-217	5.3	2.7	66	7	15	2	1.8	1.8	2.6	1.8
10	ECA-STRIGOFF-VE-209	5.4	2.5	69	5	11	2	2.1	2.5	2.5	1.0
11	ECA-STRIGOFF-VE-210	5.1	2.6	67	5	9	3	2.1	1.0	2.1	1.8
12	ECA-STRIGOFF-VE-211	5.1	2.2	68	4	12	8	2.0	2.0	2.6	1.5
8	ECA-STRIGOFF-VE-207	5.0	2.2	70	5	12	3	2.0	1.3	2.5	2.3
4	ECA-STRIGOFF-VE-203	4.5	2.6	73	9	7	1	1.7	1.5	2.4	1.0
14	ECA-STRIGOFF-VE-213	5.5	2.1	67	2	6	2	1.8	1.8	2.6	3.7
20	ECA-STRIGOFF-VE-219	4.7	2.7	65	7	7	1	2.4	2.8	2.6	2.2
22	ECA-STRIGOFF-VE-221	4.4	2.4	66	3	8	2	2.3	1.8	2.4	3.4
16	ECA-STRIGOFF-VE-215	5.1	2.0	68	5	9	1	2.3	3.0	2.7	2.7
13	ECA-STRIGOFF-VE-212	4.4	2.4	68	7	11	5	2.1	2.0	2.6	2.4
19	ECA-STRIGOFF-VE-218	4.5	2.1	66	4	7	2	2.4	2.5	2.6	2.7
23	KSTP-Check1	5.1	1.7	69	8	14	3	2.8	1.3	3.0	52.1
21	ECA-STRIGOFF-VE-220	4.8	1.9	66	-4	8	4	2.1	2.3	2.6	1.4
24	WS202-Check2	4.6	1.7	66	7	7	3	2.1	3.5	2.9	91.4
6	ECA-STRIGOFF-VE-205	4.2	1.8	65	4	20	10	2.2	2.5	2.9	3.6
15	ECA-STRIGOFF-VE-214	3.8	1.8	67	7	9	3	2.2	2.8	2.8	12.7
25	H623-Check3	5.9	0.8	68	10	8	10	3.0	1.3	3.6	70.3
5	ECA-STRIGOFF-VE-204	3.3	1.3	65	2	15	2	1.9	1.8	2.8	1.5
2	ECA-STRIGOFF-VE-201	2.5	1.4	66	3	16	5	2.3	2.0	2.8	0.9
3	ECA-STRIGOFF-VE-202	2.8	1.0	66	1	20	-1	2.9	2.0	2.5	2.3
1	ECA-STRIGOFF-VE-200	2.2	1.0	66	2	25	6	2.3	1.8	3.5	1.0
Mean		**4.6**	**2.1**	**67.1**	**4.8**	**11.3**	**3.4**	**2.2**	**2.0**	**2.7**	**11.0**
LSD (0.05)		**1.1**	**0.8**	**1.5**	**5.4**	**6.3**	**4.8**	**0.6**	**1.2**	**0.5**	**2.4**
MSe		**0.6**	**0.3**	**3.3**	**6.4**	**26.8**	**10.2**	**0.2**	**0.3**	**0.3**	**2.6**
CV		**16.2**	**25.5**	**2.7**	**53.1**	**45.7**	**93.5**	**19.5**	**27.2**	**19.2**	**50.1**
Min		**2.2**	**0.8**	**64.5**	**-3.5**	**5.9**	**-0.7**	**1.6**	**1.0**	**2.0**	**0.9**
Max		**5.9**	**3.4**	**72.5**	**9.5**	**24.9**	**10.0**	**3.0**	**3.5**	**3.6**	**91.4**

* = Optimum

** = *Striga* conditions

were of the same maturity (about 68 days to silk); therefore, the yield differences among the IR-OPVs and the checks were not due to the differences in maturity. Moreover, all IR-OPVs are streak resistant and are more resistant to GLS than the checks (Table 1).

Average grain yields of 2.3 and 1.4 t/ha were recorded for the IR-OPV and the most popular hybrid H513 across 15 farmer's fields, with an average of 1 *Striga* plant/m^2 under the IR-OPV and 7 *Striga* plants/m^2 under the hybrid (Table 2).

Economic analysis

The yield gains under *Striga*-infested conditions ranged from 0.8 to 2.7 t/ha. This represented increased gross margins of 128 to 432 US$/ha. The cost of the herbicide was estimated at 4 US$/ha. However, the seed needs to be purchased each year, unlike local varieties or improved OPVs. Seed

Table 2: Grain yield and *Striga* count for IR-OPV compared to a local hybrid check (H513) from 15 farmers' fields in Western Kenya during the 2004B season.

Site	Grain yield (t ha^{-1})		*Striga* count (plants m^{-2})	
	Check (H513)	IR-OPV	Check (H513)	IR-OPV
1	2.2	1.9	7.7	0.0
2	2.6	1.9	0.0	0.0
3	3.4	1.9	2.2	0.2
4	0.8	0.9	48.6	5.5
5	2.5	2.3	2.2	0.8
6	3.1	2.6	3.1	0.8
7	0.6	2.2	4.0	0.0
8	0.3	1.8	0.2	0.0
9	0.7	1.6	0.3	0.0
10	0.5	2.7	2.0	0.0
11	0.3	3.7	3.4	0.0
12	1.2	5.4	2.1	0.4
13	0.7	3.6	16.9	0.1
14	1.1	1.5	2.3	0.1
15	1.4	1.1	6.3	0.0
Means	1.4	2.3	6.9	0.5

price in 2004 was 1.6 US$/kg or 40 US$/ha (at a seed rate of 25 kg/ha). Considering this, the total extra cost of herbicide resistant maize would be 44 US$/ha when compared to a local or a recycled OPV, but only 4 US$/ha if compared to a hybrid. The herbicide can be mixed with the regular seed treatment chemicals; therefore, there are no additional costs of seed preparation, and there are no application costs for the farmer. When compared to recycled OPVs, therefore, the extra benefit would range from 84 US$/ha to 388 US$/ha, for an extra cost of 44 US$/ha, or a MRR of 21 to 97. For hybrids, the MRRs are from 31 to 107. These ratios suggest very high returns to the investment; therefore, the technology stands a very good chance of being adopted, if these yield increases are realized in farmers' fields.

Impact assessment

The results of the different surveys conducted in this study indicated that 40-70% of the maize area in the *Striga*-prone zone (Fig. 1) was infested with *Striga* and that grain yield of infested fields, on average, was about 50% lower than yield from *Striga*-free areas. Suppressing *Striga* infestation could, therefore, increase current average yields by 25-54%. In other words, yields could increase by 0.34-1.2 t/ha which, when averaged over 210,000 ha, translates to about 70,000-256,000 tons. At a grain price of 160 US$/ton, this amount represents 11-42 million US$. The adoption rate of this technology will determine how soon the farmers benefit from the technology. On the basis of the results obtained from the farmers' fields, however, an adoption rate of 25-50% can be expected, resulting in an expected benefit of 2.8 to 20.5 million US$ per annum.

Further research

Despite the advantages of using the IR-maize seed coating technology to control *Striga* infestation and damage on maize, it has some drawbacks. When very heavy rains follow planting, the herbicide gets leached and washed away, thus making the technology less effective. Also, after planting when the soil is dry or when a dry spell occurs immediately or soon after planting, emergence may be drastically reduced. Studies that could correct the drawbacks, such as herbicide slow-release formulations, are presently in progress.

Farmers in the *Striga*-prone area do not regularly purchase improved seed, often because of financial constraints. It is therefore very important to demonstrate the technology to the farmers as soon as possible, to allay their fears and assure them of its profitability. Moreover, collaboration with micro-credit organizations might improve adoption rates substantially. Accurate impact assessment depends on the quality of the data. It is important that crop loss due to *Striga* be accurately estimated, as well as the yield increases of the herbicide resistant maize under farmer-managed conditions.

Finally, the target area for this technology in East Africa has poor soil fertility, and farmers apply little or no fertilizer to the maize crop. To fully realize the potential benefit of the technology, efforts should be made to combine it with appropriate soil fertility management practices.

Conclusions

The use of IR-maize seed coating technology increased maize grain production and reduced the number of *Striga* seed and plants per unit land area. The technology is relatively cheap, and marginal analysis indicated good returns to the investment. This technology should be integrated with other methods of *Striga* control to effectively deplete the *Striga* seed bank in the long run. Further research is needed to address various drawbacks of the technology, including slow-release formulations that could reduce the rate of leaching of the herbicide under heavy rains and scorching under dry spells, deployment of resistant varieties and long-term economic impact assessments. The success of the IR-maize seed coating technology will largely depend on the existence of a dynamic seed sector to process and market true IR-maize coated seed.

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Effects of maize–cowpea intercropping on maize stem borers and their natural enemies

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Abstract

The effect of maize–cowpea intercropping on stem borer infestation, preservation of biodiversity, relative abundance of predators and the economic profitability of intercropping was investigated in farmers' fields in central Cameroon. The study included three treatments: (i) sole maize (*Zea mays* L.) treated with insecticide (Carbofuran), (ii) maize intercropped with cowpea [*Vigna unguiculata* (L) Walp], and (iii) untreated sole maize as the control. The experiment was laid out as a randomized complete block design (RCBD). Borer control was significantly higher for treated sole maize than maize–cowpea intercrop and the control. Although significant difference could not be always found between intercropped and untreated maize, borer control was generally higher in the intercrop. The most abundant predator was the earwig, *Diaperasticus erythrocephala*. Incidence of this and other stem borer predators was higher in intercropped and control plots than in plots treated with the insecticide. Economic analysis showed that maize–cowpea intercrop provided 1.03 and 1.50 more profit than the insecticide-treated sole maize and the untreated control, respectively. It was concluded that intercropping maize with cowpea reduces borer infestation on maize while preserving the abundance of the predators of maize stem borers.

Résumé

Une approche intégrée permettant une productivité plus élevée du maïs (*Zea mays* L) devrait inclure le contrôle cultural des foreurs de maïs. La capacité de contrôler les foreurs à travers l'association culturale maïs-niébé tout en faisant des profits et en conservant la biodiversité et l'abondance de leurs prédateurs ont été étudiés dans des champs paysans de la zone forestière du Cameroun. Les traitements évalués étaient (i) maïs en pure traité avec l'insecticide (carbofuran), (ii) maïs associé au niébé (*Vigna unguiculata* (L) Walp), et (iii) maïs en pure non traité, comme témoins. Le dispositif en block complètement randomisé a été utilisé. Les résultats montraient que le contrôle de foreurs était significativement plus élevé pour le maïs traité que pour le maïs associé et le maïs non traité. Bien que des différences significatives ne pouvaient pas toujours être obtenues entre le maïs associé et le maïs non traité, le contrôle des foreurs était généralement plus important pour le premier traitement que pour le second. Les foreurs de tige prédateurs étaient 28 et 27% plus abondants respectivement dans le maïs associé et le maïs non traité que dans les champs traités. Le prédateur le plus abondant était *Diaperasticus erythrocephala*. Il était négativement et significativement affecté sur le maïs traité, comparé aux autres traitements. L'analyse économique exécutée sur deux saisons a montré que l'association maïs-niébé était légèrement plus rentable, car il fournissait 1.03 et 1.50 plus de profit que le maïs traité et le témoins respectivement. Il a été retenu que l'association mais-niébé reduisait l'infestation des foreurs sur le maïs tout en préservant l'abondance des prédateurs des foreurs de tige du maïs.

Introduction

Stem borers are major pests of maize (*Zea mays* L) and are responsible for an estimated 50% of the maize grain-yield losses in most African countries (Usua 1968; Girdling 1978; Kumar and Sampson 1982; PNUD/FAO 1989). The major species in Cameroon include *Busseola fusca* (Fuller), *Sesamia calamistis* (Hmps), *Eldana saccharina* (Walker) and *Mussidia nigrivenella* (Ragonot) (Aroga 1987a,b; Cardwell *et al*. 1997). Synthetic insecticides may be used to control stem borers effectively, but the cost of the chemicals makes them out of reach of most African maize farmers, who are mostly resource-poor. In addition, pesticides generally have harmful side effects on human beings and the environment. Air and water contamination, postharvest residues, lack of selectivity and resurgence of resistant species, are some of examples of the side effects of pesticides on the environment (CCE, 1974). Therefore, it is advocated in national and international circles that the use of pesticides should be minimized.

Cultural control methods could be effective alternatives to the use of synthetic pesticides against arthropod pests in different agro-ecosystems. The cultural control methods use two strategies: (i) to make the environment less favorable to the pest, and (ii) to make the environment more favorable to the natural enemies of the pests. Increasing plant diversity is one of the cultural techniques that can make the ecosystems less favorable to the pest and/or more favorable to their natural enemies (Nordlund *et al.* 1984). Intercropping is one way of increasing vegetation diversity. Theoretically, plants in the intercropped systems benefit in several ways. These are the *associational resistance,* which is caused by a reduction of the pest's host-finding ability; the *resource concentration hypothesis,* which is the greater abundance of the enemy, and the diversity of natural enemies, which is refered to as the *enemies hypothesis* (Root 1973).

In Cameroon, maize is commonly intercropped with several other crops namely groundnut (*Arachis hypogaea* L.), cassava (*Manihot esculenta* Crantz.), soybean (*Glycine max* Merril.), beans (*Phaseolus* spp.) and cowpea [*Vigna unguiculata* (L.) Walp]. Cowpea is grown for its high nutritive value, as it is one of the main sources of proteins for the majority of the population in Africa (Ta'Ama 1983, 1988). Furthermore, its nitrogen fixing ability, as in most other grain legumes, is of special importance in enriching the soil (Giller and Wilson 1991; Giller *et al*. 1991; Reynolds *et al*. 1993).

Aroga and Coderre (2000) found that the population densities of stem borers on maize were significantly reduced in central Cameroon through intercropping of maize with groundnut. However, information about the effects of maize-cowpea intercropping on the dynamics of maize stem borer population buildup and associated natural enemies is lacking. The objectives of this study were, therefore, to (i) assess the effects of intercropping maize with cowpea on the abundance and diversity of maize stem borer species and associated natural enemies, and (ii) determine the economic profitability of this cropping system relative to maize crop treated with insecticide and monocropped maize as an untreated control.

Materials and Methods

Researcher-managed trials

Two researcher-managed trials were conducted in farmers' fields in Nyom II (forest zone) and Bafia (forest-savanna transition zone). The experimental design at each site was a randomized complete block with 3 treatments: (i) maize treated with Carbofuran[1], (ii) monocropped maize, and (iii) maize-cowpea intercropping. The maize variety CMS 9015 and cowpea variety BR1 were planted the same day in alternate rows at a population density of 50,000 plants per hectare, with a spacing of 0.25 m between plants and 0.80 m between rows. Each experimental plot was 26.4 m^2 (6.6 m x 4 m). The compound fertilizer 20-10-10 NPK was applied to the maize at the rate of 500 kg ha^{-1} four weeks after planting (WAP). Granules of Carbofuran were applied six weeks after planting at the rate of 15 kg ha^{-1} in the maize whorl of the plots protected with insecticide. Weed control was performed manually as necessary.

Farmer-managed on-farm trials

Twenty farmer-managed on-farm trials were established during the 2001 dry season. The trial in each farm was laid out as a randomized complete block design with the same three treatments as described

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[1] Trade name is Furadan

for the researcher-managed trials. Each farmer's field was considered as a replicate. Maize and cowpea were planted the same day on plots 20 x 10 m at 0.50 m x 0.80 m density. Insecticides and fertilizer were applied as for the researcher-managed trials.

Maize borers sampling

Visits were paid every two weeks to each site from 2 WAP until the end of the cropping season. During each visit, 100 plants were randomly sampled in the four inner rows and were examined for corn borers egg masses, larvae or pupae, and for predators and parasitoids. Then, destructive sampling was done on 10 plants randomly sampled in the outer rows for open stems and ear inspection at the reproductive stage. Eggs collected were kept in plastic vials, while the larvae collected were reared individually in petri dishes on maize leaves and/or cuttings, replenished every 2 days, until the emergence of the adult moths or until premature mortality. Pupae were also held in separate empty plastic cups until the emergence of adult moths.

Sampling of natural enemies

Dead stem borers were incubated in humid chambers and fungi that grew on them were isolated and identified. Predators were sampled using a modification of the whole-plant netting technique (Litsinger *et al.* 1991). One day before sampling, a nylon net (about 2 m high) was slipped over each of 5 randomly selected plants per plot, with its ends opened to allow free access to maize plants by both ground dwelling and flying arthropods. Plant netting was carried out about 2 hours after sunset, when predator activity on the plant canopy was highest (Hasse 1981). The next morning, plants were cut off at their bases and each of their parts were carefully examined for predators, which were caught and later identified.

Profitability of intercropping

Grain yield and its corresponding current market value were used for the economic analysis. The profit derived from intercropped plots was compared to the plots protected with insecticide. A partial budget was done for only costs and returns associated with the effects of the changes in the treatment of maize. The partial budget took into account the revenue from maize and cowpea in treated and intercropped plots, the cost of cowpea seed, Carbofuran and its application cost, and the cowpea planting and harvesting costs.

Statistical analysis

A one-way analysis of variance (ANOVA) was computed. Shannon-Weiner diversity index was calculated using the following formula $H' = -\Sigma\ (p_i)\ (\log\ p_i)$, where H′ is the index of species diversity (i.e.,

Table 1. Relative abundance and species diversity of maize stem and cob borers on maize variety CMS 9015 intercropped with cowpea.

Locality	Treatment	B. f.*	S. c.	E.s.	M.n.	H'
	Maize treated with insecticide	98.5	0.0	0	0.5	0.06
Nyom II	Maize-cowpea intercrop	96.5	3.5	0	0.0	0.21
	Control	96.0	4.0	0	0.0	0.25
	Maize treated with insecticide	96.5	2.5	0	0.0	0.14
Bafia	Maize-cowpea intercrop	96.5	2.5	1	0.0	0.19
	Control	89.0	10.0	1	0.0	0.48

*B.f.=*Busseola fusca*; S.c.=*Sesamia calamistis*; E.s.=*Eldana saccharina*; M.n.=*Mussidia nigrivenella*; H'=Shannon-Weiner's diversity index. Values in the table are means of 2 cropping seasons (1999 and 2000 second cropping seasons).

information content of sample bits/individual), Pi is the proportion of total sample belonging to one species (i.e. total number of individuals of one species/total number of individuals) (Peet 1974).

Results

Relative abundance and diversity of maize borers

B. fusca, S. calamistis, E. saccharina and *M. nigrivenella* were the stem and cob borer species collected during this study (Table 1). The first two species were present nearly in all treatments at Nyom II, while *M. nigrivenella* was absent in Bafia. On the other hand, *S. calamistis* was not found on maize treated with Carbofuran in Nyom II, but a few moths of *M. nigrivenella* were found. Borer species recorded in Bafia were present in the three treatments, except *E. saccharina,* which was absent in maize treated with Carbofuran. Species diversity indexes were low in treated maize plots and much higher in the untreated control plots at both locations.

Abundance of stem borer species

Results presented in Table 2 showed that the total number of stem and cob borer larvae of all stages and pupae collected in Nyom II were higher than in Bafia (1752 vs 324). Furthermore, the total number of borers in untreated plots was significantly higher than those from the other plots regardless of the location. *B. fusca* was the most abundant species in all the treatments. *Eldana saccharina* was absent in Nyom II while *M. nigrivenella population* was very small.

Maize borer infestation

The level of infestation of maize by stem and cob borers was significantly low on treated plots in all locations and planting dates (Table 3). In addition, the percentage of plants infested was lower in intercropped than monocropped maize, although a significant difference could be found only in the second date in Nyom II. The first planting date, which

Table 2. Abundance of maize stem and cob borer species on maize variety CMS 9015 intercropped with cowpea variety BR1 in Nyom II and Bafia, Cameroon, in 1999 and 2000.

Locality	Treatment	Borer species*				
		B.f.	S.c.	E.s.	M.n.	Total
Nyom II	Maize treated with insecticide	317 (28)**	0	0	0	317
	Maize-cowpea intercrop	393 (35)	3 (33)	0	1 (100)	397
	Control	420 (37)	6 (67)	0	0	426
	Total	1130	9	0	1	1140
Bafia	Maize treated with insecticide	149 (51)	3 (10)	1 (25)	0	154
	Maize-cowpea intercrop	67 (23)	8 (27)	1 (25)	0	76
	Control	74 (26)	19 (63	2 (50)	0	94
	Total	290	30	4	0	324

*B.f.= *Busseola fusca*; S.c.=*Sesamia calamistis*; E.s.=*Eldana saccharina*; M.n.= *Mussidia nigrivenella*. ** Figures in parentheses are percentages for a given species.

Table 3. Grain yield and borer infestation and tunneling on maize intercropped with cowpea in comparison with maize treated with Carbofuran in Nyom II and Bafia, Cameroon in 1999.

Locality	Planting date	Treatment	Parameters measured		
			Infestation, %	Tunneling, %	Yield tha^{-1}
Nyom II	31 Aug. 1999	Maize treated with insecticide	52.5±27.5a*	0±0a	5.4b
		Maize-cowpea intercrop	71.0 ± 1.3b	10.2±1.4ab	3.4a
		Control	82.5 ± 7.5b	20.0±9.6b	3.9a
	14 Sep. 1999	Maize treated with insecticide	51.3± 11.3a	2.4 ± 1.6a	2.6a
		Maize-cowpea intercrop	67.5 ± 2.5b	3.0 ± 0.5a	2.7a
		Control	72.5 ± 2.5c	6.7 ± 1.7a	1.9a
Bafia	31 Aug. 1999	Maize treated with insecticide	38.5 ± 1.5a	4.0 ± 2.4a	2.9a
		Maize-cowpea intercrop	48.5 ± 1.5ab	9.5 ± 1.2a	2.4a
		Control	58.5 ± 21.5b	8.5 ± 1.6a	2.6a

*Means followed by the same letter within a column are not significantly different at the 0.05 level of probability.

had higher infestation, may then be considered as the optimum planting date for maize in Nyom II when the objective is to have maximum natural borer infestation. The results also showed that borer infestation in maize was higher in Nyom II than in Bafia (Table 3).

Table 4. Maize stem borers' stem tunneling and corresponding yield on maize intercropped with cowpea in comparison with maize treated with Carbofuran.

Locality	Treatment	Parameters measured	
		Tunneling, %	Yield, t ha^{-1}
Mbangassina	Maize treated with insecticide	12.5a*	2.1a
	Maize-cowpea intercrop		
	Control	28.0b	1.8a
		42.3c	1.8a
Nkolnda	Maize treated with insecticide	17.6a	2.9a
	Maize-cowpea intercrop		
	Control	39.0ba	2.6a
		54.1c	2.8a
Minkoameyos	Maize treated with insecticide	3.7a	1.9a
	Maize-cowpea intercrop		
	Control	5.7a	2.2a
		7.8a	1.7a

*Means followed by the same letter within a column are not significantly different at the 0.05 level of probability.

The percentage of tunnels due to stem borers followed the same trend as the level of infestation. The proportion of stems tunneled was significantly lower in plots treated with Carbofuran than in intercropped and untreated plots (Tables 3 and 4).

The low level of infestation and low percentage of tunnels on treated maize indicate the efficacy of Carbofuran on stem borer control. The insecticide was applied six weeks after planting. At this stage the majority of larvae (especially *B. fusca*) were still in the whorl where granules of Carbofuran were applied.

A significant difference was found in maize grain yield between maize treated with Carbofuran and the other treatments in Nyom II (Table 3). In Bafia, there was no significant difference between treatments. Similar results were obtained in farmers' fields (Table 4). The grain yield in Bafia was very low in all treatments.

Maize grain yield of the insecticide treated plots was significantly higher than those of the other treatments. Also, there was a slight maize yield advantage of the maize-cowpea intercrop over the treated sole maize in 1999 at Nyom II.

Abundance of natural enemies of maize borers

Six families of predator species were associated with stem borers in all the treatments. These were Forficuludae (*Diaperasticus erythrocephala*), Coccinellidae (*Cheilomenes sulphurea sulphurea*), Blattelidae (*Blatella* sp.), Araneidae, Formicidae and Hemiptera (Table 5). Overall, earwigs

Table 5. **Abundance of maize stem borer predators and species diversity indices (H’) on maize variety CMS 9015 intercropped with cowpea variety BR1 at Nyom II and Bafia in Cameroon, 1999 and 2000.**

Location	Treatment	Number of arthropods						Total	H’
		D.e.*	C.s.	B.sp	Ants	Spiders	Others		
Nyom II	Maize treated with insecticide	39	2	1	14	22	1	79	1.74
	Maize-cowpea intercrop	50	0	2	0	23	1	76	1.13
	Control	40	3	3	9	25	2	82	1.82
	Total	129	5	6	23	70	4	237	
Bafia	Maize treated with insecticide	27	1	12	6	8	1	55	1.94
	Maize-cowpea intercrop	52	2	20	8	7	7	96	1.90
	Control	55	0	13	9	7	4	88	1.65
	Total	134	3	45	23	22	12	239	

* *D.e.=Diaperasticus erythrocephala; C*.s.=*Cheilomenes sulphurea sulphurea*; *B*. sp=*Blatella* sp.; H’=*Shannon-Weiner’s diversity index*

were the predominant predator species in each location and treatment. They were slightly more abundant in Bafia (51%) than in Nyom II (49%), and species diversity indices were slightly higher in Bafia than in Nyom II. No particular pattern of species distribution was observed among the treatments.

No parasitoid emerged from the larvae collected. However, the following five fungi species were recovered from 24 of the larvae collected: *Beauvaria bassiana, Fusarium moniliforme, F. oxysporium, F. semitectum, Aspergillus niger, Penicillium* and *Chaetonium*. All the fungi were found on larvae collected from both locations, except *Chaetonium* that was recovered from larvae collected in Bafia. *F. moniliforme* was predominant (recovered from 42% of larvae), followed by *Penicillium* (25%), *B. bassiana* (17%), *A. niger* (12%) and *Chaetonium* (4%).

Economic analysis

Total revenue per hectare derived from maize treated with Carbofuran was 500,000 FCFA and 275,000 FCFA for the maize component in the maize-cowpea intercrop. Additional revenue of 480,000 FCFA was obtained from the cowpea component of the intercrop (Table 6). Total costs were 69,065 FCFA for maize treated with Carbofuran and 55,565 FCFA for the intercrop. Subtracting total variable costs from total revenue gave net profits of 430,935 FCFA for Carbofuran-treated maize and 699,430 FCFA for intercrop. Thus an additional benefit of 268,495 FCFA was derived from intercropping. Therefore, maize-cowpea was more profitable than the use of Carbofuran to control stem borers of maize.

Discussion

The stem borer species *B. fusca, S. calamistis, E. saccharina* and *M. nigrivenella* were present in all the treatments, but their diversity indices were low in maize treated with Carbofuran. The high indices found in the untreated (control) plots within the same location suggests that maize borer species were more diversified in untreated than intercropped or treated plots. In addition, the species were more diversified in Bafia than in Nyom II. These results are consistent with those of Legendre and Legendre (1979), who suggested that low diversity indices indicated a higher biological activity of some species. In other words, low indices correspond to a less equitable species distribution. Overall, the results of the present study showed that *B. fusca* was the predominant species in all treatments in Nyom II as well as in Bafia.

Incidence of the borers was higher in untreated plots than in the other treatments. The low number of borers on the maize-cowpea intercrop supports the resource concentration hypothesis of Root

Table 6. Marginal Benefit-Cost Ratio (MBCR) of maize (variety CMS 9015) intercropped with cowpea (variety BR1) in comparison with maize treated with Carbofuran in Nyom II.

Benefit	Maize-cowpea intercrop	Treatment Maize treated with insecticide	Control
Cowpea yield (t/ha)	0.4	-	-
Maize yield (t/ha)	3.1	4.0	2.0
Revenue (x 1,000 FCFA.ha^{-1})			
From maize	775	1 000	500
From cowpea	480	-	-
Total Revenue	1255	1 000	500
Extra costs (x 1,000 FCFA.ha^{-1})			
Cost of cowpea seed	24	-	-
Cost of Carbofuran	-	37.5	
Labor cost to apply Carbofuran	-	31.565	-
Labor cost to plant cowpea	15.785	-	-
Labor cost to harvest cowpea	15.785	-	-
Total extra cost (x1,000FCFA)	55.570	69.065	-
Net Benefit (x1,000FCFA)	755	500	-
MBCR	13.0	7.2	

(1) It is assumed that maize is sold immediately after harvest. Therefore, storage loss is nil and measured maize yield is treated as net yield.

(2) Measured cowpea yield is taken as net yield with the same justification as in (1).

(3) Maize price = 250 FCFA/kg (local market price).

(4) Cowpea price = 1 200 FCFA/kg (local market price); quantity needed for seed: 20 kg/ha.

(5) Cost of Carbofuran = 2 500 FCFA/kg (local market price).

(6) Cost of labor to apply Carbofuran: 1 000 FCFA/6 hours man day x 31.565 man days/ha = 31,565 FCFA.

(7) Cost of labor to plant cowpea: 1 000 FCFA/6 hours man day x 15.782 man days/ha = 15,785 FCFA.

(8) Cost of labor to harvest cowpea: 1 000 FCFA/6 hours man day x 15.782 man days/ha = 15,785 FCFA.

(1973), which states that herbivores are more likely to find and feed on their host-plants planted as a monocrop than in intercrops. Kareiva (1983; 1985) suggested that changes in vegetational diversity largely affect herbivores by altering their patterns of immigration and emigration. Hasse (1981) and Litsinger *et al.* (1991) reported that some non-host plants in intercrop could act as mechanical barriers limiting the dispersion of larvae of some herbivores. Furthermore, according to Perrin (1977) and Theunissen (1994), intercropping may affect the ability of herbivores to find their host-plants either by hiding the plant from visually searching insects, or by masking their olfactory cues. Although mechanisms behind the resource concentration hypothesis responsible for the reduction of the number of borers in the maize-cowpea intercrops in the present study need to be determined, it may be suggested that cowpea, by covering the soil may have disturbed the dispersion of borers' larvae in intercropped plots or reinforced the activity of their natural enemies. However, our results did not confirm those of Ta'Ama (1988) who found no effect of intercropping on insect infestation and the associated yield loss. The reason for the differences in the results could be due to the fact that different crops were investigated in the two studies and the focus in Ta'Ama's study was on cowpea insects in general and not on stem borers.

Data obtained in the present study suggested that Nyom II, where stem and cob borers were more abundant with more severe damage, could be an effective location for the screening of maize germplasm for stem borer resistance. Similarly, the higher number of earwigs in Bafia (51% of the total) provides an explanation for the lower number of borers found at that location. In addition, intercropped plots contained more predators than the other plots. These results seem to corroborate the natural enemies hypothesis proposed by Root (1973). According to this author, a pest is suppressed because of the increase of an environment favorable to predators, parasites, or pathogens in an intercropping system. Natural enemies may increase in abundance in an intercrop because of more continuous availability and diversity of nutritional resources (preys, pollens, nectars) and shelters. Although there is no evidence that companion crops were a source that enriched the fauna of maize agro-ecosystems, it could be assumed that the presence of cowpea could have improved the soil cover, which is one of the most important elements of the microenvironment favorable to the survival of the earwig (Van Driesche and Bellows, 1996).

Results of the species diversity indexes obtained in the present study also indicated that predator species were more equitably distributed in Bafia than in Nyom II. The low number of predators (especially *D. erythrocephala*) observed in the treated plots (Table 5) may partly be explained by the fact that the insecticide used might have eliminated some natural enemies present in these plots. These results, therefore, emphasize the incompatibility between Carbofuran and *D. erythrocephala* if used in the same integrated pest management program.

An additional benefit of 268 495 FCFA has been derived from intercropped plots showing their superiority over the other treatments. Cowpea is also a prestigious food sold for more than four times the price of maize in the local markets. In addition, the N-fixing ability of cowpea could improve the soil fertility. Reynolds *et al.* (1993) reported an increase in the N output of cereal-intercropped systems involving cereal and N-fixing legume crops, with the N coming largely from the legume. Two mechanisms are known to be involved in the improvement of the N status of a cereal associated with a legume: the nitrogen transfer (lateral movement and/or transfer to the subsequent crop) and the sparing use (or effect) of the soil mineral nitrogen by the legume, thereby leaving more to be exploited by the cereal (Giller and Wilson 1991; Giller *et al.* 1991).

Maize-cowpea intercropping, which was found in this study to be an effective control method for maize stem borers while simultaneously improving the soil fertility and increasing revenue, is highly recommended to farmers at the locations where the study was conducted and similar ecologies.

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Section 4

Economics and Extension

Increasing employment opportunities through participation of informal women's groups in maize production

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Abstract

Maize (*Zea mays* L.) is a major crop produced by the indigenes of Lere and Kaura Local Government Areas (LGAs) of Kaduna State, Nigeria. The women, who contribute 60-90% of household food, are involved in maize production either as individuals or on a group basis. Collective marketing of the commodity is one of the reasons attracting women into maize production. This study was designed to assess how women farmers' groups in the two LGAs collectively produce and market maize. The goal was to identify the strengths and weakness of the groups and use the information to make appropriate recommendations for the empowerment of women farmers to increase their production. The data were collected using two sets of instruments: an interview schedule administered to women farmers' groups and a questionnaire administered to nearly 200 individual members of the groups. Data collected were subjected to frequency distribution, t-test and Spearman rank correlation analysis, as appropriate. The results showed that planning of group activities, record keeping, access to credit, membership contribution, linkages with other organizations, leadership and external support influenced women's participation in group activities. The majority of members reported that, as a result of their participation in group activities, they had increased the use of improved varieties, diversified economic activities and increased maize production. These changes have translated into increased income, better food security, increased literacy, and improved hygiene in members' households. The results led to the conclusion that informal women's groups are potential channels for communicating information to rural women for enhanced maize production.

Résumé

Dans l'état de Kaduna, en particulier à Lere et Kaura, le maïs est la culture majeure produite par les indigènes, aussi bien comme culture alimentaire que comme culture de rente. Les femmes, qui contribuent entre 60–90% à la production alimentaire familiale, sont sérieusement impliquées dans la production de maïs, soit individuellement, soit en groupe. La commercialisation collective de la céréale est une des raisons pour lesquelles les femmes sont impliquées dans la production de maïs. Cette étude a été conçue pour évaluer la manière dont les groupes d'agricultrices de Lere et de Kauru produisent et vendent collectivement le maïs. L'objectif était d'identifier les forces et faiblesses du système de commercialisation en groupe. L'information obtenue de l'étude pourrait servir de base pour des recommandations appropriées qui permettraient aux agricultrices d'augmenter leur production. Les données pour l'étude ont été recueillies en utilisant deux groupes de questionnaires. Un interview administré aux groupes de femmes selon un programme etabli et un interview adminstré a a pres de 200 membres individuels du groupe. Les données ont été analysées en utilisant des statistiques descriptives et le 't-test', la correlation de spearman quand approprié. Les résultats ont montré que la planification d'activités de groupe, la gestion des archives, l'accès au crédit, la contribution en tant que membre du groupe, les liens avec d'autres organisations, le leadership et le soutien externe influençaient la participation des femmes aux activités de groupe. La majorité des membres ont rapporté qu'ils avaient enregistré des changements dans leur production, suite à leur participation aux activités de groupe, à travers l'accroissement de l'utilisation de variétés améliorées et l'agrandissement de la taille des champs et l'accroissement du rendement. Ces changements dans la production se sont traduits par l'augmentation des revenus, la sécurité alimentaire, l'augmentation de l'alphabétisation et l'amélioration de l'hygiène dans les ménages des membres. Il peut être conclu que les groupes informels peuvent servir de canaux efficaces de communication de l'information aux femmes rurales afin d'améliorer la production de maïs.

Introduction

Much of the literature on the productivity of the subsistence farmer assumes that the small-scale farmer, who is to produce more food, is a man. In Africa, perhaps more than elsewhere in the world, this is a false assumption. It is predominantly the women who produce the food crops, in addition to helping their husbands to produce, harvest and market the cash crops. Results of research conducted in Nigeria on the contribution of women to agricultural development showed that, depending on socio-cultural factors, women's input on the farm was about 60-90% of total tasks performed (Pala 1976; Lamming 1983; Amali 1988; Auta *et al.* 2000). The inputs of women were highest in food production, processing and the marketing of agricultural commodities, which they do on an individual basis and/or in groups.

At present in Nigeria there is a variety of farmer groups found in rural areas. Mercoiret and Barthone (2003) categorized such groups into three. Included in the first category are those that were introduced into the country in the 1960s following a direct state intervention through its administrative and technical services based on key economic or technical functions. The second category comprises those involved with internal or external intervention, including women and youth groups, which have been created by administrative services supported by national or international donors to diversify their activities. The third category of farmer groups, which is the focus of this paper, includes those groups resulting from local or autonomous initiatives or from a demonstration effect of successful groups that might be thriving within the locality.

Traditionally, women in Nigeria form groups to perform certain functions such as production, processing, marketing and handcrafting. In some cases, they share tasks of labor on each other's farms on a rotational basis. Marcoiret and Barthone (2003) opined that the role that women farmers can play in defining objectives and management of agricultural development programs will depend on how well they can organize themselves in an autonomous manner.

The objective of the research reported in this paper was to assess the strengths, weaknesses and level of the participation of women farmer groups in the production of maize (*Zea mays* L.) in Lere and Kauru Local Government Areas (LGAs) of Kaduna State, Nigeria. The results obtained from the study provided the basis for recommendations that would empower women farmers to carry out their maize production activities more efficiently.

Methodology

With the assistance of the Cooperative Officers in the Kauru LGA and Agricultural Development Projects (ADPs) in the Lere LGA, some "active" women groups were identified, from which 19 or 30% were randomly selected in each LGA for this study. About 50% of the members in each group were in turn randomly selected, giving a total of 195 individual respondents. Data were collected through focus group discussion with each of the groups as well as through a questionnaire administered to the 195 individual members. In both cases, attention was focused on maize production and marketing.

The factors affecting the participation of women in group activities were assessed based on scoring techniques. The maximum level of individual factors was assigned a value of 5 and appropriate values were assigned on different criteria influencing these factors (Table 1). These scores were used to calculate the level of participation of the groups; groups with a mean score of less than 2 were classified as

Table 1: Scores assigned for factors influencing women's participation in group activities.

Variables	1.00	2.00	3.00	4.00	5.00
External support to groups in the past 5 years	Group had not received external support	Group had received external support once	Group had received external support twice	Group had received external support 3 times	Group had received external support more than 3 times
Regularity of meeting by groups	No fixed schedule for meetings	Meet annually	Meet at least 2 times a year	Meet at least 4 times a year	Meet at least once a month
Average attendance of meetings	No record of attendance	1- 25% members in attendance	26- 50% members in attendance	51- 75% members in attendance	> 75% members in attendance
Group records	No record of attendance of meetings, minutes of meetings, financial transactions and services provided to members.	Records of one of the following: attendance of meetings, minutes of meetings, financial transactions and services provided	Records of 2 of the following: attendance of meetings, minutes of meetings, financial transactions and services provided	Records of 3 of the following: attendance of meetings, minutes of meetings, financial transactions and services provided.	Records of all of the following: attendance of meetings, minutes of meetings, financial transactions and services provided to members.
Leadership qualities of groups	Group had not attained any of the following: elect leaders democratically, conduct meetings, change leadership when due, render financial accounts to members.	Group had attained 1 of the following: elect leaders democratically, conduct meetings, change leadership when due, render financial accounts to members.	Group had attained 2 of the following: elect leaders democratically, conduct meetings, change leadership when due, render financial accounts to members.	Group had attained 3 of the following: elect leaders democratically, conduct meetings, change leadership when due, render financial accounts to members.	Group had attained all of the following: elect leaders democratically, conduct meetings, change leadership when due, render financial accounts to members.
Planning of group activities in 2003	No planning of group activities	1- 25% plans accomplished	26- 50% plans accomplished	51-75% plans accomplished	More than 75% plans accomplished
Training of members in the past 5 years	No training received.	One training received.	Two training received.	Three training received.	More than three training received
Members contribution in 2003	No contributions made by members	1- 25% of members paid contributions	26- 50% members paid contributions	51- 75% members paid contributions	More than 75% paid contributions
Access to credit in the past 5 years	Received no credit facilities.	Received credit once, < 50% recovery rate.	Received credit once, > 50% recovery rate.	Received credit more than once, < 50% recovery rate.	Received credit > once, more than 50% recovery rate.
Relationship with other organizations	No linkage .	Linkage with one organization,	Linkage with two organizations.	Linkage with three organizations.	Linkage with more than three orgs.
Provision of services to group members in the past 5 years	No services provided to members	Services provided once, members not satisfied	Services provided more than once, members not satisfied	Services provided once, members satisfied	Services provided more than once, members satisfied.

having a poor level of participation, those with a mean score between 2 and 3 had an average level of participation, while groups with scores greater than 3 had a good level of participation.

Data collected from the respondents were subjected to frequency counts and expressed in percentages. To assess the changes in the level of agricultural production due to women's involvement in group activities, a comparism of their pre- and post-group formation levels of involvement was done using t-test. The Spearman rank correlation analysis was used to determine the degree and type of associations among the factors affecting women's participation in group activities, including maize production.

Results and Discussion

Characteristics of women groups

As shown in Table 2, 42% of the groups had less than 20 members while 37% had 21-30 members. About 63% of the group members were less than 40 years of age. This shows that majority of the group members were sufficiently young to possess the energy needed to carry out agricultural activities. The modal class for family size was 5-10, which contained 63% of the members. Only about 25% of the members had attended primary school; 57% did not have any formal education. About 86% of group members indicated crop farming as their main occupation while 71% kept livestock as a secondary occupation. About 30% of group members earned an annual income within the range of ₦40,000-₦50,000.00.

Level of involvement of women in agricultural activities

The agricultural activities investigated in this study included maize production, poultry keeping and small ruminant production. The results showed that 99%, 85% and 75% of the groups were involved in the production of maize, small ruminant and poultry (Table 3). These activities were embarked upon by groups to earn cash and as a source of protein for the family. About 39% of individual members also had 51-75% level of involvement in maize production. The t-test value (3.29; $P \leq 0.01$) showed a significant difference between the level of women's involvement in agricultural activities pre- and post-group formation (Table 3).

Reasons for women's involvement in agricultural activities

Group members had various reasons for getting involved in agricultural activities. The reasons, in order of importance, were source of income, interest, and family tradition. About 71%, 49% and 45% of members were engaged in maize production, small ruminant production and poultry keeping to increase their income. About 56% produced maize

Table 2. Characteristics of women's groups in the Lere and Kauru Local Government Areas of Kaduna State, Nigeria.

	Lere		Kauru		Totals	
Characteristics	Freq	%	Freq	%	Freq	%
Group Membership						
< 20	5	35.7	3	60	8	42.0
21-30	5	35.7	2	40	7	36.8
31-40	4	28.6	-	-	4	21.0
Totals	14	100	5	100	19	100
Ages of Members						
< – 20	-	-	-	-	-	-
20 – 30	17	11.9	13	26	30	15.5
31 – 40	70	49.0	22	44	92	47.7
41 – 50	56	39.2	15	30	71	36.8
Total	143	100	50	100	193	100
Household Size						
< 5	34	23.8	5	10	39	20.2
5 – 10	86	60.1	35	70	121	62.7
7 – 10	23	16.1	10	20	33	17.7
Total	143	100	50	100	193	100
Level of Education						
No schooling	82	57.3	27	54	109	56.5
Primary school	36	25.2	12	24	48	24.9
Secondary school	21	14.7	8	16	29	15.0
Post secondary school	2	1.4	-	-	2	1.0
Adult education	-	-	3	6	3	1.6
Koranic education	2	1.4	-	-	2	1.0
Primary Occupation						
Crop farming	118	82.5	18	96	166	86.0
Civil servant	10	7.0	2	4	12	6.2
Livestock production	9	6.3	-	-	9	4.7
Secondary Occupation						
Crop farming	26	18.2	2	4	28	14.5
Civil servant	3	2	-	-	3	1.6
Livestock production	115	80.4	22	44	137	71.0
Average annual Income						
< ₦5,000.00	-	-	-	-	-	-
₦5,000.00-N10,000.00	7	4.9	-	-	7	3.6
₦10,001-N20,000.00	3	2.1	-	-	3	1.6
₦20,001-30,000.00	11	7.7	2	4	13	6.7
₦30,001-N40,000.00	30	21.0	8	16	38	19.7
₦40,001-N50,000.00	50	31.0	17	34	57	29.5
> 50,000.00	42	29.4	5	10	47	24.4

Table 3. **Level of involvement in agricultural activities by women's groups in the Lere and Kauru Local Government Areas of Kaduna State, Nigeria.**

Agricultural activity	Lere		Kauru		Totals	
	Freq	%	Freq.	%	Freq	%
Maize Production						
< 25%	12	8.4	-	-	12	1.5
25-50	33	23.1	6	12	39	20.2
51-75	50	35.0	25	50	75	38.9
>75%	47	32.9	19	38	66	34.2
Totals	142	99.3	50	100	192	99.5
Poultry Production						
<25	78	54.5	39	78	117	60.6
25-50	26	18.2	1	2	27	14.0
Totals	105	73.4	40	80	145	75.1
S/Ruminant Production						
<25%	84	58.7	39	78	123	63.7
25-50	39	27.7	1	2	40	20.7
Totals	123	86.0	40	80	163	84.5

Table 4. **Reasons for involvement in agricultural activities as given by Women's Groups in the Lere and Kauru Local Government Areas of Kaduna State, Nigeria.**

Reasons for involvement in agricultural activities	Lere		Kauru		Totals	
	Freq.	%	Freq.	%	Freq.	%
Increased Income						
Maize Production	102	71.3	34	68	136	70.5
Poultry Prod.	67	46.9	20	40	87	45.1
S/Ruminant Production	60	42	34	68	94	48.7
Interest						
Maize Production	89	62.2	20	40	109	56.4
Poultry Prod.	65	45.5	21	42	86	44.5
S/Ruminant Production	44	30.8	21	42	65	33.6
Family Tradition						
Maize Production	31	21.7	20	40	51	26.4
P/Keeping	9	6.3	19	38	28	14.5
S/Ruminant Production	6	4.2	18	36	24	12.4

because of their interest in the crop while 26% grew the crop because it has become a family tradition (Table 4).

Factors affecting women's participation in group activities

Some factors were found to affect women's participation in group activities, including maize production and other agricultural activities. These factors included linkages with other organizations, group meetings, leadership, external support, record keeping, training of members, membership contribution, access to credit and services

Table 5. **Spearman rank correlation coefficients between level of performance and factors affecting the performance in group activities of women's groups in the Lere and Kauru Local Government Areas of Kaduna State, Nigeria.**

Factors affecting performance	Correlation Coefficient (r value) with level of performance
External support	0.249*
Linkage with other organizations	0.272*
Group meetings	0.226
Leadership	0.255*
Record keeping	0.521**
Training	0.027
Group planning	0.566**
Membership contribution	0.346**
Access to credit	0.460**
Provision of goods and services to members	0.120

*,**r-values significantly different from zero at 0.05 and 0.01 levels of probability.

Table 6. **Changes resulting from involvement in group activities by members of women's groups in the Lere and Kauru Local Government Areas of Kaduna State, Nigeria.**

Changes	Lere LGA		Kauru LGA		Totals	
	Freq	%	Freq	%	Freq	%
Increased farm size	9	6.3	-	-	9	4.7
Increased no. of animals	18	12.6	-	-	18	9.3
Use of improved varieties	79	55.2	33	66	112	58.0
Diversification of activities	80	55.9	31	62	111	57.5
Increased income	89	62.2	34	68	133	68.9
Increased food security	40	28.0	1	20	41	21.2
Increased literacy	46	32.2	38	76	84	43.5
Improved hygiene	21	16.1	15	30	36	18.6
Improved housing	26	18.2	4	8	30	15.5
Changes in welfare	143	100	50	100	193	100

provided to group members. Spearman rank correlation coefficients indicated that group planning (r=0.566; $P\leq0.01$), record keeping (r=0.521; $P\leq0.01$), access to credit (r=0.460; $P\leq0.01$), membership contribution (r=0.346 $P\leq0.01$), linkage with other organizations (r=0.272; $P\leq0.05$), leadership (r=0.255; $P\leq0.05$) and external support (r=0.249; $P\leq0.05$) had significant positive relationships with performance of women's groups (Table 5). However, group meetings, training of members and services provided to members did not show any significant relationship with group performance.

Changes recorded by members' households as a result of their involvement in group activities

All group members reported changes because of their involvement in group activities (Table 6). About 58% of the members used improved seed and 57% had diversified their activities. Similarly, 69% had increased income while 44% had improved their literacy level. All the group members reported improved general well-being (welfare) as a result of their involvement in group activities.

A comparison was made between the social and economic conditions of members and their households before and after getting involved in group activities. The t-test value (t=4.10; *P*=0.01) showed a significant improvement in the socio-economic status of the women resulting from their involvement in group activities. However, results in Table 6 showed no increase in the size of farms of members, probably because of increased pressure on land as a result of population increase, which has led to a reduction in land holdings. This calls for intensification of agricultural activities through the use of appropriate techniques and improved, high yielding varieties.

Recommendations

On the basis of the results obtained in this study, the following recommendations could be made on how women's groups could maintain the factors that were identified as their strengths and improved on the factors identified as weaknesses.

1. Training needs of women should be identified to ensure that appropriate training is provided for the empowerment of the women.
2. The frequency, venue and time of meetings should be determined and publicized if all are not involved in the planning process so that members are aware and make proper planning to attend and also to contribute meaningfully to the discussion.
3. Members should be consulted on the type of services they need; the needs should be prioritized and met on time and in appropriate quantity to all members, based on available resources.
4. Women should be taught proper record keeping, including accounting procedures, so that their produce, whether sold or consumed within the household, is properly quantified.
5. There is need for making a very special arrangement to ensure that women have access to credit facilities.

Conclusion

The participation of women in group activities in two Local Government Areas of Kaduna State, Nigeria, was influenced by several factors, including planning of group activities, access to credit, leadership, external support, linkages with other organizations, record keeping and membership contribution. However, training, conduct of meetings and services provided to members did not significantly influence the participation of women in group activities. Therefore, if women farmers are given the appropriate orientation, it would enable them to participate actively in group activities leading to increased maize production and income as well as an improved standard of living, thereby enhancing rural development.

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Spatial distribution of farm plots and enterprise combination as tools for determination of extent of maize adoption in the Sudan savanna

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Abstract

A study of enterprise combinations and spatial distribution of maize (*Zea mays* L.) farm plots was conducted in 2004 at four WECAMAN Project locations (Banigahannu and Zurmi in Zamfara State, Shaiskawa and Baude in Katsina State) in the Sudan savanna ecology of Nigeria. The objective of the study was to develop simple visual tools for monitoring the extent of maize variety adoption in the ecology. Extra-early maize varieties were introduced to farmers in all the four communities in 1999. Prior to this introduction, maize was not cultivated in these locations. It was hypothesized that enterprise combination and spatial distribution of maize-based farm plots will provide indications of the level of adoption of maize cultivation at locations in which maize cultivation is relatively new. Relative farm distances from homestead were jointly estimated with farmer groups during the cropping season of 2004 and their locations were identified using Geo-Positioning System (GPS). Focus group discussions were used to generate additional information and the factors responsible for the observed spatial distribution and enterprise combinations. High divergence in both enterprise combinations and spatial distribution of maize farm plots were found among the locations. The study identified five concentric circles and four enterprise combinations that reflected various stages of adoption of maize cultivation over a period of six years. The widest spatial distribution of maize farm plots occurred in the third year of cultivation at Zurmi and Baude, but not until the fourth and fifth year at Shaiskawa and Banigahannu, respectively. Enterprise combination was highest (5-7 crops) at Banigahannu and lowest at Zurmi (2-3 crops). Advanced level of adoption was reflected by remoteness of farms in the outer concentric circles, few crops in enterprise combinations, and higher level of use of purchased inputs such as fertilizer and manure. Distance to farm plots was found to be a factor of access to land, level of community acceptance and a decreasing incidence of on-farm stealing of maize resulting from a significant number of producers. It was concluded that enterprise combinations involving only 2-3 crops was an indicator of advanced stages of maize technology adoption in the Sudan savanna ecology.

Résumé

Une étude combinée de l'entrepreunariat et de la distribution spatiale de parcelles de maïs a été conduite en 2004 dans quatre localités du projet WECAMAN (Banigahannu et Zurmi dans l'état de Zamfara, Shaiskawa et Baude dans l'état de Katsina) dans l'écologie de la savane soudanaise du Nigéria. L'objectif de l'étude était de développer des outils visuels simples pour contrôler ainsi que pour déterminer l'étendue de l'adoption des variétés de maïs dans l'écologie concernée. La culture de maïs extra-précoce a été introduite auprès des agriculteurs dans toutes les quatre communautés en 1999. Antérieurement à cette introduction, le maïs n'était pas cultivé dans ces localités. Il a été émis l'hypothèse que la combinaison de l'entrepreunariat et de la diffusion spatiale du maïs sur la base des parcelles en milieu paysan, fournirait des indications sur le niveau d'adoption de la culture de maïs dans les localités dans lesquelles la culture du maïs serait un phénomène récent. Des distances relatives entre les habitations et les parcelles ont été conjointement estimées avec des groupes d'agriculteurs pendant la saison des cultures en 2004 et leurs emplacements ont été identifiés en utilisant Système de Géo-Positionnement (SGP). Les discussions de groupes ont permis de générer des informations supplémentaires et les facteurs qui étaient responsables des combinaisons de la diffusion spatiale observée et de l'entrepreunariat. Une forte divergence des combinaisons entre l'entrepreunariat et la diffusion spatiale de parcelles de maïs a été observée entre les localités. L'étude a identifié cinq cercles concentriques et quatre combinaisons d'entreprenariats qui reflétaient les divers stades d'adoption de la culture du maïs sur une période de six années. La diffusion spatiale la plus large de parcelles de maïs en milieu paysan est survenue plus tôt pendant la troisième année à Zurmi et Baude, mais pendant la quatrième et cinquième année à Shaiskawa et à Banigahannu, respectivement. La combinaison d'entreprenariats était la plus élevée à Banigahannu, entre 5 et 7 cultures mais en nombre plus faible à Zurmi. Le niveau élevé d'adoption a été affecté par l'éloignement des parcelles dans les cercles concentriques extérieurs, le faible nombre des cultures associées et les niveaux élevés d'utilisation d'intrants achetés tels que les engrais / le fumier. La distance entre les habitations et les parcelles était liée au facteur d'accès à la terre, le niveau d'acceptation de communauté et une incidence décroissante du vol d'épis de maïs dans les champs résultant d'un nombre significatif de producteurs.

Introduction

The slow pace of change in the African food production situation remains a major concern of research and extension institutions as well as of donors and international development organizations. There are indeed many dimensions to the issue as well as a diversity of opinions on how to resolve the food and development problems in Africa (Byerlee 1994; Bosc and Hanak Freud 1995; Abalu 1997; Johnson and Evenson 2000; Badu–Apraku and Fakorede 2003). For the future of agriculture on the continent, particularly in West and Central Africa (WCA), two more perplexing issues exist. The first is to identify the conditions favoring adoption to improve productivity; the second is to develop mechanisms for measuring the extent of adoption by smallholder farmers to prioritize the research and development agenda.

Adoption of technological innovations is a major source of productivity growth and an important factor in determining investment in agricultural research and extension. Bosc and Hanak Freud (1995) noted that the category of research results most interesting to smallholder farmers appears to be the improved genetic materials. These farmers face serious constraints such as shortage of labor and capital; they have a high aversion to risk, combined in many cases with a lack of fertile land thus making adoption of complete technical packages less attractive, if not impossible.

Smallholder farmers in WCA have a history of spontaneous experimentation with crops and are constantly on the lookout for varieties that interest them, which they readily exchange with one another (Adesina and Zinnah 1993; Manyong *et al*. 1998; Onyibe *et al*. 2003a; Gyasi *et al.* 2003). Yet the development of simple and time-saving mechanisms for monitoring the spread and extent of adoption of genetic materials has not been given due research attention. This has constrained continuous assessment of impact of research and extension programs and makes justification for increased investments on research and extension difficult.

A recent study by Menkir (2003) elucidated the role of GIS in targeting maize germplasm to farmer's needs in WCA. From the study it is obvious that scope exists for the use of this technology, especially when integrated with a biophysical spatial database to develop a robust framework for systematic monitoring and assessment of adoption and impact of maize germplasm. But securing the technical and human resource capability for such endeavor is a challenge that will take a while to resolve.

Conducting on-site adoption and impact assessment studies, therefore, remains an option, which, like most other socio-economic studies, is a highly resource-demanding activity. For that reason, researchers are frequently compelled to adopt resource-use efficient methods of collecting data, which sometimes compromise the quality of their results and their interpretation. Presently, most adoption studies rely on the use of secondary data sources, interviews and questionnaires to generate data. Even when direct observations are

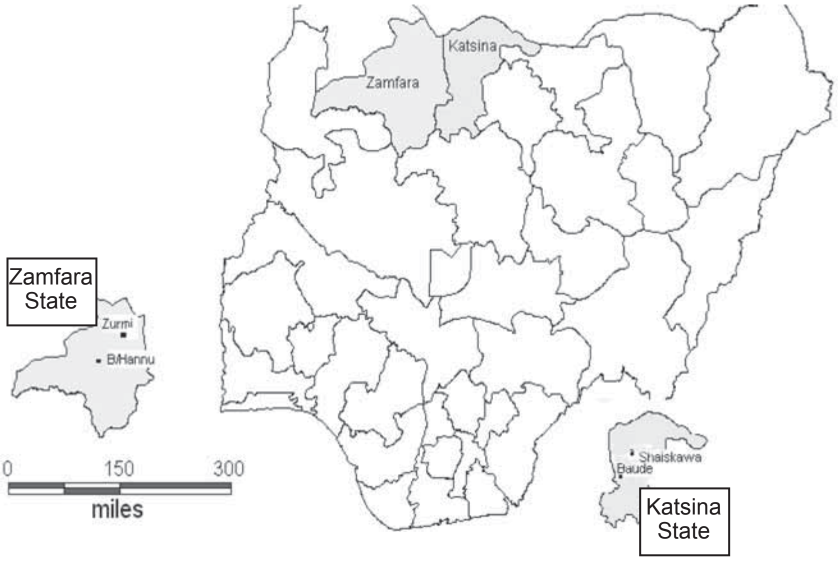

Figure 1: Map of Nigeria Showing study areas

integrated, specific visually measurable scales that could guide their application are not yet fully developed.

In the present study, we used spatial distribution of maize farm plots and crop enterprise combinations to delineate the pattern of adoption of maize at four locations in the Sudan savanna ecology where maize cultivation is a recent phenomenon. The objective was to develop simple visual tools for monitoring the extent of maize variety adoption in the ecological zone.

Methodology

Study area

This study was conducted within the Sudan savanna ecology of two States in Nigeria (Lat 12′0-13.2^{0}N and Long 4^{0}30′ -8^0 20′E) (Figure 1). Detailed description of the culture, characteristics of farmers, maize potential and production constraints have been reported for Katsina State (Onyibe *et al.* 2003a & b) and are similar to those of Zamfara State. The study was conducted at four locations: Shaiskawa and Baude in Katsina State, Banigahannu and Zurmi in Zamfara State. In 1999, under a WECAMAN-supported maize promotion project, extra–early maize varieties were introduced to farmer groups in the four locations. The groups were organized, registered and trained by the Project. The four communities share several commonalities including culture, lifestyle and key production practices. However the main difference among the communities is that maize was introduced to the women's groups at Baude, while men's groups were the recipients of project intervention at the other three locations.

The groups were supplied with treated foundation seeds, which they used to established group farms in their respective locations under the supervision of Extension Agents (EAs) from their State's Agricultural Development Project (ADP) authorities and Project scientists. Prior to the intervention of the Project, maize cultivation was not an established practice in these locations, due to short and erratic seasonal precipitation. After the introduction of extra-early maize, technical advisory services were made available to the farmers at each location for five years.

Survey

A survey was conducted in the four communities during the sixth year of the project. A focus group discussion (FGD) technique, combined with questionnaires and direct estimation of relative farm distances was used.

Sampling Procedure. At each location, members of the research team, accompanied by a member and a non-member of the maize farmers' group (Association) jointly conducted the initial recruitment of the FG participants and in setting a date for the group discussion and farm walk involving direct farm plot distance estimations. Each group was originally intended to be limited to 15-20 persons. In Baude, only 13 women participated out of which 4 persons were non-members of the women maize farmers association because the set date coincided with a wedding ceremony involving some enlisted/volunteered FGD members. Membership of the FG was 24 in Shaiskawa, 26 in Banigahannu and 23 in Zurmi. At these three locations, 6-7 persons who were non-members of the location maize farmers association were enlisted. On the whole, a total of 105 farmers were involved in the FGD across the four sites, excluding the 8 persons (2 at each location) who conducted the recruitment of FGD members. The 8 persons facilitated translation of difficult Hausa phrases during discussions. All the discussions were held in the local language (Hausa) hence, FGD facilitators were those that had demonstrated proficiency in oral Hausa.

Rolling measuring tapes and walking strides were used to estimate relative farm distances. Lists of maize farmers and farm plots were compiled prior to obtaining the measurements. The relative positions of the farm plots were identified using a GPS facility. At the end of the exercise, a scattered chart diagram of the plots was jointly developed with farmers and superimposed on the dates (year) of cultivation to generate the pattern of adoption in concentric circles.

Table 1 shows the relative radii of the five concentric circles that was adopted in the study. The homesteads circle (HC) was used as the reference circle. The basis for this was that, during the first year of introduction of extra-early maize to the four locations, the sites selected

Table 1. Relative radii of the five concentric circles used in a field survey conducted in four communities in the Sudan savanna ecology of Nigeria.

Code	Circle	Specification used
HC	Homestead Circle [Reference Circle (RC)]	50 m around dwelling house
1st Circle	First concentric circle [after RC (ARC)]	51-150 m
2nd Circle	Second concentric circle (ARC)	151-350 m
3rd Circle	Third concentric circle (ARC)	351-750 m
4th Circle	Fourth concentric circle (ARC)	751 m to 1.5 km and over

RC = Reference Circle (50 m away from homestead at a location)
ARC = After Reference Circle.

Table 2. Codes and description of explanatory variable used in stepwise multiple regression analysis of the data collected during a field survey of maize adoption conducted in four communities in the Sudan savanna ecology of Nigeria.

S/No.	Code	Description of variable
1	AGE	Age of respondent
2	YRSCM	Years of maize cultivation experience
3	NOFF	Number of farm plots owned
4	ETAF	Estimated total area of farms
5	YOC	Yield of other crops
6	NOMAZF	Number of maize farmers
7	PMAZ	Price of maize
8	PROFG	Prices of other food grains
9	NOMAZF	Number of maize farmers
10	NDFR	Need for different food
11	CPTPROB	Control of pest problems
12	NOEAV	Number of extension agent visits
13	PRFERT	Price of fertilizer
14	NOFS	Number of on- farm thefts
15	PRMAZS	Price of maize seed.
16	PEDU	Education level of respondents
17	FMLYSI	Family size
18	NOKID	Number of children

for demonstrations of the technology by all the participating groups were all confined to within 50 m radius around each community.

Other data collected included crop enterprise combinations, distance of maize farm plots from the communities, crop yield and prices, fertilizer costs, ranking of the potential of maize, and socioeconomic characteristics related to the subject under study.

Data analysis

Descriptive statistical methods were employed to interpret the data. Correlation analysis of 18 variables in the survey tool (Table 2) was conducted to identify variables that were statistically related. Non-correlated variables were fitted into a stepwise multiple regression

Table 3. Component crops in maize-based mixtures in four rural communities in the Sudan savanna ecology of Nigeria.

Shaiskawa	Baude	Banigahannu	Zurmi
Sorghum	Sorghum	Sorghum	Millet
Cotton	Groundnut	Millet	Cowpea
Groundnut	Millet	Cotton	Sorghum
Millet	Cowpea	Cowpea	Maize
Cowpea	Cotton	Groundnut	Melon
Kenaf	Melon	Potato	
Melon	Maize	Kenaf	
Maize	Egg plant	Maize	
Egg plant		Roselle	
		Egg plant	

model to identify determinants of relative distances of farm plots and crop enterprise combinations for maize varieties introduced into the new locations (Manyong *et al.* 1998; Onyibe *et al.* 2003b).

The empirical analysis adopted the following linear regression models of relative farm plot distances and enterprise combination:

$$Y_{rfpd} = \beta_o + \beta_1\text{Age} + \beta_2\text{YrsCMaz} + \beta_3\text{NoFP} + \text{NoMazF} + \beta_4\text{ETAF} + \beta_5\text{Ymaz} + \beta_6\text{YOC} + \beta_7\text{Pmaz} + \beta_8\text{POFG} + \beta_9\text{NoMazFr} + \beta_{10}\text{NDFR} + \beta_{11}\text{CptProb} + \beta_{12}\text{NoEAV} + \beta_{13}\text{Prfer} + \beta_{14}\text{NOfS} + \beta_{15}\text{PrMazS} + \beta_{16}\text{Edu} + \beta_{17}\text{FmlySi} + \beta_{18}\text{Nokid} + \varepsilon \text{ --(a)}$$

$$Y_{cc} = \beta_o + \beta_1\text{Age} + \beta_2\text{YrsCMaz} + \beta_3\text{NoFP} + \text{NoMazF} + \beta_4\text{ETAF} + \beta_5\text{Ymaz} + \beta_6\text{YOC} + \beta_7\text{Pmaz} + \beta_8\text{POFG} + \beta_9\text{NoMazFr} + \beta_{10}\text{NDFR} + \beta_{11}\text{CptProb} + \beta_{12}\text{NoEAV} + \beta_{13}\text{Prfer} + \beta_{14}\text{NofS} + \beta_{15}\text{PrMazS} + \beta_{16}\text{Edu} + \beta_{17}\text{FmlySi} + \beta_{18}\text{Nokid} + \varepsilon \text{ --- (b)}$$

In these models, Y_{rfpd} = relative farm plot distance, Y_{cc} = number of crops in an enterprise, β_o = intercept, $\beta_1, \beta_2, \ldots\ldots.., \beta_{18}$ are regression coefficients and ε = error term.

The inclusion of these variables was based on their significance in previous studies by Onyibe *et al.* (1999 and 2003a,b) in the Sudan savanna and confirmed during the FGD in this study. It was hypothesized that the enterprise combinations and spatial distribution of maize-based enterprise farms would provide indications of the level of adoption of maize cultivation at locations in which maize cultivation was recently introduced.

Results and Discussion

Crops cultivated and cropping pattern

Table 3 shows the range of crops cultivated at the four locations. As many as ten, nine, eight and five crops were cultivated, mostly in mixtures, at Banigahannu, Shaiskawa, Baude and Zurmi, respectively.

Table 4. Number of crops grown in mixtures with maize for six years (1999–2004) by the respondents in a field survey conducted in four rural communities in the Sudan savanna ecology of Nigeria.

No. of crops in an enterprise	No. of respondents					
	1999	2000	2001	2002	2003	2004
Shaiskawa (n=24)						
Maize Sole	-	-	-	-	-	-
Maize + 1 crop	-	-	-	-	-	-
Maize + 2 crops	-	2	4	9	10	9
Maize + 3 crops	3	5	8	6	8	10
Maize + 4 crops	7	8	7	3	4	4
Maize + 5 crops	11	7	3	4	2	1
Maize + 6 crops	-	3	2	2	-	-
Maize + 7 crops	3	-	-	-	-	-
Baude (n=13)						
Maize Sole	-	-		-	-	-
Maize + 1 crop	-	2	3	2	2	2
Maize + 2 crops	6	4	3	5	6	8
Maize + 3 crops	-	7	5	5	5	2
Maize + 4 crops	3	-	2	1	1	1
Maize + 5 crops	4	-	-	-	-	-
Banigahannu (n=26)						
Maize Sole	-	1	1	-	-	1
Maize + 1 crop	3	2	-	-	1	-
Maize + 2 crops	5	6	12	10	14	13
Maize + 3 crops	9	12	12	16	10	12
Maize + 4 crops	3	-	1	-	1	-
Maize + 5 crops	4	-	-	-	-	-
Maize + 6 crops	-	5	-	-	-	-
Maize + 7 crops	2	-	-	-	-	-
Zurmi (n=23)						
Maize Sole	-	-	-	-	-	-
Maize + 1 crop	5	7	17	20	21	20
Maize + 2 crops	7	13	2	3	2	3
Maize + 3 crops	8	3	4	-	-	-
Maize + 4 crops	3	-	-	-	-	-

Enterprise combinations

The number and types of crop in an enterprise was found to vary remarkably between locations and years (Table 4). For maize-based systems, the number of crops in an enterprise was highest at Banigahannu, with about seven crop types, and least at Zurmi (Table 4). Overtime, a general decreasing trend in the number of crops in maizebased enterprise was observed throughout the four locations, with the rate of decrease being highest at Zurmi, followed by Banigahannu both in Zamfara State and least at Shaiskawa.

The results showed that sole maize was not popular across the four locations; only one farmer (at Banigahannu) planted maize as a sole crop. In an earlier study, Onyibe *et al.* (2003b) found that the majority of farmers in the Sudan savanna ecology showed a preference for

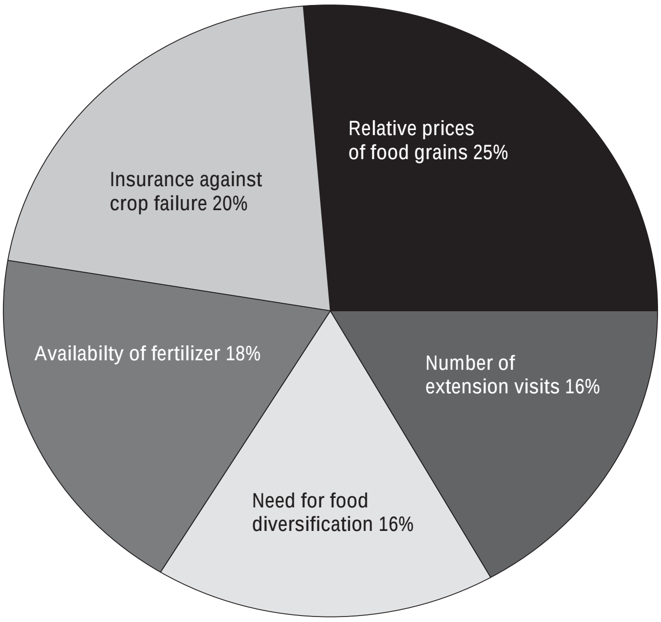

Figure 2: Factors determining number of crops in a maize-based enterprise

maize intercropped with cotton, cowpea and groundnut and a low interest in intercropping maize with traditional cereals of the zone (sorghum and millet). This is probably because maize has been displacing other cereal crops in the zone.

Thus in this ecology, maize is cultivated in similar manner to sorghum or millet; that is, by intercropping with non-cereal crops. In years when maize grain price is favorably high and fertilizer prices are fair, the farmers readily plant larger land areas to maize in preference to sorghum in their enterprises. But farmers revert partially to their traditional crops when maize price falls and/or fertilizer price is very high. Some of the factors that determine the number of crops in maize-based enterprises as indicated by the farmers involved in the survey (Fig. 2) included the relative prices of food grains (25%), insurance against crop failure due to pests (20%), availability (cost) of fertilizer (18%), need for diversification of food (16%) and the number of visits by EAs (16%).

Contrary to previous findings of Gbadegesin *et al.* (2002), the need for food diversity and reduction in pest pressure were found to be less important in the determination of numbers of crops in enterprise combinations by the respondents. This indicates farmer's growing sensitivity to economic benefits when taking decisions about their crop production enterprises.

The results also showed that EAs significantly influenced how and what the farmers produced. What is not clear, however, is how the

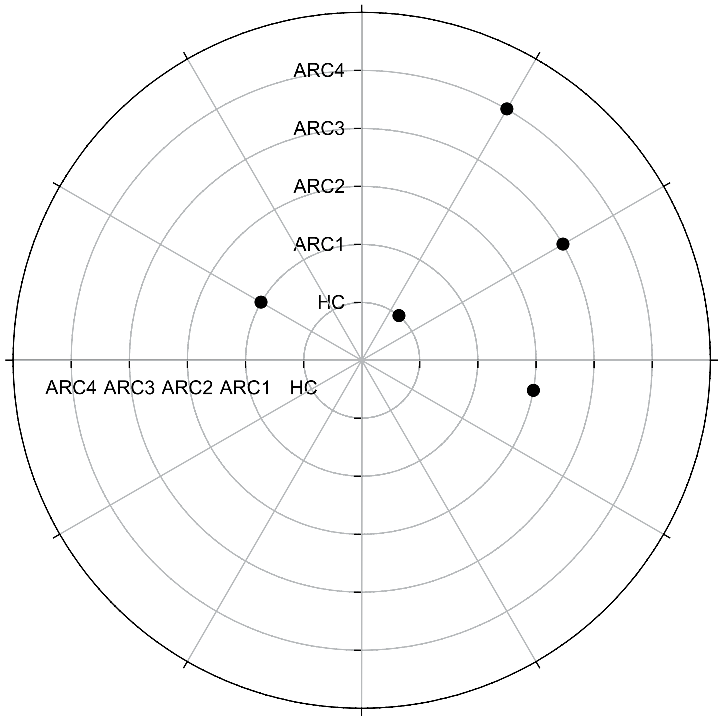

Figure 3: Concentric circles reflecting spatial disposition of farm plots.

reduction in the number of crops in an enterprise, occasioned by the advice of EAs, would impact on the income of the farmers in view of the many distortions in the marketing arena in which EAs often lack the technical skill to assist the farmers (Onyibe and Daudu 2005). It can only be hypothesized at this point that the EAs encourage farmers to reduce the number of crops in an enterprise in order to improve the effectiveness of recommended technological packages adopted by the farmers. On the other hand, farmers select what to retain based on economic considerations. The inclusion of maize in such an instance indicates a high level of its acceptance and potential at the locations. From the results it is apparent that enterprise combinations involving only 2-3 crops indicate advanced stages of adoption of maize by the farmers in this study.

Spatial distribution of maize farms

Five concentric spatial distributions of farm plots were identified (Fig. 3), which are reflections of different adoption stages. The trend in the spread of maize-based farms over time is presented in Table 5.

The results indicated that within the first two years of introducing maize to the communities, most of the maize farms were within the first circle (Homestead circle). The number of maize-based farm plots in outer concentric circles increased progressively to the extent that more farms were located at the outer circles than at the Homestead circle.

Table 5. **Distribution of maize farms within relative distances from homesteads at four locations in the Sudan savanna ecology of Nigeria.**

Relative distance from Homestead (circle)	Number of maize farms					
	1999	2000	2001	2002	2003	2004
Shaiskawa						
Homestead Circle	100	85	65	30	20	10
1st Circle	0	15	30	20	20	10
2nd Circle	0	0	5	20	30	20
3rd Circle	0	0	0	20	20	40
4th Circle	0	0	0	10	10	20
Baude						
Homestead Circle	100	40	10	10	10	5
1st Circle	0	20	30	20	10	5
2nd Circle	0	10	30	30	30	30
3rd Circle	0	20	20	30	30	40
4th Circle	0	0	10	20	20	20
Banigahannu						
Homestead Circle	100	80	60	30	30	20
1st Circle	0	20	30	30	20	30
2nd Circle	0	0	10	30	20	20
3rd Circle	0	0	0	10	20	20
4th Circle	0	0	0	0	10	10
Zurmi						
Homestead Circle	100	70	20	10	10	10
1st Circle	0	20	20	20	20	10
2nd Circle	0	10	30	20	20	10
3rd Circle	0	0	20	30	30	30
4th Circle	0	0	10	20	20	40

The rate of increase of farm plots at the outer circle was highest at Zurmi and Baude and least at Banigahannu and Shaiskawa. While farm plots were in the outermost circle by the third year at both Zurmi and Baude, no farm plot was sited in this outermost circle at Banigahannu until the fifth year, and until the fourth year at Shaiskawa.

From the farmers' perspective, the factors that determined the distance to the farm plots included the need to observe and know more about the technology, the number of maize farmers, level of on-farm stealing and the size of farm (Fig. 4). This clearly shows farmers' tradition of experimenting with new technology before fully embracing it, and as soon as they are convinced of the potential benefit of such technology, they pass it around to other farmers and in the process increase the number of adopters of the technology. This informal process of 'technology transfer' accelerates its adoption at distant farms. When farmers confirm the potential of the technology themselves, they guard it jealously to prevent it or its produce from being stolen, until such a time that more farmers have adopted it and the temptation to steal the technology or its produce has reduced considerably. Arokoyo *et al.* (1997) reported that during the first field

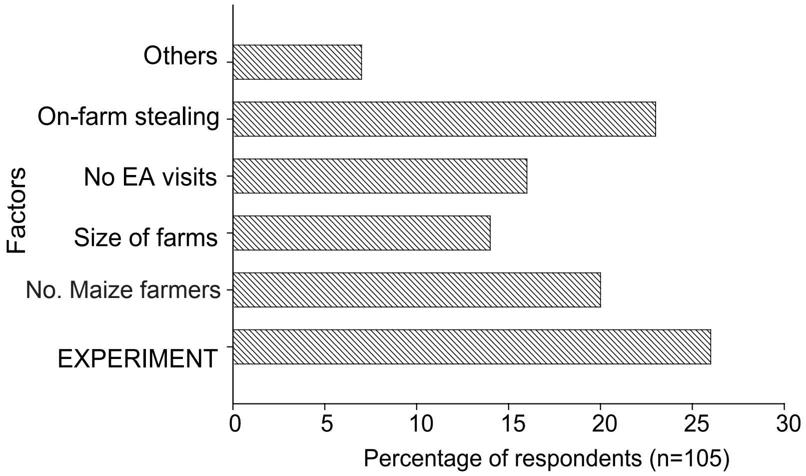

Figure 4: Factors affecting selection of farm location in relation to distance from homestead.

day on extra-early maize held at Katsina State, most of the matured maize cobs were stolen during the field day, and the remaining shortly after the field day. Though the quantity (mostly one or two cobs) taken by the farmers was small on an individual basis, it showed the potential of the technology and underscored the need for caution on the part of the farmers in taking the technology to distant farms where monitoring would be likely to be quite difficult.

The results of this study showed that it took the farmers about 3-4 years to gain enough confidence to try the use of the new technology in distant farms. Thus, the position of maize farm plots on the different concentric circles reflected the level and stage of adoption. From the results, the occurrence of farm plots in the third concentric circle, which occurred by the fourth year, probably indicated the start of adoption of the technology.

Relative farm distances

The 18 explanatory variables (Table 2) made different contributions to the two dependent variables (relative distance to farm and number of crops in an enterprise). Nine of the variables accounted for 77.3% of the distance to farm plots (Table 6). The price of maize (PMaz) had a highly significant ($P>0.01$) positive correlation with the number of maize farmers (NoMaz F). The number of on-farm thefts (NoF S) and price of fertilizer (Pfert) were two highly significant ($P>0.01$) determinants of the relative distance of maize farm plots. This indicated that enhanced access to a fair maize price and availability of fertilizer at affordable prices, along with improvement of extension coverage and security of farm produce, would accelerate the outward spread of maize technology from the HC to the concentric circles in the zone.

Table 6. **Significant parameter estimates from stepwise multiple regression of relative distance of farm plots from homestead on selected variables.**

Parameters	Estimated Coefficient	T. Ratio	R^2
No. of farm plots	0.692	3.438*	0.533
Size of farm	0.611	3.6004*	0.517
No. of maize farmers	0.730	4.521**	0.449
No. of yrs in maize production	0.405	2.836*	0.548
Price of maize	0.742	4.432**	0.451
Price of other food grains	0.662	3.688*	0.505
No. of EA visits	0.386	2.487*	0.587
Price of fertilizer	-0.588	-3.859**	0.498
No. of on-farm thefts	-0.739	-5.417**	0.437
Overall			0.773

** Significant at 0.05 and 0.01 levels of probability respectively

Table 7. **Statistically significant parameter estimates from stepwise multiple regression of number of crops in maize-based enterprise selected variables.**

Parameters	Estimated Coefficient	T. Ratio	R^2
No. of farm plots	0.522	3.695*	0.393
Size of farm in ha	0.533	4.900**	0.249
Yield of maize in kg	0.592	4976**	0.256
Yield of other crops in kg	0.528	3.698*	0.388
Need for different food	0.498	3.582*	0.398
Price of maize	0.586	4.899**	0.268
No. of EA visits	-0.541	-4.925**	0.251
Pest control	0.532	3.710*	0.378
Yrs of maize cultivation experience	-0.565	-4.887**	0.273
Overall			0.689

** Significant at 0.05 and 0.01 levels of probability respectively.

Determinants of enterprise combinations

Nine variables accounted for 69% of the variance of the number of crops in a maize-based enterprise (Table 7). The number of EA visits (No EAV) and years of farming experience (YrsMaz) had highly significant (*P*>0.01) negative effects on number of crops in an enterprise. This suggests that EAs greatly influenced the number of crops in enterprise combinations and this is a reflection on the level of effectiveness of extension services in the rural communities covered in this study. Since EA:farmer ratio is low, it is likely that the pace of reduction in the number of crops in enterprise combinations overtime at locations poorly served by EAs may be less remarkable. The results seem to indicate increasing farmers' concerns for economic issues, such as the price of maize. Hence, strategies that enhance improved coverage of extension service are in order, especially as throughout the study, farmers' perception of the current and future potential of maize production (Table 8) is high in the Sudan savanna ecology.

Table 8. Trend of farmers rating/projection of the potential of extra-early maize in the Sudan savanna ecology of Nigeria using 2004 as the base year.

Location	5 yrs ago (1999)	Last year (2003)	2004	5 yrs from now (2009)	Crop being displaced	Two most important cereals at the time of maize introduction (1999)
Shaiskawa	5th	3rd	3rd	2nd	Cotton/ sorghum	Sorghum/Millet
Bande	6th	3rd	3rd	2nd	G/nut & Sorghum	Sorghum/Millet
Banigahannu	6th	4th	4th	2nd	Sorghum	Sorghum/Millet
Zurmi	No potential	3rd	3rd	1st or 2nd	Sorghum	Millet/Sorghum

Conclusion

This paper contains the report of a case study of how the spatial distribution of farm plots and crop enterprise combination may be used to monitor the level of adoption of newly introduced maize cultivars. The level of occurrence of maize farm plots at the different concentric circles reflects the level and stage of adoption. Results of the study indicated that enterprise combinations involving only two or three crops are a reflection of advanced stages of adoption of maize in the four rural communities used for the study. The distance to farm plots was found to be a factor of access to land, level of community acceptance and a decreasing incidence of on-farm stealing of maize resulting from a significant increase in the number of producers. In conclusion, spatial distribution of farm plots and crop enterprise combinations are tools that provide insights into the progress in adoption of new crop varieties that could be captured easily and are, therefore, useful additional guides for extension intervention efforts.

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Influence du mode d'egrenage sur la qualité des semences certifiées de maïs dans le Departement de l'Atlantique (sud-Bénin)

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Résumé

Les semences représentent le capital de base de la production agricole et leur qualité a une importance décisive pour le résultat de l'exploitation. Mais plusieurs facteurs peuvent affecter cette qualité et contribuer à la détérioration rapide des semences. C'est dans ce contexte que la présente étude a été initiée en vue de mesurer l'effet du mode d'égrenage sur la qualité des semences certifiées de maïs, *Zea mays* au sud Bénin. Quatre différents modes d'égrenage (manuel, battage, mécanique et égrenoir) ont fait l'objet de l'étude. La qualité des lots de semences décortiquées de chaque traitement a été mesurée au moyen de test de germination, conformément aux directives élaborées par l'Association Internationale d'Essais de Semences. Ainsi, les plantules ont été appréciées et séparées en plantules normales et anormales. Il résulte de cette étude que le mode le plus adéquat est le mode manuel avec un taux de germination de 93,50 % suivi de l'égrenoir qui affiche un taux de germination de 88,50 %. Ces deux modes s'adaptent bien aux petits producteurs de semences certifiées. Les deux autres traitements ont présenté des résultats significativement différents. Le mode à proscrire est le battage avec un taux de germination de 66,50% qui réduit de près de 50 % la densité de culture. Le taux de germination de 79,50 % du mode mécanique peut être amélioré par un simple réglage des accessoires de l'égreneuse actionnée par un moteur. C'est le mode le mieux indiqué pour les grands producteurs de semences certifiées de maïs.

Abstract

Seed is a major input in agricultural production and its quality has a decisive effect on crop productivity. Several factors affect seed quality negatively, including mechanical damage to the seed during processing. The objective of this study was to evaluate the effect of four shelling methods (manual, mechanical, threshing manual and shelling tool) on the quality of certified seeds of maize (*Zea mays* L.) in south

Bénin. Seed quality was determined by the standard germination test according to the rules of the International Seed Testing Association. Following germination, the percentage of normal and abnormal seedlings was determined. Results of this study showed that the manual method was the best, with 93.50 % germination, followed by the use of the manual shelling tool, which had 88.50 % germination. Both of these methods are within the limits of the financial resourses of small-scale, resource poor seed producers. There was a significant difference between the results of the two other treatments. Threshing had a germination rate of 66.50% and reduced plant density to 50%. The mechanical method had a germination rate of 79.50%, which may be improved upon by adjusting the accessories of the mechanical sheller. The mechanical method is the most efficient method for the large-scale certified seed producers.

Introduction

L'utilisation des semences de qualité est indispensable pour promouvoir l'économie de tout Etat en voie de développement basée essentiellement sur la production agricole. Les semences représentent alors le capital de base de la production agricole, et leur qualité a une importance décisive pour le résultat de l'exploitation. Elles constituent par conséquent un facteur important de développement agricole, car elles demeurent le premier intrant que l'agriculteur utilise et le premier maillon de la chaîne alimentaire.

S'il est évident que sans semences il n'y a pas de production, la qualité et la quantité de la production dépendent dans une large mesure de la qualité de ces semences. Plusieurs facteurs affectent ou peuvent affecter cette qualité et contribuer à la détérioration rapide de ces semences. Il est généralement admis que la teneur en eau et la température auxquelles les semences sont conservées constituent des facteurs importants qui affectent leur longévité. En effet, plusieurs travaux ont montré l'effet préjudiciable de ces facteurs sur la qualité des semences (Walters and Engels, 1998 ; Hu et al., 1998 ; Ellis et al., 1990 ; Ellis, 1991). D'autres facteurs limitants résultent entre autres, des opérations post récoltes. Au nombre de ces opérations, l'égrenage peut facilement contribuer à l'altération des semences qui perdent rapidement leur qualité. Cependant, peu d'études ont été réalisées dans ce domaine. C'est dans ce contexte que la présente étude est initiée, en vue de mesurer et d'évaluer l'effet du mode d'égrenage sur la qualité des semences certifiées de maïs au sud du Bénin.

Matériel et Méthodes

Zone d'étude. L'étude a été réalisée dans le département de l'Atlantique, au Centre de recherche Agricole sud Bénin à Niaouli (Latitude 6° 44′ 24,2′′ ; Longitude 2° 08′ 18,6′′ ; Altitude 115 m). Les différents lots d'échantillons de semences certifiées sont fournis par les producteurs agréés de trois communes (Kpomassè, Toffo et Zè).

Matériel végétal. Le matériel végétal utilisé est le maïs, la variété DMR ESR W qui reste presque la seule variété améliorée en vulgarisation dans la zone d'étude.

Matériels techniques. Le sable marin proprement lavé pour le débarrasser de son sel et bien séché, est utilisé comme substrat pour les tests de germination. Des bacs de germination en bois préalablement troués à la base pour laisser couler le surplus d'eau, sont utilisés comme germoir. L'eau de robinet utilisée pour l'arrosage n'a subi aucun traitement

Méthodes

La qualité des semences est généralement mesurée, appréciée à partir de leur taux de germination ou faculté germinative qui en est une caractéristique importante. Des échantillons de semences certifiées produites en première saison de la campagne 2004-2005 sont prélevés auprès des multiplicateurs avec un taux d'humidité de 23 %. Les échantillons du lot égrené à la main par les ouvrières et ceux en épis sont prélevés à ce taux. L'ensemble des échantillons ainsi prélevés est séché à un taux d'humidité de 15% avant d'être traités à la station. Quatre lots sont constitués suivant les modes d'égrenage à étudier (T1 = manuel strict ; T2 = Battage ; T3 = mécanique ; T4 = manuel avec cône à décortiquer ou égrenoir).

Pour évaluer le comportement de ces différents lots d'échantillon, un test de germination est réalisé en dix jours pour permettre un meilleur développement des différents organes. Chaque échantillon est constitué de quatre cents (400) grains, répartis en lots de cent (100) grains. Chaque lot de cent (100) grains est semé dans le bac de germination rempli de sable marin ayant servi de substrat. Il est préalablement arrosé. Les grains sont semés à 1- 1,5 cm de profondeur dans de petits sillons tracés dans le sable ; les sillons sont espacés de 2 à 2,5 cm et les semis de 1 cm d'écartement. Les grains ainsi semés sont recouverts de sable et humectés.

Aux termes de dix (10) jours de germination, les plantules sont analysées et appréciées, puis séparées en plantules normales et plantules anormales d'une part, et en graines mortes et fraîches de l'autre (ISTA, 1985a; 1985b; 1993). L'essai est installé dans un

Tableau 1. Moyenne des différents types de plantule et graines.

Traitement	Plantules normales	Plantules anormales	Graines fraîches	Graines mortes
T_1	93,50 a	4,25 d	1,00 b	1,25 b
T_2	66,50 c	24,50 a	4,25 a	4,75 a
T_3	79,50 b	17,25 b	1,75 b	1,50 b
T_4	88,50 a	10,25 c	0,50 b	0,75 b
LSD	5,94	5,60	1,60	1,81

Les chiffres affectés de lettres différentes présentent une différence significative au seuil de 0,05.

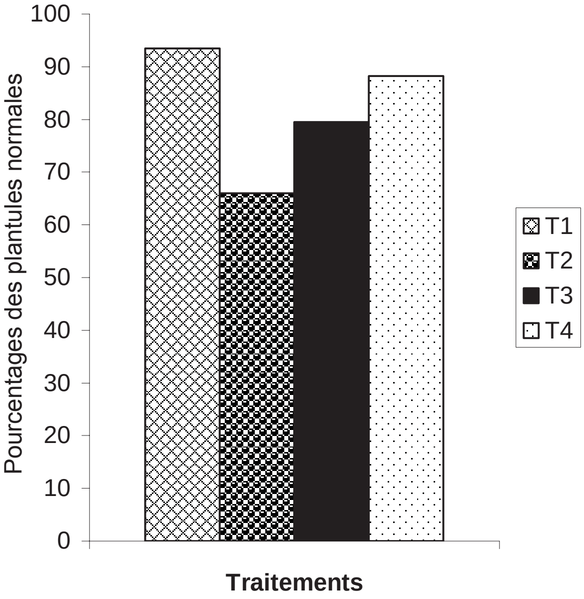

Figure 1: Evolution des plantules normales.

dispositif de bloc complètement randomisé à quatre répétitions et les données collectées sont analysées au moyen du programme SAS version 6.04 sous Windows.

Résultats et Discussion

Au terme du test de germination d'un lot de semences, les germes produits n'ont pas le même aspect, le même développement puis la même vigueur. Les résultats de l'analyse des variances reproduits dans le tableau 1 ci-dessus viennent confirmer cette assertion. En effet, on y observe des différences significatives tant entre les traitements qu'à l'intérieur.

Comparaison des plantules normales

Dans un test de germination, seules les plantules normales sont à considérer pour la détermination du taux de germination d'un lot de semences (ISTA, 1985a, 1985b; 1993). La Figure 1 indique l'évolution des plantes normales suivant les différents modes d'égrenage étudiés lesquels constituent les traitements.

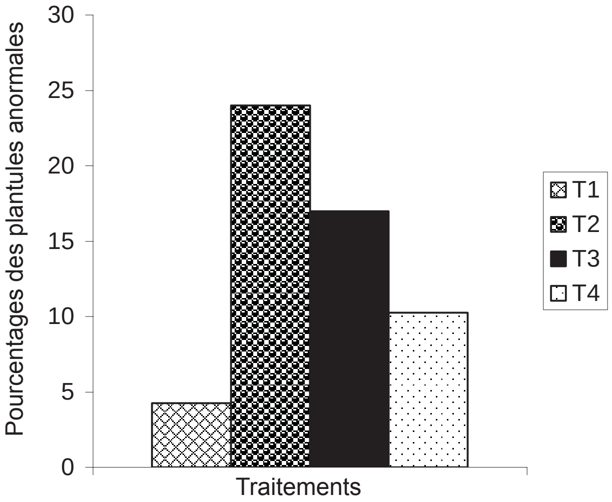

Figure 2. Evolution des plantules anormales issues des différents modes d'égrenage.

Le traitement T_1 donne le meilleur résultat avec un taux de germination de 93,50 %. Ce traitement peut être considéré comme une référence parce que les grains n'ont subi aucune pression transmise par un appareil. Ce traitement fort appréciable est suivi du traitement T_4 qui affiche une moyenne de 88,50 % de taux de germination. La différence entre ces deux traitements n'est pas significative au seuil de 0,05. Toutefois, l'écart de 5% paraît un peu grand et est dû au taux d'humidité élevé des grains auquel les producteurs ont traité les semences ; ce qui rend difficile le détachement des grains. Il est alors nécessaire d'exercer une pression pour que les grains se détachent des rafles. Cette force crée un choc que reçoivent les germes qui sont rapidement altérés. Il en résulte qu'un taux d'humidité élevé peut contribuer facilement, à la perte de qualité des semences au cours de l'égrenage, avant leur passage au stade de conservation. Ce phénomène met aussi en exergue la grande fragilité des semences qu'il faut manipuler avec beaucoup de soins.

Comparaison des plantules anormales

La Figure 2 présente les différentes proportions des plantules anormales issues des différents modes d'égrenage. Les pertes de viabilité des semences, traduites par la forte proportion des plantules anormales, correspondent aux traitements ayant fourni les faibles taux de plantules normales.

Il s'agit des traitements T_2 et T_3 qui ont donné respectivement 24,50 % et 17,25 % de plantules anormales. Ces fortes proportions de plantules anormales justifient bien l'influence de ces traitements

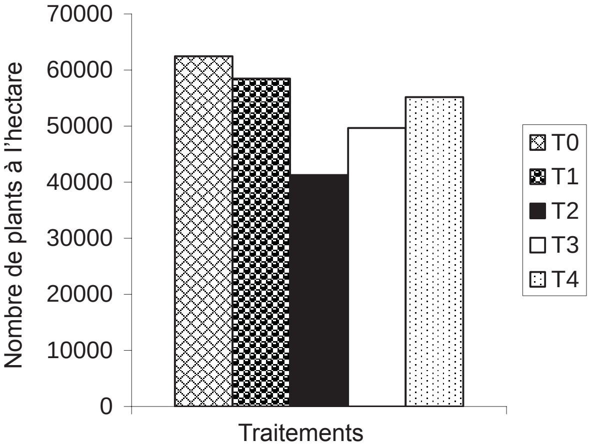

Figure 3. Effet des traitements sur la densité de population.

sur la qualité des semences de maïs. La détermination du taux de germes anormaux est alors primordiale parce qu'il conditionne la valeur du lot de semences. Il doit être aussi faible que possible, car un fort pourcentage de germes anormaux réduit considérablement celui de la faculté germinative et par conséquent, la qualité des semences. Il est à noter que le mode mécanique peut fournir de bons résultats si un bon réglage des accessoires de l'équipement est fait.

Effet des traitements sur la densité de population

La densité de population est un indice incontestable de rendement. Ce dernier est le premier objectif visé par les producteurs. La densité de population pour la production de maïs est fixée à 62500 plants à l'hectare par les services de la vulgarisation et sert donc de référence. En application des résultats obtenus, la Figure 3 montre clairement que le mode d'égrenage a un effet très négatif sur la densité de population, et par conséquent sur le rendement. En effet, le traitement T_2 seul réduit cette densité à 41.250 plants à l'hectare, soit près de 50 % de celle vulgarisée, hormis l'effet des autres facteurs (sécheresse, maladies et insectes, pauvreté des sols, etc.). Cet état de choses occasionne une grande perte aux agriculteurs et provoque une réduction substantielle de leur revenu.

Conclusion

Les résultats de la présente étude montrent clairement que les modes d'égrenage ont effectivement des effets néfastes sur la qualité des semences de maïs. Le pire des modes à proscrire est le battage avec 66,50 % de taux de germination, étant donné qu'il réduit la densité de population de près de 50 %, occasionnant ainsi un manque à gagner aux agriculteurs. Toutefois, le mode le plus adéquat reste l'égrenage manuel qui donne un fort taux de germination (93,50 %) et s'adapte bien aux petits multiplicateurs. Il est suivi de l'égrenage manuel utilisant le cône à décortiquer avec 88,50 % de taux de germination. Pour améliorer la performance de ce mode, il faut que les épis soient bien séchés. Un bon réglage de l'égreneuse va permettre au mode mécanique d'afficher un meilleur taux de germination et se mettre au service des gros multiplicateurs compte tenu de sa capacité.

Les résultats de cette étude sont utiles aussi bien aux inspecteurs du service du contrôle et de la certification qu'aux autres techniciens semenciers. L'appréciation des plantules est importante sinon primordiale dans la détermination du taux de germination d'un lot de semences.

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Promotion des nouvelles variétés de maïs et des pratiques culturales dans les zones du nord Togo

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Résumé

Le maïs est aujourd'hui une culture incontournable pour la population septentrionale du Togo. Il est cultivé dans la région de la Kara et des Savanes pour ses grains à multiples usages. En vue d'accroître d'une façon permanente la production du maïs, l'Institut Togolais de Recherche Agronomique, en collaboration avec le réseau WECAMAN a introduit des nouvelles variétés de maïs très performantes dans l'écosystème de la partie septentrionale du pays afin de dégager les préférences des paysans suivant les localités. Cette étude visait la promotion de l'utilisation des nouvelles variétés de maïs et l'amélioration des pratiques culturales dans le Nord du Togo pour accroître les rendements du maïs. Six (06) variétés de maïs extra précoces et précoces ont été utilisées. Les variétés de niébé IT81D-985 pour la Kara et TVx 1850 01F pour les Savanes et une variété de soja, Jupiter, pour les deux régions ont été associées au maïs pour améliorer la fertilité des sols. Trois années d'activités ont permis d'observer que quelle que soit la zone d'implantation des tests, les nouvelles variétés sont plus précoces (cycle moyen de 86 jours) que la variété locale Ikenne 8149SR (cycle moyen de 100 jours). Les nouvelles variétés sont également plus rentables si les paquets technologiques qui les accompagnent sont respectés. Quant aux tests relatifs aux pratiques culturales en vue de gérer la fertilité des sols, les légumineuses (soja et niébé) ont contribué à augmenter les rendements en maïs après 2 années d'activités. Les paysans ont apprécié les avantages de l'association culturale en même temps que son effet améliorateur du sol. Des journées agricoles organisées par les paysans producteurs, les chercheurs et les agents de vulgarisation ont permis de connaître la réaction des producteurs vis-à-vis des technologies améliorées.

Abstract

Maize (*Zea mays* L.) is an important crop for in Northern Togo. It is cultivated in the Kara and Savanna regions for its grain, which has several uses. In order to increase maize production on a sustainable basis, the

Togolese Institute of Agricultural Research (ITRA), in collaboration with the West and Central Africa Maize Network (WECAMAN) introduced improved high yielding maize varieties in the ecosystems of the northern part of the country in response to the perceived farmers' preferences for maize in the study areas. The objective of the study was to promote the adoption of improved maize technologies (varieties and cropping practices) with a view to increase yields in the northern part of Togo. Six early and extra- early maturing varieties were used. Cowpea [*Vigna unguiculata* (L) Walp.] variety IT81D-985 (in Kara) and TVx 1850-01F (in Savanna) and one soybean [*Glycine max* (L.) Merril] variety Jupiter in both regions were planted in association with maize to improve soil fertility. The results obtained after three years of activities indicated that the improved maize varieties matured earlier (86 days from planting to maturity) than the local check, Ikenne 8149SR (100 days). The improved varieties were also more profitable when the recommended cultural practices were fully applied. Planting the grain legumes (soybeans and cowpeas) with maize improved soil fertility and increased grain yield of maize after 2 years of activities. Interaction with the farmers during field days showed that farmers appreciated the advantages of cropping system and its potential in improving soil fertility.

Introduction

Le maïs est aujourd'hui la principale culture des populations togolaises. Dans le Nord du Togo (Région de la Kara et des Savanes) cette culture est devenue depuis quelques années, une céréale alimentaire de base des populations rurales aux côtés du sorgho et du mil. Selon les statistiques récentes, les superficies cultivées en maïs dans ces deux régions sont nettement en progression par rapport aux autres céréales (DSID, 2002). Cependant, les paysans continuent par faire face aux problèmes qui entravent la production du maïs.

En vue d'accroître d'une façon permanente la production du maïs, l'Institut Togolais de Recherche Agronomique, en collaboration avec le réseau WECAMAN a introduit des variétés améliorées de maïs précoces et extra-précoces, très performantes dans l'écosystème de la partie septentrionale du pays afin de dégager les préférences des paysans suivant les localités. Par ailleurs, la dégradation des sols dans cette partie du pays a atteint un niveau qui ne permet pas aux paysans d'avoir une production suffisante sans l'utilisation d'engrais minéraux. Les prix de ces engrais ne cessent d'augmenter d'année en année et leur utilisation devient difficile aux agriculteurs pauvres en ressources. Or, des études antérieures dans ces régions ont montré que le système de culture basé sur l'association céréale-légumineuse permet d'augmenter le niveau de l'azote dans le sol et d'améliorer la productivité des céréales (Fusell 1985 ; Salez, 1985 ; De Queiroz and Galwey, 1987 ; Toky *et al.,* 1997). Parmi les légumineuses qui ont été testées les légumineuses à graines comestibles ont été préférées par les paysans par rapport aux autres légumineuses destinées uniquement à l'amélioration de la fertilité du sol.

Les objectifs de la présente étude sont de promouvoir l'utilisation des nouvelles variétés de maïs dans le nord du Togo et d'améliorer les pratiques culturales pour accroître les rendements du maïs. La recherche a été menée pendant trois années successives, 2002, 2003, 2004, en vue de voir l'évolution des rendements découlant de l'amélioration de la fertilité des sols à travers l'utilisation des légumineuses à graines.

Matériel et Méthodes

Sites d'implantation des tests

Les tests ont été réalisés à Barkoissi dans la région des Savanes (préfecture de l'Oti) et à Koumonde, Sarakawa et Pagouda dans la région de la Kara. Le climat dans les deux régions comprend deux saisons à savoir : une saison sèche qui va de novembre à avril et une saison des pluies de mai à octobre. Les précipitations annuelles varient en moyenne de 900–1100 mm dans les savanes et de 1200–1300 mm dans la Kara. Les pluviométries enregistrées en 2004 sont 1060,9 mm à Sarakawa, 1276,1 mm à Aledjo-Koumonde et 1276,1mm à Pagouda dans la région de la Kara. La quantité de pluie enregistrée à Barkoissi est de 668,7mm. Les types de sol les plus représentés sont les ferrugineux tropicaux lessivés sur une grande profondeur avec un pH variant entre 6 et 7.

Le matériel végétal

Six (06) variétés améliorées de maïs et une variété témoin:

Trois variétés de maïs extra-précoces : 95TZEE-W ; 95TZEE-Y ; TZESR-W x GUA 314; 3 variétés de maïs précoces : TZECOMP$_3$C$_2$; AB11 et DMRESR-W et Une variété témoin de maïs : Ikenne 8149SR.

Deux variétés de légumineuses à graines : Niébé : IT81D 985 pour la Kara et TVx1850-01F pour les Savanes; Soja : Jupiter dans les deux régions.

Méthodologie

Promotion des variétés améliorées de maïs. Dans ce test, l'approche « parcelle mère » et « parcelle fille » a été utilisée. La parcelle mère est celle qui comporte l'ensemble du matériel à tester et un témoin local; dans ce cas trois variétés extra-précoces d'une part et trois variétés précoces d'autre part. Les parcelles filles quant à elles reçoivent une variété améliorée et un témoin local. Deux groupes de paysans ont été constitués dans chacune des régions de la Kara et des Savanes.

- Dans le premier groupe, deux paysans ont eu des parcelles ″mères″ pour les variétés extra précoces (95TZEE-w, 95TZEE-y, TZESRw x GUA 314 et un témoin local) et deux autres paysans pour les variétés précoces (TZECOMP$_3$C$_2$, AB11, DMRESRw et un témoin local).
- Dans le deuxième groupe, huit autres paysans (4 pour chaque type de maturité) ont mis en place des ″parcelles filles″ où ont été comparées les variétés améliorées par rapport à la variété locale.
- La taille des parcelles ″mère″ est de 200 m² (20m x 10m), tandis que celle des parcelles ″filles″ est de 400 m² (20m x 20m).

Amélioration des pratiques culturales. Huit paysans au niveau de chaque région ont chacun mis en place cinq parcelles :
T$_1$= maïs/niébé ; T$_2$ = maïs/soja ; T$_3$ = maïs en pur ; T$_4$ = niébé en pur et T$_5$ = soja en pur.
La variété DMRESRw a été utilisée. La superficie des parcelles est de 20m x 20m=400m².

Conditions de réalisation des tests

- Labour : les paysans ont fait des labours sur billons.
- Ecartement de semis :
  - maïs extra précoce : 0,64m x 0,40m à deux plants par poquet ;
  - maïs précoce : 0,75 m x 0,40m à deux plants par poquet ;
  - le niébé et le soja ont été semés sur les mêmes lignes que le maïs : 20 cm entre les poquets de niébé (densité 125000 pieds/ha) et 10 cm entre les poquets de soja (250000 pieds/ha).
- La fertilisation préconisée est 200 kg de NPK$_{15-15-15}$/ha et de 100 kg d'urée/ha.
- Les sarclages sont faits à la demande.
- L'encadrement des paysans a été fait par les chercheurs de l'ITRA et les conseillers agricoles de l'ICAT (Institut de Conseil et d'Appui Technique). Des visites régulières et organisées ont été faites pour permettre aux paysans de la région de connaître la performance des nouvelles variétés de maïs et les alternatives pour améliorer la fertilité des sols de la zone.
- Les données collectées ont porté essentiellement sur la performance du maïs et sur le comportement des paysans face aux alternatives. L'analyse statistique utilisée est la comparaison des moyennes par le logiciel MSTATC.

Tableau 1. Cycle des différentes variétés extra précoces dans les régions Kara et Savanes.

Régions	Paysans	Cycle végétatif (nombre de jours du semis à la maturité)			
		95TZEE-W	95TZEE-Y	TZESR-Wx-GUA314	Témoin
KARA	Tchakpala Yao	83	85	86	100
	Bode Alassani	85	87	88	97
Moyenne KARA		84	86	87	99
SAVANES	Kounaré Samari	87	85	93	102
	Goussiene Dénanga	89	89	86	99
Moyenne SAVANES		88	87	90	101

- Le ratio équivalent terre est utilisée pour analyser la performance des systèmes de cultures pures par rapport aux cultures associées. Ce ratio se calcule comme suit :

$$LER = Pm/P'm + Pl/P'l,$$

où

Pm est la production du maïs en association
P'm la production/ha du maïs en pur
Pl, la production de la légumineuse à graines en association
P'l la production de la légumineuse en pure

Résultats et Discussions

Les tests variétaux de maïs

Cycle de développement des variétés dans les zones d'essai. Quels que soient les lieux de production, les résultats montrent que le cycle des variétés du semis à la maturité est pratiquement le même pour les variétés extra précoces dans les deux régions soit en moyenne 86 – 90 jours contre une moyenne de 100 jours pour la variété témoin Ikenne 8149SR (Tableau 1). Les variétés précoces (Tableau 2) sont de même cycle que le témoin Ikenne soit en moyenne 100–102 jours du semis à la maturité.

Rendements des variétés de maïs

Variétés extra précoces de maïs. Les rendements ont été meilleurs dans la région de la Kara, toutes variétés confondues. Les variétés extra-précoces ont été plus productives que le témoin soit une moyenne de 1825 kg/ha contre 1500 kg/ha dans la Kara et de 1347,5 kg/ha contre 1575 kg/ha dans les Savanes pour la variété 95TZEE-w

Tableau 2. Cycle des différentes variétés précoces dans les régions Kara et Savanes.

Régions	Paysans	Cycle végétatif (nombre de jours du semis à la maturité)			
		TZE-Comp3C2	AB11	DM-RESRw	Témoin
KARA	Kéléou				
	Essodézam	103	99	103	103
	Landa Esso	99	102	100	102
Moyenne KARA		101	101	102	103
	Sambiani				
SAVANES	Biéntiéné	105	98	98	99
	Bentigré				
	Bendjoa	100	101	100	101
Moyenne SAVANES		103	100	99	100

Tableau 3. Rendement des variétés extra-précoces de maïs au niveau des parcelles "mères".

Régions	Paysans	Variétés			
		95TZEE-W	95TZEE-Y	TZESRwx-GUA314	Témoin
KARA	Djoua Esso	1100	1400	1200	1000
	Bodé Alassani	2550	1800	2000	2000
Moyenne KARA		*1825*	*1600*	*1600*	*1500*
SAVANES	Koumaré	1800	1737,5	1525	2075
	Samari	895	725	950	1075
	Goussiéne				
	Dénanga				
Moyenne SAVANES		*1347*	*1231*	*1237*	*1575*

(Tableau 3). Pour ces variétés extra-précoces, la 95TZEE-W et le témoin Ikenne ont donné les meilleurs rendements dans la Kara et dans les Savanes respectivement au niveau des parcelles mères. Quant aux parcelles filles, la 95TZEEW1 et la TZESRWxGUA 314 se sont montrées plus performantes dans la Kara et dans les Savanes (Tableau 4).

Variétés précoces de maïs. Les Tableaux 5 et 6 indiquent comme pour les variétés extra-précoces que les variétés précoces sont plus productives dans la région de la Kara, soit 3025 kg/ha pour la DMRESR contre 1900 kg/ha pour le Témoin à Kara et 981,25 kg/ha pour la TZLcomp3C2 contre 709,37 kg/ha pour le Témoin dans les Savanes.

D'une manière générale, la chute des rendements potentiels des nouvelles variétés obtenus chez les différents paysans semble être liée au retard enregistré lors des installations des essais et à l'irrégularité des pluies. Par ailleurs, ces variétés ont été en général, plus productives que la variété témoin Ikenne 8149SR. Les rendements sont aussi

Tableau 4. Rendement des variétés extra-précoces de maïs au niveau des parcelles "filles".

Régions	Paysans	Variétés			
		95TZEE-W1	95TZEE-Y	TZESRw x GUA314	Témoin
	Moussa Rafa		2000		1400
	Aminou Tagba		1500		1250
KARA	Ouro-Djéri Nou-	2850			1200
	houm			2500	2000
	Kézié Zakari			1250	1250
	Adam Ibrahim	2330			1500
	El-Hadji Soulé				
Moyenne KARA		*2590*	*1750*	*1875*	*1433*
	Bamondé Yamine			2800	2000
	Noundjo Lalle		925		1013
SAVANES	Kamboki Nangue			700	575
	Langa Yabi	975			1000
	Kantati Djatoike			2325	1050
	Kombaté Nanguyé		900		1250
Moyenne SAVANES		*975*	*913*	*1942*	*1148*

Tableau 5. Rendement des variétés précoces de maïs au niveau des parcelles "mères".

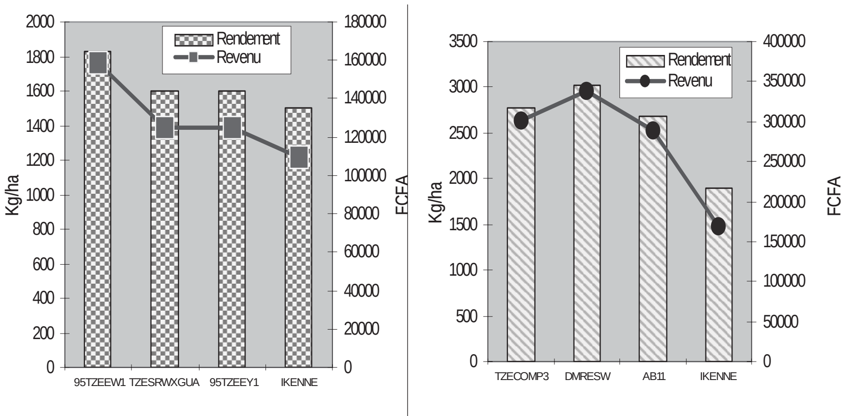
Régions	Paysans	Variétés			
		TZE-Comp3C2	AB11	DMRESRw	Témoin
KARA	Djakpala	3560	3080	3250	1600
	Yawa	2000	2300	2800	2200
	Landa Esso				
Moyenne KARA		*2780*	*2690*	*3025*	*1900*
Savanes	Sambiani	1025	725	925	625
	Biéntiéné	937,5	725	825	793,75
	Bentigré				
	Bendjoa				
Moyenne SAVANES		*981,25*	*725*	*875*	*709,37*

fonction de la technicité des paysans; ceux qui ont respecté les recommandations relatives aux paquets technologiques ont obtenu les meilleurs rendements.

Rentabilité économique des nouvelles variétés de maïs. Le bénéfice des producteurs (Figures 1 et 2) est calculé à partir du coût de production et de la valeur de la production. Le coût de production prend en compte le coût des intrants et le coût de la main d'ouvre pour les différents travaux du labour jusqu'à la récolte et l'égrenage. Pour les deux régions, le coût moyen de production à l'hectare se présente comme suit :

Tableau 6. Rendement des variétés précoces de maïs au niveau des parcelles "filles".

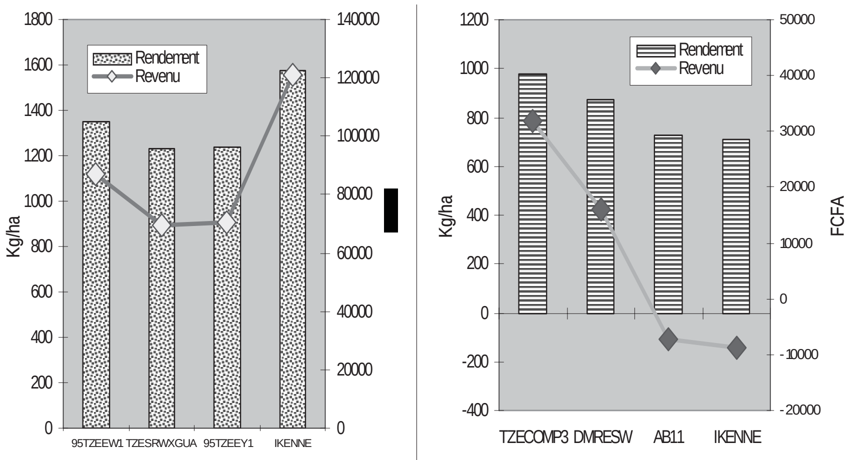
Régions	Paysans	Variétés			
		TZE-Comp3C2	AB11	DMRESRw	Témoin
KARA	Kadjina Tanou	2600	-	-	2000
	Alaza Tchaou	-	-	3200	2830
	Patchiritom	-	3000	-	1400
	Eyadéma	-	-	3250	3200
	Gnalia Haram	-	2200	-	1800
	Kéléou Essodazam	2800	-	-	1400
	Abi Tcha				
Moyenne KARA		*2700*	*2600*	*3225*	
SAVANES	Lamboni Yen-	-	-	875	700
	doubou	-	800	-	688
	Laré Bawa	-	-	675	525
	Douti Niépack	825	-	-	675
	Damekaté Yao	970	-	-	725
	DjondjonKodjo	-	562,5	-	494
	Lamboni Alassani				
Moyenne SAVANES		*898*	*1363*	*775*	*635*



Variétés extra-précoces

Variétés précoces

Figure 1. Revenu par rapport aux variétés de maïs dans la région de la Kara.



Variétés extra-précoces

Variétés précoces

Figure 2. Revenu par rapport aux variétés de maïs dans la région des Savanes.

Coût moyen à l'hectare:

- semences 350 F x 25kg = 8750 F
- engrais 155 F x 300 kg = 46500 F
- main d'œuvre = 60000 F

Total = 115250F

Le prix moyen du kilogramme de maïs est de 150 F. Notons, cependant, que les producteurs préfèrent vendre leur maïs quand le prix est élevé sur le marché et atteint 175 à 200 F / kg. Les variétés extra-précoces ont procuré aux paysans des bénéfices qui varient :

- de 109750F pour Ikenne à 158500 F TZEEW1 dans la région de la Kara
- et de 121000 F pour Ikenne à 86950 F pour 95TZEEW1 dans la région des Savanes.

Le bénéfice du paysan varie pour les variétés précoces d'un b301750 F pour TZEcomp3 dans lab région de la Kara.

Il apparaît clairement à travers la Figure 1 que dans la région de la Kara, les précoces et extra précoces ont procuré aux producteurs de meilleurs revenus. La tendance inverse est observée avec les variétés précoces dans la région des Savanes où les revenus sont très faibles et même négatifs. Dans cette même région la Figure 2 indique qu'avec les variétés extra précoces le paysan tire meilleurs profits quand les conditions pluviométriques sont défavorables. C'est pour cela que les paysans de ladite région ont toujours exprimé une forte demande vis à vis de ces variétés extra-précoces. La leçon à tirer est qu'il faut

Tableau 7. Evolution des rendements maïs de 2002 à 2004.

Région		Rendements maïs (kg/ha)			
	Pratiques culturales	Année 2002	Année 2003	Année 2004	Moyenne Pratique culturale
KARA	Maïs/niébé	2295	2313	1470	*2026*
	Maïs/soja	2077	2287	1880	*2081*
	Maïs pur	2660	2090	2124	*2287*
	LSD $_{0,05}$	*632*	*503*	*402*	
	CV	*25,14%*	*21,04%*	*20,57%*	
SAVANES	Maïs/niébé	1965	5300	1472	*2912*
	Maïs/soja	1688	5381	1308	*2790*
	Maïs pur	1323	5060	2014	*2798*
	LSD $_{0,05}$	*349*	*207*	*121*	
	CV	*19,64%*	*3,67%*	*7,08%*	

nécessairement respecter le calendrier de semis si l'on veut tirer meilleur profit de la culture du maïs ou, si les pluies s'installent en retard, utiliser des variétés extra-précoces qui répondent mieux aux conditions difficiles.

Gestion de la fertilité des sols par l'association maïs /légumineuses à grains. A Kara, on observe une évolution positive des rendements de l'année 1 à l'année 2 quand les légumineuses ont été associées au maïs (Tableau 7).

Le rendement de la culture pure du maïs a chuté en deuxième année. Ces résultats font penser immédiatement à un effet améliorateur des légumineuses. Cette augmentation de rendement est observée sur toutes les parcelles dans la région des Savanes. Cependant, les paysans ont obtenu des rendements plus faibles en troisième année (2004) avec la culture en pur donnant le meilleur résultat. Ceci peut être attribué au retard accusé dans la mise en place des parcelles et aux caprices pluviométriques observés dans l'année surtout dans la région des Savanes. Mais avec le calcul du ratio équivalent terre (LER) (Tableaux 8 et 9) il apparaît que les pratiques culturales proposées sont globalement plus avantageuses pour les producteurs surtout quand on considère que les légumineuses se vendent à un prix élevé et laisseront leurs résidus pour une meilleure protection du sol.

Analyse coût/profit du système d'association maïs/légumineuses. Une tendance similaire est observée dans la région des Savanes quant aux avantages des cultures associées par rapport aux cultures pures. Les LER se situent entre 1,13 et 1,39 pour le niébé alors qu'ils sont de 1,07 et 1,33 pour le soja. Ces gains de rendement du maïs cultivé en association indiquent que les légumineuses ont contribué à

Tableau 8. Rendements (kg/ha), et ratio équivalent terre dans les associations maïs/niébé dans les régions de la Kara et des Savanes en 2004.

Région	Paysans	Maïs pur	Maïs associé avec niébé	Niébé pur	Niébé associé	LER
Kara	Paysan 1	1500	1400	350	300	1,70
	Paysan 2	3000	1200	600	300	0,90
	Paysan 3	1800	1200	600	500	1,53
	Paysan 4	2800	1500	600	400	1,24
	Paysan 5	2200	2000	600	500	1,74
	Paysan 6	2000	1800	1800	450	1,15
	Paysan 7	1500	1200	1000	300	1,10
Moyenne Kara		*2114,3*	*1471,4*	*792.9*	392,9	1,33
Savanes	Paysan 1	1750	1250	1200	600	1,21
	Paysan 2	2750	2350	1225	500	1,29
	Paysan 3	1950	1625	950	500	1,35
	Paysan 4	1350	925	650	400	1,32
	Paysan 5	2150	1350	750	350	1,13
	Paysan 6	2250	1750	1100	600	1,35
	Paysan 7	1900	1050	650	550	1,39
Moyenne Savanes		*2014,3*	*1471,4*	*932.1*	*500,0*	1,29

Tableau 9. Rendements (kg/ha), et ratio équivalent terre dans les associations maïs/soja dans les régions de la Kara et des Savanes.

Région	Paysans	Maïs pur	Maïs associé au Soja	Soja pur	Soja associé	LER
Kara	Paysan 1	1500	1450	400	280	1,62
	Paysan 2	3000	3000	600	300	1,50
	Paysan 3	1800	1200	1200	300	0,95
	Paysan 4	2800	2400	500	300	1,46
	Paysan 5	2200	2200	300	450	1,66
	Paysan 6	2000	1600	910	500	1,35
	Paysan 7	1500	1300	1950	450	1,09
Moyenne Kara		*2114,3*	*1878,6*	*837,1*	*368,6*	1,37
Savanes	Paysan 1	1750	1050	900	450	1,10
	Paysan 2	2750	2150	900	400	1,24
	Paysan 3	1950	1470	1100	600	1,33
	Paysan 4	1350	850	450	250	1,23
	Paysan 5	2150	1150	550	300	1,07
	Paysan 6	2250	1555	950	450	1,16
	Paysan 7	1900	900	750	500	1,16
Moyenne Savanes		*2014,3*	*1303.6*	*800.0*	*421.5*	1,18

améliorer la productivité du sol comme l'ont prouvé d'autres auteurs (Salez 1985, Marathe, 1994, Toky et al 1995) et plusieurs autres activités menée avec WECAMAN au Togo. L'essentiel de ce travail n'était pas de démontrer à travers des analyses de sols que les légumineuses améliorent la fertilité des sols mais d'amener les agriculteurs à comprendre la pratique et à s'en approprier.

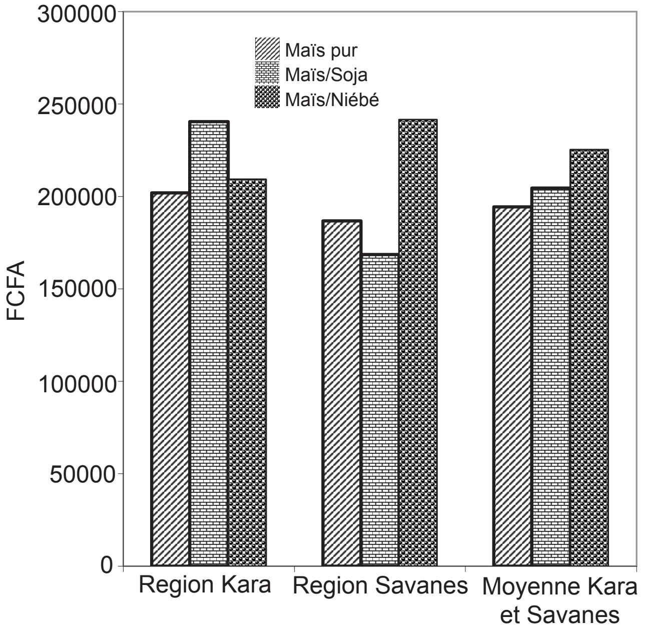


Figure 3: Revenus provenant des différentes pratiques culturales.

Le revenu est calculé en prenant en compte le coût des intrants et de la main d'œuvre, du labour jusqu'à l'égrenage. Le coût de production calculé plus haut (115250FCFA) est utilisé pour évaluer la rentabilité du maïs. A ce coût a été ajouté le coût de production de la légumineuse pour calculer le revenu obtenu à partir de l'association culturale.

Pour le soja : 500 F/kg de semences de soja x 25kg/ha = 12500F
Main d'œuvre :=15000 F
Le Coût de production maïs/soja = 115250 F + 12500 F + 15000F= 142750F

Pour le niébé : 500F/kg x 8 Kg de semences = 4000 F
Main d'œuvre : 15000 F

Le Coût de production maïs/niébé = 115250 F + 4000F + 10000F = 129250F

Le prix moyen du kg des légumineuses était à 300 F pour le niébé et a 275 pour le soja

Des marges bénéficiaires de 201895 F et 186895 F sont obtenus pour le mais en culture pure dans la région de la Kara et des Savanes respectivement (Figure 3) L'association maïs/soja et l'association maïs/niébé donnent des meilleurs revenus dans la Kara et les Savanes respectivement confirmant ainsi la rentabilité de l'association maïs/légumineuses non seulement en terme d'amélioration de la fertilité des sols mais aussi des revenus du producteur.

Sensibilisation des producteurs à l'utilisation des technologies améliorées de production de maïs

Dans le souci de faire connaître les nouvelles variétés de maïs et les pratiques culturales introduites dans la partie septentrionale du pays, des journées agricoles ont été organisées dans les régions de la Kara et des Savanes. Un autre objectif de la journée agricole était de recueillir les impressions des producteurs agricoles sur la performance des nouvelles variétés de maïs par rapport à leurs propres variétés. Ces journées agricoles, en plus des paysans pilotes, des chercheurs et des agents de la vulgarisation, connaissent la participation des paysans des villages environnants, des ONG en activités dans la région, des autorités politiques et traditionnelles.

Dans les régions de la Kara et des Savanes, les paysans ont parcouru la parcelle d'un paysan pilote retenu pour apprécier le comportement des nouvelles variétés. Des discussions se sont enchaînées de la part des paysans qui ont apprécié la précocité et les autres caractéristiques des variétés introduites. Il ressort des discussions que les semences de cette variété soient disponibles. Tous les participants à la journée agricole en l'occurrence les paysans se sont montrés très motivés et ont activement participé aux débats et souhaitent avoir les semences améliorées pour emblaver une superficie plus grande.

Ces rencontres permettent également aux producteurs de baptiser les variétés afin de les distinguer facilement parmi les autres variétés qui existent dans le milieu. Ceci est très important et pourra aider plus tard dans les études d'impacts ; car tout ce qui est précoce était appelé « maïs de deux mois » ou même à tord « Ikenne ». Ainsi à Kara par exemple, la variété 95TZEE-W est surnommée 'FALAZI-N'DOKI''qui veut dire « maïs de soudure ». A Barkoisi dans la région des Savanes, la 95TZEE-WXGua 314 est appelée « KASSAA » qui signifie « c'est bon ».

Conclusion

Les résultats des différents tests réalisés dans les deux régions du Nord -Togo permettent de tirer les conclusions suivantes :

- Les nouvelles variétés de maïs introduites dans les zones de la Kara et des Savanes sont performantes et répondent aux besoins des producteurs. Les extra précoces sont très appréciées dans la région des savanes où elles répondent mieux aux conditions pluviométriques irrégulières.
- Des journées de rencontre sur les parcelles-tests où chercheurs, vulgarisateurs et agriculteurs, organisent des débats ont permis d'apprécier la précocité des variétés améliorées par rapport aux variétés locales des paysans;

- Au niveau des tests associations maïs/légumineuses par rapport au maïs en pur, il a été noté une augmentation de rendement du maïs sur les parcelles ayant reçu le niébé et le soja pour la troisième année consécutive par rapport à la campagne précédente.
- Les rendements très bas obtenus chez certains paysans peuvent s'expliquer d'une part par le retard accusé dans l'installation des tests et d'autre part par l'irrégularité des pluies qui entraîne souvent la négligence dans les techniques culturales (entretien cultural, période d'épandage d'engrais) par les paysans découragés malgré les visites répétées des conseillers agricoles.

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Socio-economic determinants of fertilizer use intensity for maize-based production systems in the northern Guinea savanna of Nigeria

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Abstract

There has been considerable interest in soil fertility management for increased crop productivity in the agricultural sector of developing countries. This study aimed at understanding the current status of soil fertility management and the identification of socio-economic characteristics influencing the decision of households on fertilizer use intensity in maize-based production systems in the northern Guinea savanna of Nigeria. A total of 160 households involved in maize–based cropping were interviewed using a structured questionnaire to collect information on household socioeconomic profile and production data relating to the 2003/2004 cropping season. Data collected were analyzed using descriptive statistics and dichotomous binary logit model. Analysis revealed that households combine techniques like application of organic and mineral fertilizer and crop planting pattern in maintaining the fertility of their soils. Fertilizer use intensity, measured by ratio of (N + P_2O_5 + K_2O) and total area cultivated for all maize–based cropping were 204.5 and 221.7 kg/ha in Katsina and Kaduna States respectively. The ratio of N: P_2O_5: K_2O/ha were 49.5:98.3:56.7 in Katsina State and 58.7: 109.4: 53.6 in Kaduna State. The estimated logit models revealed that fertilizer use intensity is significantly influenced by previous year's income, land ownership, engagement in off-farm activities and experience in maize farming. Structural transformation that would encourage intensification in the use of fertilizer in order to increase productivity among rural farm families will need to take these variables into consideration.

Résumé

Il y a un interêt considérable dans la gestion de la fertilité du sol pour une augmentation de la productivité du secteur agriculture dans les pays en voie de developpement. Cette étude visait à comprendre le statut actuel de la gestion de la fertilité du sol et l'identification des caractéristiques socio-économiques influençant la décision des ménages sur l'intensité d'utilisation des engrais dans les systèmes de production à base de maïs dans le Nord de la savane guinéenne du Nigéria. Un total de 160 ménages impliqués dans les associations à base de maïs a été interviewé en utilisant un questionnaire structuré afin de recueillir les informations sur le profil socioéconomique des ménages et les données de production relative à la saison des cultures 2003 / 2004. Les données recueillies ont été analysées en utilisant des statistiques descriptifs et des modèles dichotomiques de régression binaires. L'analyse a révélé que les ménages combinent des techniques comme l'application d'engrais minéral et organique et de modèle de dispositif de semis de la culture afin de maintenir la fertilité de leurs sols. L'intensité d'utilisation des engrais, mesurée par la proportion de (N + P_2O_5 + K_2O) et la superficie totale emblavée pour tous les systèmes associant le maïs étaient de 204.5 et 221.7 par hectare dans les états de Katsina et de Kaduna respectivement. Les proportions de N: P_2O_5: K_2O par hectare étaient de 49.5:98.3:56.7 dans l'état de Katsina et de 58.7:109.4:53.6 dans l'état de Kaduna. Les modèles ont révélé que la décision des ménages concernant l'utilisation intensive des engrais est significativement influencé par l'engagement dans les activités hors champs, les revenus tirés des champs l'année précedente, l'état de propriétaire terrien et le nombre d'années d'expérience dans la culture du maïs. Les transformations structurelles qui encourageraient l'intensification de l'utilisation des engrais pour accroitre la productivité dans les familles rurales devraient prendre ces variables en consideration

Introduction

The problem of declining soil fertility in the crop-based farming systems of sub-Saharan Africa (SSA) has been well documented (Mortimore *et al.* 1990; Donovan and Cassey 1998; Sanchez 2002). This problem has raised concerns about the sustainability of agricultural production to be able to keep pace with the increasing population growth rate in these countries. To maintain acceptable yield levels, the use of organic soil amendments, in combination with inorganic fertilizers has been identified to be more sustainable in the cropping systems of the savanna regions. However, their cost, erratic availability, coupled with low returns and unreliable markets for agricultural produce frequently deter farmers from using them (Honlonkou *et al.* 1999). The development of soil fertility maintenance options has often focused on technical interventions with little or no consideration about institutional and policy elements as well as farm-household socio-economic characteristics. According to Doppler *et al.* (1999), sustainability in the adoption of soil fertility technology by farmers should take into consideration agro-ecological and socio-economic differences in farm locations, diversity of resource endowment and farmers' social status. Future strategies for increasing agricultural productivity will have to focus on using all available nutrient resources more efficiently and in a sustainable manner, taking into consideration farming activities, non-farm elements and, more specifically, off farm activities of the farm-household.

The study reported here was conducted in the northern Guinea savanna (NGS) of Nigeria where soil nutrient depletion is very high due to intensive farming and inappropriate application of fertilizers, causing negative balance in soil nutrients (Adedeji and Kormawa 2002). The inappropriate management of soil fertility is a serious problem that threatens the sustainability of agriculture in this zone. This study aimed at understanding farmers' perception of soil fertility management and the identification of socio-economic characteristics influencing the decision of households on fertilizer use intensity for maize-based production systems. Maize (*Zea mays* L.) is one of the most important food grains in the NGS ecological zone of Nigeria. The popularity of maize in this ecology has been enhanced by the fact that it became not only a major food crop for many homes but also a commercial crop on which many agro-based industries depend for raw materials. Kyiogwon *et al.* (2002) indicated that the high potential of maize in the NGS could only be realized through the use of fertilizer because of the low inherent fertility of the savanna soils. Ogunfowora (1996) also asserted that fertilizer is the most important input for maize production in terms of its contribution to output and productivity within the shortest possible time. This study, therefore, attempted to identify socio-economic factors influencing fertilizer use intensity for sustainable improvement in soil fertility maintenance for maize–based production systems in the NGS ecological zone of Nigeria.

Methodology

The study area

The NGS where the research was conducted, covers about 13% of the total land-mass in the country (Manyong *et al.* 2001). The zone is located between latitudes 11°07′ and 13°22′ N and longitudes 6°52′ and 9°22′ E. Two seasons can be distinguished – the rainy season from May to September/October and a long dry season from October to May. Maximum temperature during the rainy period is between 27 and 34°C and minimum temperature is about 18–21° C. Soils in this zone have a sandy loam to clay loam textured topsoil, with a pH of 5–7 and an organic carbon content ranging between 0.5 and 1.5%. The soil properties as described by Norman (1982) are leached ferruginous tropical soil. The surface soil is reddish fine loam clay to sandy loam. Selection of the study area was based on the criterion that the area is prone to nutrient mining as a result of intensive cultivation practices.

Two States (Kaduna and Katsina), which are about the leading States in maize production in Nigeria, were used as case studies for the ecological zone. The suitability of the biophysical and socio-economic features for maize production was the other criterion used to select the States for the study.

Sampling procedure

A multistage sampling procedure was applied to select 160 households involved in maize-based production system in Katsina and Kaduna States. In the first stage, eight local government areas (LGA), four in each State, were selected based on the intensity of maize production. The selection was done to reflect the typical situation for maize-based farming systems. Secondly, one village was also selected from each of the LGAs using the above criterion. Finally, 20 households were selected at random from the list of households in the village to make up a sample size of 160. However, only 147 questionnaires were retrieved and analyzed. The surveyed villages in Kaduna State were Kaya, Saminaka, Tashan Saibu and Makarfi while those in Katsina State were Dandume, Machika, Mahuta and Daudawa.

Data collection

The data used in this study came from both primary and secondary sources. Secondary data on recommended levels of N, P_2O_5 and K_2O were obtained from results of on-station trials conducted by the Institute for Agricultural Research, Samaru, Zaria.

A survey of households was conducted to collect data from the household heads. A structured questionnaire was used to gather both qualitative and quantitative information covering all aspects of social and economic activities, land use pattern, cropping systems, perception of soil fertility management, use of organic and mineral fertilizer for maize production, preferences, production expenses and output levels. The survey was conducted during the 2002/2003 agricultural year.

Analytical framework

Estimates of binary logistic regression coefficients were used to identify the factors influencing fertilizer-use intensity in the study area using the Statistical Package for Social Sciences (SPSS) version 10. Data on quantities of both organic and mineral fertilizers were converted into three basic nutrient components (N, P_2O_5, and K_2O). Fertilizer-use intensity was computed as the fertilizer input (sum of N, P_2O_5, and K_2O) expressed as a proportion of total land area under maize-based production.

In binary logistic regression, the dependent variable is converted into a dichotomous binary variable coded 0 and 1. Farmers with low fertilizer-use intensity, those households who apply less than 25% of the recommended fertilizer rate 311.46 kg/ha (120 N, 137.46 P_2O_5 (60 P) and 54 K_2O (45 K))–were assigned the value of zero while those who applied above 25% were assigned the value of 1. Earlier studies (Carsky and Iwuafor 1999; Manyong *et al.* 2001) have shown that application of at least 25% of the recommended fertilizer rate is required for an appreciable increase in maize yield. Thus households applying this rate or less were assumed not to be deriving much benefit from this input.

Ten socio-economic variables were assumed to influence the decision of households to use fertilizer intensively on maize-based farms: total cropped area, age of household head, years of formal schooling, number of years of experience in maize farming, engagement in off-farm activities (dummy = 0 not involved, and 1 if involved), previous season's farm income, land ownership (dummy = 0 if hired or leased / borrowed and 1 if inherited or purchased), number of livestock units, farmers' perceived soil fertility status and household size. The data for the two States were pooled to increase efficiency in model estimation. Dummy variables (Kaduna = 1 and Katsina = 0) were used to account for differences in fertilizer use between the two States.

The logit model has the following functional form:

$$L_n (P_i / 1\text{-}P_i)) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \ldots\ldots\ldots + \beta_k X_k + \in$$

P_i = the probability that the household used fertilizer intensively;
$(1 - P_i)$ = the probability that the household did not.
β_0 = Intercept
β_1 --- β_k = the coefficients of the explanatory variables $X_1 \ldots\ldots X_k$
$\in$ = error term with zero mean
$L_n (P / 1\text{-}P))$ = log odds ratio

Results and Discussion

Household socio-economic profile and perception of soil fertility maintenance

The age of respondents ranged between 21 and 75 years with an average of 43 years in Katsina State and 47 years in Kaduna State. About 75% of the respondents had only Quranic education while only about 9% went through secondary school. The pattern of livelihood sources revealed that about 92% of the household took farming (crop and livestock) as their major occupation; others were traders involved in both agricultural and non-agricultural products. Other sources of livelihood are hunting and civil service. Average experience in maize farming was 19 and 25 years in Katsina and Kaduna States. Land was acquired mainly through inheritance (59%), while about 17%, 4%,

Table 1. Percentage of farm households in Kaduna and Katsina States using different techniques in maintaining soil fertility for maize-based cropping systems.

Techniques	Katsina	Kaduna	Both locations
Mineral fertilizer	92	100	96
Organic manure	90	52	74
Crop rotation	51	42	45
Mixed cropping	37	29	33
Fallow	4	2	2

Multiple responses allowed.

13% and 7% of the total area cultivated by the sampled households were purchased, gifted, leased, and rented, respectively. The implication of this distribution is that 80% of the households owned the land they cultivated while only about 20% rented or leased farmlands. The household size varies from 4 to 26 people per household with a mean of 9 persons. The proportion of household labour capacity is only about 25% of the total, indicating that most of the labour requirement on the farm has to be sourced from outside the household.

About twelve maize-based cropping patterns were identified in the study locations. Maize was cropped as a sole crop by about 64% of the sampled households in Katsina State and about 75% in Kaduna State. Maize-sorghum, maize-cowpea, maize-sorghum-cowpea, maize-cocoyam, maize-cotton, maize-groundnut, maize-sorghum-soybean, maize-millet, maize-millet-cowpea, maize-rice and maize-soybean were the predominant maize-based mixtures in the study locations. The average farm size allotted to maize-based crops varied from 0.8 to 23 ha with an average of 5.3 ha in Katsina State and 6.5 ha in Kaduna State. Cattle, sheep, goats, and poultry constituted the essential animal components of the farming system.

The farmers analyzed the fertility status of the soils. About 82% perceived that the soils were inherently not fertile, while only about 18% indicated that the soils were good enough. The infertility of the soil was attributed to inadequate fertilizer, particularly mineral fertilizer and organic manure, and inadequate farmland resulting in continuous cultivation on the same piece of land. Techniques used by the households in maintaining soil fertility as indicated in Table 1 include application of mineral fertilizer (93% of the households), farmyard manure (78%), crop rotation (45%), cultivating crops in mixtures (cereal–legume) (68%) and fallow (3%). Application of organic and mineral fertilizers is the most commonly used method. Even with the high cost of mineral fertilizers, farmers indicated that they could not obtain much from maize without applying this input; thus, most of the farmers interviewed used mineral fertilizers at varying levels.

Table 2. Levels of fertilizer use (kg/ha) in maize-based cropping systems by farm households in Kaduna and Katsina States.

	Katsina	Kaduna	All
N	49.5	58.7	53.4
$P_{2l}O_5$	98.3	109.4	101.7
K_2O	56.7	53.6	54.1
FUI	204.5	221.7	217.9

FUI = Fertilizer Use Intensity

Organic manure represents one of the important means of maintaining soil fertility in the study location. About 90 and 52% of the households sampled in Katsina and Kaduna States used farmyard manure on their farms. The manure was mainly from cattle, sheep, goat, and chicken droppings/bedding materials, household wastes, cooking ash and municipal waste (refuse dumps). The households indicated awareness of the importance of organic manure, not only in enriching the fertility of soils but also in improving soil physical properties. However, they preferred applying mineral fertilizers because of ease of application, the manageable quantity required during each application and the efficiency in increasing crop yield.

Fertilizer-use intensities, measured by the ratio of ($N + P_2O_5 + K_2O$) and the total area cultivated for all maize–based crops, were 204.5 and 221.7 kg/ha in Katsina and Kaduna States (Table 2).

The ratio of N: P_2O_5: K_2O/ha was 49.5:98.3:56.7 in Katsina State and 58.7:109.4:53.6 in Kaduna State. The sources of these nutrients were N:P:K (15:15:15), single super-phosphate, urea, farmyard manure, livestock droppings and household wastes. Analysis of the nutrients applied indicated that less than half of the recommended 120 kg N was used while the ratios were higher for P_2O_5 and K_2O in both States. This was attributed to the higher content of available P_2O_5 and K_2O from organic manure compared to the available N. The primary source of N was inorganic fertilizer, which accounted for about 85% of the total. The quantities of both the organic and mineral fertilizer used were observed to be low. The low rate of mineral fertilizer used by the households was attributed to the high cost of fertilizer, low cash income of the household, and lack of credit facilities while that of manure were mainly associated with the small number of livestock kept, which could not produce enough manure in a season, and the free-range system that does not allow efficient collection and management of manure. Also, marketing of manure was limited in the study locations due to the fact that most of the households do not have enough for their own farms.

Table 3. Socio-economic factors influencing decisions on fertilizer-use intensity by maize farm households in Kaduna and Katsina States.

Variable	Coefficients	S.E.	Sig.	Exp(B)
Total area cropped	- 0.020	0.196	0.921	0.981
Age of household head	- 0.050	0.043	0.245	0.951
Years of formal schooling	0.098	0.060*	0.101	1.103
Experience in maize farming	0.113	0.047**	0.016	1.119
Involvement in off farm activities	1.626	0.621***	0.009	5.083
Previous year's income	0.000	0.000***	0.002	1.000
Land ownership	1.637	0.519***	0.002	5.140
Livestock unit	0.088	0.073	0.226	1.092
Household labor force	0.002	0.041	0.955	1.002
Perceived fertility status	0.137	0.234	0.560	0.873
State	0.632	0.515	0.219	
Constant	-3.604	1.808**	0.046	0.027

-2 ln (LMR) (d.f.) = 11) = 108.288) (P < 0.001) Nagelkerte $R^2 = 0.522$

Socio-economic factors influencing fertilizer-use intensity

The hypothesis that a certain socio-economic profile predisposes households to intensification of fertilizer use in maize-based farms can be accepted based on the estimated logistic regression model presented in Table 3. The model fits the data very well, with the calculated Chi-square value of 63.57 (df=11; $P \leq 0.001$). The percentage of correct prediction was 83.7, which is quite good. Besides, the Nagelkerte goodness of fit test showed that the models significantly fit the data for the study locations. The good fit of the models proved that the variables tested in this study were valid for the purposes of explaining fertilizer-use intensity for maize-based cropping system in the study area.

With the exception of farm size and age, all other variables in the model had a positive influence on fertilizer-use intensity. The decision by households to use fertilizer intensively was significantly influenced by the following household's socio-economic variables: previous year's income, land ownership, engagement in off-farm activities and experience in maize farming.

Conversely, age of household head, number of years in school, farm size, household size, number of livestock units and farmers' perceived soil fertility status had no significant influence on fertilizer use. Involvement in off-farm activities, previous year's income and land ownership had a significant ($P<0.01$) positive influence on fertilizer-use intensity. Holding all other variables constant, the odds of using fertilizer more intensively is about 5 times more for households engaged in off-farm activities compared to those who do not. Engagement in off-farm activities promotes intensive use of fertilizer since cash availability is considered as the most important constraint. Income from off-farm activities can be used to purchase fertilizer for crop production. Similar results were reported by Green *et al.* (1993), who found that income from off-farm employment significantly influenced farmers' decisions to adopt the recommended fertilizer application rate in Malawi.

There was a higher tendency for farmers who owned the farmland they cultivated to use fertilizer more intensively compared to those who leased or rented their farmlands. The odds ratio (Exp (β)) for this variable was 5.140, which suggests that farmers who own farmlands are almost 5 times more likely to use fertilizer more intensively than those who borrow or rent the farms they cultivate. This is expected, because farmers tend to invest more in soil fertility management strategies if they own the land than when it is borrowed or rented.

The results also support the hypothesis that previous year's income and experience in maize farming have positive effect on decisions on fertilizer use. That is, farmers with more years of experience in maize production are likely to use fertilizer more intensively. Years of experience in farming contribute to human capital development and, therefore, households that are more experienced in maize farming are likely to be knowledgeable on the importance of intensive fertilizer use for increased maize production.

Conclusions

The objective of this study was to identify farm-family specific variables that were detrimental to the decision to use fertilizer and increase productivity. Mineral fertilizer was the most important input for replenishing soils in the study locations, however, the rate of application was found to be low due to high cost of fertilizer, low output price/cash income of the household and lack of credit facilities. Engagement in off farm activities, previous year's income, years of experience in maize farming, and type of land ownership had positive effect on household decision on fertilizer use. Structural transformation that would encourage intensification in the use of fertilizer in order to increase productivity among rural farm families will need to take into consideration access to credit, not only for fertilizer but also to diversify income into off-farm sources. Engagement in off-farm activities promotes intensive use of fertilizer since cash availability is considered as the most important constraints. Changes in the land tenure system to ensure more security on land ownership is also indispensable for encouraging intensification in fertilizer use.

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Unexploited yield and profitability potentials of improved varietal technologies: the case of hybrid maize in Western Ethiopia

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Abstract

In view of the considerable potential for increasing food production through the generation and use of new agricultural technology, many developing countries have invested in agricultural research and extension. However, the issue of whether the intended production gains from new technologies have actually been realized by poor farmers has received little or no attention. This paper used a stochastic frontier efficiency decomposition methodology to derive the technical, allocative, and economic efficiency measures for a sample of hybrid maize producers in Western Ethiopia. The results revealed under-exploitation of the potential of hybrid maize and indicated that farmers could increase production, on average, by 26% if they all adopted the recommended management practices. Furthermore, adoption of the recommended management practices coupled with optimum use of inputs, especially fertilizer, would enable the farmers to reduce production costs by an average of 39%. Increased yields would lower per unit production cost and increase the profitability of maize production. This would in turn ensure sustainable use of improved agricultural technologies. Education, provision of input credit, and timely availability of critical inputs are positively and significantly related to the efficiency of hybrid maize production.

Résumé

Au vu du potentiel considérable nécessaire à l'augmentation de la production alimentaire à travers les générations et l'utilisation de nouvelles technologies agricoles, beaucoup de pays en voie de développement ont investi dans la recherche agricole et la vulgarisation. Cependant, la question de savoir si les gains ont réellement été réalisés par les agriculteurs pauvres à partir de l'application des nouvelles technologies, a reçu peu ou aucune attention. Cette étude utilise une méthodologie de décomposition stochastique frontière d'efficacité afin de dériver les mesures d'efficacité technique, locative, et économique pour un échantillon de producteurs d'hybrides de maïs dans l'Ouest de l'Ethiopie. Les résultats ont révélé des sous-exploitations considérables des potentiels de rentabilité et de rendement des hybrides de maïs et ont indiqué que les agriculteurs pourraient augmenter la production en moyenne de 26% s'ils adoptaient toutes les pratiques de gestion recommandées. De plus, l'adoption des pratiques de gestion recommandées couplées avec l'utilisation optimum d'intrants, surtout d'engrais, permettrait aux agriculteurs de réduire les coûts de production en moyenne de 39%. L'augmentation des rendements baisserait les coûts par unité de production et améliorerait la rentabilité de la production de maïs. Cela en retour, assurerait l'utilisation durable des technologies agricoles améliorées. L'éducation, l'approvisionnement en intrants par crédit, et la disponibilité des intrants au moment voulu, sont positivement et significativement liés à l'efficacité de la production d'hybride de maïs.

Introduction

The development strategy of the Ethiopian government focuses on agriculture and food security. An economic reform program was initiated through a structural adjustment program under the auspices of the World Bank and IMF. The reforms included the removal of substantial taxation of agriculture, market liberalization, and devaluation (Mulat 1999). Input and product markets have been liberalized and extension services expanded and re-organized (Techane and Mulat 1999; Mulat 1999). Within the framework of the agricultural development-led industrialization policy of the government, a new system of agricultural extension known as participatory demonstration and training extension system was launched in 1994/95 to demonstrate to farmers the benefits of a package of inputs, notably balanced and higher rates of fertilizer, improved seeds, pesticides and better cultural practices. Widespread adoption of high yielding varieties of major cereal crops by the majority of resource-poor farmers has been considered a key strategy by the government. Maize (*Zea mays* L.) is the principal component crop of this strategy. Through the new extension system, the use of fertilizer and improved maize seeds has increased considerably over the years (Mulat 1999).

There has been a growing concern, however, that the yields of major cereal crops have remained too low to justify the increasing cost of purchased inputs, especially fertilizer. Mulat (1999) argued that the average cereal yield increased by only 0.3% per annum between 1990 and 1997, and there is no indication that yields have significantly improved since 1994, in spite of the sharp increase in the use of fertilizer and other inputs. Unfavorable input-output prices have undermined the profitability of using improved technologies. The situation is worsened if farmers fail to exploit the yield potential of improved varieties through adoption of optimal management practices and input combinations. A number of factors could contribute to underutilization of the potentials of new technologies. For instance, continuous disequilibria and shocks associated with changing technological and policy environments could undermine farmers' ability to respond to the new demands and to adjust their practices with a view to achieving efficient use of technology and resources (Schultz 1964).

It is argued that some new agricultural technologies have only been partially successful in improving productive efficiency (Kalirajan and Shand 1991; Xu and Jeffrey 1998). This is often attributed to lack of ability and/or willingness to adjust input levels on the part of producers due to familiarity with traditional agricultural systems and/or the presence of institutional and cultural constraints (Schultz 1964; Ghatak and Ingersent 1984; Ali and Byerlee 1991). The extension services are not strong enough to provide adequate and timely technical advice on new methods and procedures while credit facilities are grossly inadequate for farmers to have easy access to sufficient amounts of modern inputs. New technologies demand a new set of skills and knowledge as well as access to credit and educational services if their productivity-enhancing potentials are to be exploited fully (Kalirajan 1991). Deviations of farmers' practices from technical recommendations and sub-optimal application of inputs would ultimately lead to technical and allocative inefficiencies. There is, therefore, a need to examine the extent, and identify the determinants of farmer efficiency under application of improved technology.

The objective of this paper is, therefore, to quantify farm-specific technical, allocative, and economic efficiencies of improved maize producers and to identify the farm-specific factors influencing efficiency levels. The selection of maize is based on its importance, more than any other crop, in terms of production, area coverage, and better availability and utilization of improved production technologies (improved seeds, improved cultural practices, etc.) (Mulat 1999). The Bako area in Western Ethiopia is well known for its maize production potential and farmers benefit significantly from improved maize varieties released mainly by the Bako Agricultural Research Center over the last couple of decades. The rest of the paper is organized as follows. The analytical framework is discussed in the next section, whereas the third section presents the sources of data and empirical procedures. The results are presented and discussed in the fourth section and the last section contains the conclusions reached from the study.

Analytical framework

The stochastic efficiency decomposition methodology presented by Bravo-Ureta and Rieger (1991), which was an extension of the model introduced by Kopp and Diewert (1982), was used in this study.

The production technology of a firm is represented by a stochastic production frontier as follows:

$$Y_i = f\left(X_i; \beta\right) + v_i - u_i \tag{1}$$

where Y_i measures the quantity of agricultural output of the i^{th} firm, X_i is a vector of the input quantities, β is a vector of parameters, and $f\left(X_i; \beta\right)$ is the production function; v_i s are assumed to be independently and identically distributed $\mathrm{N}(0,\sigma_v^2)$ random errors, independent of the u_i s; and the u_i s are non-negative random variables, associated with technical inefficiency in production, and are assumed to be independently and identically distributed as half-normal, $u \sim \left|N(0,\sigma_u^2)\right|$. The maximum likelihood estimation of equation (1) yields estimators for β and λ where $\lambda = \frac{\sigma_u}{\sigma_v}$ and $\sigma^2 = \sigma_u^2 + \sigma_v^2$. Jondrow *et al.* (1982) have shown that the assumptions made on the statistical distributions of v and u, mentioned above, make it possible to calculate the conditional mean of u_i given $e_i = v_i - u_i$ as:

$$E(u_i | e_i) = \sigma * \left[\frac{f*(e_i\lambda/\sigma)}{1 - F*(e_i\lambda/\sigma)} - \frac{e_i\lambda}{\sigma} \right] \tag{2}$$

where $F*$ and $f*$ are, respectively, the standard distribution and the standard normal density functions, evaluated at $e_i\lambda/\sigma$, and $\sigma^{2*} = \sigma_u^2\sigma_v^2/\sigma^2$. Therefore, equations (1) and (2) provide estimates of u and v after replacing e, σ, and λ by their estimates.

If v_i is now subtracted from both sides of equation (1), we obtain:

$$Y_i^* = f\left(X_i; \beta\right) - u_i = Y_i - v_i \tag{3}$$

where Y_i^* is the farmer's observed output adjusted for the statistical noise captured by v_i, $f(\cdot)$ is the deterministic frontier output, and u and v are, respectively, the inefficiency and random components of overall deviations from the frontier. Adjusted output Y^* is used to derive the technically efficient input vector, X^t. Following Bravo-Ureta and Rieger (1991), the technically efficient input vector, X_i^t, is derived by simultaneously solving equation (1) (with the u_i term now reduced to zero so that $Y_i^* = f(X_i; \beta)$) and the observed input ratios $\frac{x_1}{x_i} = k_i (i > 1)$, where k_i is equal to the observed ratio of the two inputs in the production of Y_i^*.

The production function in equation (1) is assumed to be self-dual (i.e., Cobb-Douglas) so that the dual cost frontier can be derived algebraically and written in a general form as follows:

$$C_i = h(W, Y^*; \alpha) \tag{4}$$

where C_i is the minimum cost associated with output Y_i^*, W is a vector of input prices, and α is a vector of parameters to be estimated. The economically efficient input vector, X_i^e, is derived by applying Shephard's lemma and substituting the input prices and adjusted output level into the resulting system of input demand equations:

$$\frac{\partial C_i}{\partial W_k} = X_i^e(W, Y^*; \theta) \tag{5}$$

where θ is a vector of parameters, $k = 1, 2, \ldots\ldots, K$ inputs. The observed, technically efficient, and economically efficient costs of production are equal to $W_i^/ X_i$, $W_i^/ X_i^t$, $W_i^/ X_i^e$, respectively. These cost measures are used to compute technical (TE) and economic (EE) efficiency indices as follows:

$$TE_i = \frac{W_i^/ X_i^t}{W_i^/ X_i} \tag{6}$$

$$EE_i = \frac{W_i^/ X_i^e}{W_i^/ X_i} \tag{7}$$

Following Farrell (1957), the allocative efficiency (AE) index can be derived from equations (6) and (7) as follows:

$$AE_i = \frac{W_i^/ X_i^e}{W_i^/ X_i^t} \tag{8}$$

Following the quantification of the technical, allocative, and economic efficiency measures, a second stage analysis involves a regression of these measures on several hypothesized socio-economic and institutional factors affecting efficiency of farmers (Kalirajan 1991; Bravo-Ureta and Reiger 1991; Bravo-Ureta and Evenson 1994; Assefa 1995; Sharma *et al.* 1999).

Empirical model and data

This study used the Ethiopian Rural Households Survey (ERHHS) data collected during the 1999/2000 cropping season from a sample of 60 hybrid maize producers in Bako Tibe sub-district in Western Ethiopia. The data were collected by the Department of Economics, Addis Ababa University.

Farm-specific efficiency

For the investigation of the technical, allocative and economic efficiencies of improved maize producers, the following stochastic frontier production function was estimated:

$$\begin{aligned}\ln Y_i = \beta_0 + \beta_1 \ln(land_i) + \beta_2 \ln(labor_i)\\ + \beta_3 \ln(fertilizer) + \beta_4 \ln(materials_i) + (V_i - U_i)\end{aligned} \tag{9}$$

where $\ln$ denotes the natural logarithm (base, e); Y_i denotes the total quantity of maize output in kg; *land* denotes the total land planted to maize in hectares; *labor* denotes the total of family labor, exchange labor, and hired labor used in man-days; *materials* denotes the implicit quantity index of seeds and chemicals (pesticides, insecticides, herbicides, and fungicides) estimated as the value of all seeds and chemicals deflated by a weighted price index of the inputs, the weights being the share of each input in total cost ; and β_i, v_i, u_i are as defined earlier.

The solution to the cost minimization problem in equation (10) is the basis for deriving the dual cost frontier, given the input prices (W_k), parameter estimates of the stochastic frontier production function ($\hat{\beta}_k$) and the adjusted output level Y_i^*.

$$\operatorname*{Min}_x C = \sum_{k=1}^{K} W_k X_k \tag{10}$$

Subject to $Y_i^* = \hat{A} \prod X_k^{\hat{\beta}_k}$

Substitution of the cost minimizing input quantities yields the following dual cost function:

$$C(Y^*, W) = \psi W_A^{\alpha_1} W_L^{\alpha_2} W_F^{\alpha_3} W_M^{\alpha_4} Y^{*\mu} \tag{11}$$

where $\alpha_k = \mu \hat{\beta}_k$, $\mu = \left(\sum_k \hat{\beta}_k\right)^{-1}$, $\psi = \frac{1}{\mu}\left(\hat{A} \prod_{k=1}^{K} \hat{\beta}_k^{\hat{\beta}_k}\right)^{-\mu}$,

$\hat{A} = \exp(\hat{\beta}_0)$, W_A is the observed mean seasonal rent of a hectare of land in Birr (1US$=8.50 Birr), W_L is the observed mean daily wages in Birr; W_F is the price of fertilizer per kg in Birr; and W_M is the price index of seeds and chemicals.

Factors affecting efficiency

Several factors could be hypothesized to explain technical, allocative, and economic efficiency variations. Many authors (Kalirajan and Shand 1989; Assefa 1995; Getachew 1995; Coelli and Battese 1996) suggested that the level of efficiency of farmers is determined by a host of socio-economic and institutional factors. Inefficiency mainly arises due to managerial incompetence and hence the variation in efficiency could be examined in the context of management characteristics such as training, background, and motivation. Different production practices may also contribute to observed variation in efficiency among farmers. However, a number of farm and farmer attributes have to be used as proxy variables because of lack of adequate direct measures on some of the variables, which are simply unobservable. Socio-economic and institutional factors that could directly or indirectly affect the quality of the management of the farm are believed to impact on efficiency levels. Accordingly, variables that were hypothesized to affect efficiency levels in this study are farm size, age, credit, education, extension services, timely availability of inputs, plot ownership, and participation in the product market. For the investigation of socio-economic and institutional factors affecting efficiency levels, the following model was estimated:

$$\begin{aligned}\ln\left(\mathrm{E_i}/1-\mathrm{E}_i\right)=\delta_0+\delta_1(FRMSZ_i)+\delta_2(AGE_i)+\delta_3(PREDUC_i)+\delta_4(CRDT_i)\\ +\delta_5(TNUR_i)+\delta_6\left(INPTIM_i\right)+\delta_7(EXTV_i)+\delta_8(MRKT_i)\end{aligned} \tag{12}$$

where E_i is an efficiency measure representing technical or allocative efficiency; *FRMSZ* denotes the total land area cultivated; *AGE* denotes the age of the household head; *PREDUC* is a dummy variable representing primary education (equals 1 if the household head attained primary education and 0 otherwise); *CRDT* denotes access to credit (equals 1 if the farmer had access to input credit during the season for improved maize production, and 0 otherwise); *TENUR* is a dummy for land tenure in terms of plot ownership (equals 1 if the plot has been allocated by the government, and equals 0 if it has been sharecropped, rented in, or borrowed); *EXTV* denotes the number of visits to a farmer by an extension agent during the cropping season; and *INPTIM* denotes timely availability of modern inputs (equals 1 if the farmer acquired the necessary inputs in time and 0 otherwise); and *MRKT* denotes access to market (equals 1 if the farmer has sold maize and 0 otherwise). The variables used in the analysis are presented in Table 1.

Empirical results

Parameter estimates

The maximum-likelihood (ML) estimates of the parameters of the stochastic frontier production function were obtained using the computer program LIMDEP 7.0 (Greene, 1995). These results are

Table 1. Descriptive statistics of the variables used in the analysis.

Variable	Mean	Standard deviation
Maize yield (kg/ha)	3224.00	1356.00
Maize land (ha)	1.33	0.85
Labor (man days)	59.00	51.33
Fertilizer (kg)	131.00	253.70
Materials (index)	25.00	18.00
Land rent (Birr/ha)	560.00	85.00
Wage rate (Birr/day)	5.00	2.19
Price of fertilizer (Birr/kg)	2.20	0.60
Price index of materials	5.00	1.20
Farm size (ha)	2.43	1.23
Family size	8.00	3.00
Age	41.00	11.00
Extension visit	0.77	1.44
Oxen	2.33	2.01

Table 2. Average production function and stochastic production frontier for hybrid maize producers in Bako, Western Ethiopia.

Variable	Average function (OLS) estimates	Stochastic frontier (ML) estimates
Intercept	5.01** (7.04)	5.819** (11.537)
Land	0.531** (3.08)	0.581** (4.412)
Labor	0.206^{+} (1.923)	0.119^{+} (1.974)
Fertilizer	0.325** (3.112)	0.309** (2.05)
Materials	0.116^{+} (1.895)	0.105 (1.33)
Adjusted R^2	0.76	-
F-statistic	48.49**	-
Returns to scale	1.178	1.104
λ	-	1.997* (2.04)
σ^2	-	0.484** (7.62)
Log likelihood	-	-19

$^{+}$, *, ** Significant at 0.10, 0.05 and 0.01 levels of probability. The figures in parentheses represent *t*-ratios for the average functions, and asymptotic *t*-ratios for the frontier functions.

presented in Table 2. Also presented in Table 2 are the OLS estimates of the average production function for comparison. As expected, the signs of the slope coefficients of the stochastic production frontier are positive. Except for the coefficient of materials input, all the estimated coefficients (or partial output elasticities) are highly significant. The elasticities of output with respect to land and fertilizer (0.581 and 0.309, respectively) suggest that improved maize production is responsive to land and fertilizer. Moreover, based on restricted least squares regression, the hypothesis of constant returns to scale was strongly rejected, indicating that the farmers operated under increasing returns

Table 3. Frequency distribution of technical (TE), allocative (AE), and economic (EE) efficiency estimates for a sample of improved maize producers in Bako, Western Ethiopia.

Level (%)	TE % farmers	AE % farmers	EE % farmers
<50	5.0	0.0	16.7
50-60	3.3	0.0	26.7
60-70	16.7	3.3	31.7
70-80	36.7	36.7	21.7
80-90	30.0	38.3	3.3
90-100	8.3	21.7	0.0
Mean (%)	74.0	82.0	61.0
Minimum (%)	31.0	67.0	26.0
Maximum (%)	93.0	100.0	88.0

to size. This may be due to the small size of the maize farms, showing that farmers operated in a sub-optimal zone of production.

The estimate of the variance parameter, λ, is also significantly different from zero, which implies that the inefficiency effects are significant in determining the level and variability of maize output of farmers in the Bako area of Ethiopia. Therefore, variation in maize output level across farmers is mainly due to factors within the control, of farmers and not to the random factors beyond their control like weather, disease, etc. Alternatively, the traditional (average) production function with no technical inefficiency effects is not an adequate representation of the data.

The dual frontier cost function, derived analytically from the stochastic production frontier shown in Table 2, is as follows:

$$\begin{aligned}\ln C_i = -4.064 + 0.527 \ln W_{land} + 0.149 \ln W_{labor} + 0.233 \ln W_{fertilizer} \\ +0.091 \ln W_{materials} + 0.897 \ln Y_i^* \qquad (13)\end{aligned}$$

where C_i is the cost of producing maize, Y_i^* is total maize output in kg, adjusted for any statistical noise.

Using the frontier cost function, average input prices, and the respective equations, the technical (TE), economic (EE), and allocative (AE) efficiency indices were computed for each maize producer. The frequency distributions and summary statistics of the estimated technical, allocative, and economic efficiency indices for the sample maize producers are presented in Table 3. The estimated mean technical, allocative, and economic efficiency indices are 74%, 82%, and 61%, respectively.

High technical inefficiency means that there is considerable yield variation among maize farmers. Table 1 also shows high yield variability among adopters of hybrid maize, with a mean yield of about 3.2 t/ha and a standard deviation of 1.4 tons/ha or a coefficient of variation of 42%. The results suggest that farmers could increase

Table 4. Factors affecting the productive efficiency of maize producers in Bako, Western Ethiopia.

Variable	Efficiency	
	TE	AE
Constant	0.891(1.71)	2.784 (2.95)
FRMSZ	-0.423 (-0.87)	0.065 (1.02)
AGE	-0.017 (-1.91)$^+$	-0.449 (-0.26)
EXTV	0.24 (1.10)	-0.124 (1.04)
PREDUC	0.265 (2.33)*	0.566 (1.94)$^+$
TENUR	0.22 (1.03)	0.045 (0.87)
CRDT	0.278 (2.25)*	0.235 (0.87)
INPTIM	0.103 (1.91)$^+$	0.121 (0.58)
MRKT	0.010 (2.01)*	0.208 (1.36)
R^2	0.74	0.52
Adj. R^2	0.70	0.48
F	12**	5$^+$

$^+$, *, ** Significant at 0.10, 0.05 and 0.01 levels of probability. The figures in parentheses are *t*-ratios, corrected to two significant digits.

hybrid maize production by an average of 26% if they all adopted the recommended management practices. Adoption of the recommended management practices coupled with optimum use of inputs, especially fertilizer, would enable the farmers to reduce production costs by an average of 39%, thereby increasing the profitability of hybrid maize production.

The results show that maize production under new technology involves substantial inefficiencies. This conforms with expectation in that substantial inefficiency of production under new technologies is argued to prevail until such time that farmers acquire enough technical and allocative knowledge and get better access to credit and extension services (Ghatak and Ingersent 1984; Ali and Chaudhry 1990; Ali and Byerlee 1991). Xu and Jeffrey (1998) also obtained significantly lower technical, allocative, and economic efficiency indices for hybrid rice production in China as compared with conventional rice production across all the three regions studied. Singh *et al.* (2000) obtained lower technical, allocative, and economic efficiency for newly established Indian dairy processing plants after liberalization of the dairy industry compared to the old plants as they needed time to reach full operation, the right choice of products and other managerial skills required for higher performance.

Determinants of efficiency

A regression model of determinants of farmer efficiency was estimated to identify the important socio-economic and institutional factors influencing technical and allocative efficiencies. The results are presented in Table 4.

The adjusted R-squared value and the corresponding F-statistic show that the model fits the data reasonably well. The results indicate that education, input credit access, timely availability of inputs, and market participation are positively and significantly related to technical efficiency. The influence of age on technical efficiency is negative and significant. Seyoum et al. (1998) also obtained a negative and significant influence of age on the technical efficiency of maize producers, both within and outside the SG2000 project, in eastern Ethiopia. As expected, farmers' access to input credit, such as fertilizer, chemicals, and improved inputs (i.e. due to lack of access to formal credit sources), timely availability of inputs, education, and market participation enhance technical efficiency. Assefa (1995) also obtained a positive and significant impact of education, timely input supply, and credit on technical efficiency of crop production in central Ethiopia.

Farm size, plot ownership, and extension contact turned out to be insignificant. The nonsignificance of the farm size variable is probably due to the continuous redistribution of agricultural lands in Ethiopia, which may rule out farm size variations to exist to such an extent that either "small" or "large" farms will have efficiency advantages. Assefa (1995) also obtained a similar result for central Ethiopia. For rice production in China, Xu and Jeffrey (1998) obtained insignificant influence of farm size on technical efficiency except that the signs were mixed: positive for modern agricultural regions and negative for traditional areas.

The extension variable, though positive, is not significant. This may be because as the number of farmers embraced in the extension program increases from year to year, the intensity of technical advice provided by the extension staff would become more and more limited. As can be seen from Table 1, the average number of visits by extension staff to the sample households was less than one in a growing season. It could be deduced that farmers mostly planned and implemented their farming operations with little or no extension advice. Assefa (1995) obtained positive and significant impact of the extension variable on technical efficiency only in one of his two study areas. Seyoum *et al.* (1998) obtained significant and positive influence of the extension variable on the technical efficiency of maize producers within the SG2000 project, and insignificant in the case of maize producers outside the project. This is acceptable because of the more intensive nature of technical advice that was extended to participating farmers through extension staff during the demonstration years of the SG2000 project. Plot ownership is positive but insignificant, signifying that owner cultivators are not necessarily more technically efficient than the sharecroppers, but this is in sharp contrast with the study by Corppenstedt and Abbi (1996) who found that sharecroppers are more technically efficient than owner cultivators in three regions in Ethiopia.

On the other hand, none of the variables except education significantly influenced allocative efficiency. Education is positively and significantly related to allocative efficiency. This is in agreement with the findings of Abay and Assefa (1996) for Ethiopian smallholders and Sharma *et al.* (1999) for swine producers in Hawaii. The results confirm the role of education in boosting production, through its effect on the ability to access, process, and use new information and develop the technical and allocative knowledge of farmers. Educated farmers are expected to be more capable of accessing and using new information on farming practices, market opportunities, and the entire environment under which they operate.

Conclusions and policy implications

This paper used a dual stochastic frontier efficiency decomposition methodology to derive the technical, allocative, and economic efficiency measures for a sample of maize producers in Western Ethiopia. The results indicated that hybrid maize producers exhibited production inefficiencies. If farmers used the recommended management practices and optimal input combinations, they could substantially increase the profitability of hybrid maize production. An examination of the relationship between efficiency and various socio-economic and institutional variables revealed that primary education, provision of input credit, and timely availability of critical inputs such as fertilizer, seeds and chemicals are important factors influencing the technical efficiency of maize producers. Allocative efficiency is positively and significantly related to education. The results suggest that any attempt to improve the productive efficiency of farmers must give due attention to education, provision of credit, and timely supply of modern inputs. Policies and strategies that promote rural education, credit, and timely availability of inputs would be instrumental to the realization of considerable economic gains in maize production.

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Socio-economics of community-based maize seed production in the Guinea savanna of Nigeria

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Abstract

The objectives of this study were to assess the socio-economic feasibility of maize seed production at community level, identify farmers' preferences among the varieties introduced and investigate the problems and prospects of the technology. The ultimate goal is to promote sustainable community-based maize seed production in the Guinea savanna ecological zone of Nigeria. Using a semi-structured questionnaire, 50 participating farmers in the project were surveyed. Descriptive statistics and farm budgeting techniques were used to analyze the data collected from the participating farmers. The results showed that, at the initial stages of the project, most farmers preferred the ACR Pool–16 maize variety because of its high yield and easy milling quality. At the later stages, TZL Comp 1 became the preferred variety due to its resistance to *Striga* parasitism. The least preferred variety was TZEE Y_1 because yellow maize was not in popular demand in the study area. The total variable costs per hectare of maize seed farm was ₦41, 815.43 (US$ 1=₦130). Labour and fertilizer costs accounted for about 53% and 19% of the total variable costs. An average seed yield of 2100 kg/ha was realized, amounting to about ₦168,000/ha**.** A gross margin of ₦126,184.57/ha was estimated. The return to investment on maize seed production was about ₦3 per Naira invested. The benefits accruing to participating farmers included increased income and improved social status in their communities. The major problems highlighted by the farmers were high labor demand and poor market/prices of maize seed. In spite of these problems, the farmers considered maize seed production as a profitable enterprise.

Résumé

Cette étude avait pour objet d'évaluer la faisabilité socio-économique de la production communautaire durable de semences de maïs, identifier les préference des paysans entre les variétés introduites et investiguer les problemes et prospects de la technologie. Le but final est la promotion de la production comunautaire de semence de maïs dans les zone de savanne guinéenne du Nigéria. En utilisant la méthode d'interview semi-structurée, 50 agriculteurs participants au projet financé par le WECAMAN, ont été enquêtés. Des techniques de statistiques descriptives et de budgétisation des champs ont été utilisées pour analyser les données recueillies. Les résultats ont montré que la plupart des agriculteurs préféraient la variété ACR Pool - 16 parce qu'elle a eu des rendements élevés, est facile à moudre et produit des quantités importantes de farine. TZL Comp 1 est devenu plus tard la variété préférée a cause de sa résistance au *Striga* tandis que la variété la moins préférée était TZEE Y1 à cause de sa couleur jaune qui est très peu appréciée dans la zone de l'étude. Le coût variable total encouru pour cultiver un hectare de semences de maïs était de 41, 815.43 Naira. Le coût de la main d'oeuvre et de l'engrais comptait pour près de 53% soit près de 19% du coût variable total. Une moyenne de 2100kg par hectare a été réalisée, ce qui correspond à environ 168.000 Naira/ha. Une marge brute de N126, 184.57 Naira/ha a été estimée. Les bénéfices obtenus de l'investissement dans la production de semences de maïs était de 3.00 Naira par Naira investi. Cela confirme que les agriculteurs ont effectivement amélioré leurs revenus et leurs statuts dans la communauté depuis leur participation au projet. Les problèmes majeurs soulignés par les agriculteurs impliqués dans le projet, étaient la forte demande en main d'œuvre et les prix faibles des semences de maïs sur les marchés. Malgré ces problèmes, les agriculteurs ont relevé à l'unanimité que la production de semences est une entreprise rentable dans les zones d'étude.

Introduction

Maize (*Zea mays* L.) is one of the most important food crops in the savanna ecology of northern Nigeria. It is well adapted to the mono-modal rainfall pattern of this ecology and, in terms of area cultivated and amount consumed as food, maize ranks next to sorghum [*Sorghum bicolor* (L.) Moench] (Ahmed 1994). The importance of maize is due to the fact that it is a major food crop for many households as well as a major commercial crop upon which many agro-industries depend for raw material. Although there is evidence of increased maize production in Nigeria, the farmers are faced with major production constraints, including poor access to, and high unit cost of inputs, little or non-availability of credit and poor quality seed. Often farmers use as seed grains from their previous harvests or purchased directly from the open market without regard to genetic purity. In an effort to overcome the production constraints, WECAMAN has since 1994 been funding a project on community-based seed production and facilitated input and credit availability to participating farmers. The aim of the project is to promote strategies that will enhance a timely supply of good quality seed at affordable price to farmers, facilitate timely procurement and distribution of production inputs and train farmers on techniques of maize seed production at the community level. The farmers received training in techniques of quality seed production while fertilizer was provided to them on credit basis. This project was first initiated in the Sudano-Sahelian ecology of Kano, Katsina, Jigawa and Zamfara States of Nigeria. The project was later extended to Gombe and Taraba States, both in the Guinea savanna of northern Nigeria.

The objectives of this study were to evaluate the profitability of the community-based maize seed production scheme in Gombe and Taraba States, identify farmers' preferences among the varieties introduced and investigate the problems and prospects of the technology, with a view to ensuring a sustained supply of high quality maize seeds.

Theoretical Framework

The theoretical basis for this study is the social change theory, using the diffusion-adoption paradigm. According to Straus (1959), the essence of human life is change, development and growth. This process of change, he stressed, involves interaction within the social system. Voh (1982) noted that social change is the term used to describe changes in socio-economic lifestyles and values of people, technological innovation and social institutions.

Social change assumes the introduction of “change material’’ into a community through alternative ideas, practices or choices to transform or supplement the existing ones. This is synonymous with what Kaimowtz (1987) termed “planned social change’’ which, when introduced, should be compatible with existing farming systems and socio-economic structures of the community. The diffusion and adoption perspective of social change theory emphasizes the process of spreading new ideas from its source to its ultimate users or adopters (Rogers 1983). This perspective forms the basis against which the farmers' perception of maize seed production technology could be examined. The process is expected to create awareness, interest, understanding and final adoption or a behavioral change in the life of the user of the innovation.

The following are some questions that could justify the behavioral patterns of the farmers regarding the technologies introduced by WECAMAN to the communities under study. (i) How was the technology introduced, and what were the farmers' levels of awareness? (ii) What were the farmers' perceptions about the technologies? (iii) What were the technology options and what were the farmers' preferences among the options?

The level of involvement of farmers in projects could be regarded as a social activity which, according to Manya (1984), is influenced by the task environment, the project itself and the personal characteristics of the individual farmers. The level of community involvement in projects helps in shaping people's perception and attitudes about the project (Negri 1998). This information could be used to explain the interrelationship between research, extension and farmers when describing the level of acceptance and socio-economic significance of innovations. Byerlee (1998) stressed the importance of this approach as a way of furnishing information feedback to sponsors of research (WECAMAN in this case) and managers of research and extension (e.g., IAR) on the viability, necessary adjustments and recommendations needed for effective adoption.

Methodology

This WECAMAN-sponsored project was conducted in two savanna States in Nigeria: Gombe State in the northern Guinea savanna (NGS) and Taraba State in the southern Guinea savanna (SGS). The two ecological zones, especially SGS, are characterized by a relatively long rainy season thus making it possible to grow two crops of extra-early maize varieties in a year in the zone. The project was carried out at Dadinkowa and Kumo villages in Gombe State while the villages covered in Taraba State were Tella and Bantaje. Two varieties each of early (TZE Comp-W, Acr Pool 16-DT) and extra-early (TZEE-Y_1, TZEE-W_1) and one intermediate variety with tolerance to *Striga* (Acr 97 TZL Comp 1) were used in the project. The maize varieties were introduced to 13 selected farmers for multiplication in the 2002 season. Other farmers in the communities joined the project in the 2003 and 2004 cropping seasons. The farmers were allowed to freely decide on the maize variety they wished to multiply.

A survey of the participating farmers was carried out using a semi-structured questionnaire to collect both qualitative and quantitative data from 50 farmers, 13 of whom were actually trained in seed production by WECAMAN (WECAMAN 2003), while the others were those that took up the technology from the primary farmers involved in the project. The data collected included socio-economic profiles of the participating farmers, their perception about the introduced varieties, area devoted to maize seed production, input and output levels, and constraints and prospects of maize seed production.

Descriptive statistics and farm budgeting techniques were used to analyze the data collected from the participating farmers. The general model for the partial budgeting may be given as:

$$GM = GFI - TVC$$

In this model GM = Gross margin, GFI = Gross farm income and TVC = Total variable costs. The reference period for the

Table 1. Socio-economic profiles of participating farmers in the community seed multiplication project conducted in Taraba and Gombe States in Nigeria.

Socio-economic characteristic	Taraba	Gombe	Average
Age of farmers (yrs.)	53	43	44
Educational status (% of farmers)			
Quranic	88	91	86
Primary	30	25	28
Secondary	20	15	18
Tertiary	10	20	16
Major occupation: (% of farmers)			
Farming	75	71	72
Trading	23	18	20
Civil servant	2	10	8
Average plot size for maize seed (ha)*			
Year 1	0.25	0.25	0.25
Year 2	0.65	0.50	0.50
Year 3	1.17	0.80	0.98

* This is the average for those who participated each year.

survey was 2003/2004 agricultural year; that is, the record of the third year of production.

Results and Discussion

Farmers' socio-economic characteristics and perception of the project

The age of the sampled farmers ranged between 30 and 60 years with an average of 44 years (Table 1). All the respondents were married men; women in the study locations were not fully involved in farming because of restrictions imposed by their Islamic beliefs. All respondents had one form of education or another, with 86% having at least Quranic education. This relatively high literacy level made it easier for the project personnel and extension agents to explain and disseminate the technologies involved in maize seed production to the farmers. Patterns of livelihood sources showed that 72% of the respondents were farmers while about 20% were traders involved in livestock marketing, agro-chemicals and butchering. Only 8% were civil servants.

About 57% of the respondents had heard about the project directly from the project personnel and this group was the first batch of farmers to be involved in the project. As the project continued gradually, other farmers got to know about it from friends, their group executives and extension agents. Results of the survey showed clearly that the farmers' level of knowledge about maize seed production

Table 2. Number and percentage of farmers indicating preferences for maize varieties used in the community seed multiplication project conducted in Taraba and Gombe States in Nigeria.

Variety	1st year		2nd year		3rd year	
	No.	%	No.	%	No.	%
TZL Comp 1	10	20	15	30	20	35
TZE Comp 5	5	10	5	10	9	16
ACR Pool – 16	17	34	15	30	12	21
TZE Comp 3	9	18	5	10	7	12
TZEE W1	9	18	10	20	10	17
TZEE1	0	0	0	0	0	0
Total	50	100	50	100	58*	101+

*Total number of farmers greater than 50 implies multiple responses

+Greater than 100 because of rounding off error.

was very low. The farmers complained of the complexity and high labor demand associated with the technology, especially for planting and fertilizer application. Also the farmers had great difficulty in understanding, identifying and distinguishing the characteristic differences between the maize varieties. Initially, the farmers opted to participate in the project with much uncertainty. By the third year of implementation, the number of participants had almost doubled, as the farmers became more confident that seed multiplication had a great potential as a profitable business.

The farmers had strong preferences for the maize varieties used for seed production (Table 2). At the initial stages of the project, ACR Pool-16 was the preferred variety. This was due to its relatively high yield potential and good milling quality. By the third year of the study, however, TZL Comp 1 was the preferred variety because it is *Striga* tolerant.

Costs and returns analysis

Land use. Average land area allocated to maize seed production in the first year of the project was 0.5 ha. In the second and third years, however, about 40% of the participating farmers increased the area to 1ha while about 14% devoted more than 1ha in the third year. The total land area used for maize seed production has therefore increased over the last three years, an indication of a high level of acceptance of this project by the communities.

Labour use. The farmers considered labor as the most important input required for maize seed multiplication. According to them, seed production requires extra effort to ensure that all the agronomic practices are adhered to strictly and adequate measure is taken during harvesting and shelling to prevent seed damage. The family labor force could not

Table 3. Average labor costs and their relative proportions for the various farm operations in the community seed multiplication project conducted in Taraba and Gombe States in Nigeria.

Activities	Average cost (₦ /ha)	% Total labor cost
Clearing	1,586	7
Ridging	3,514	16
Planting	1,057	5
Weeding	3,510	16
Fertilizer application	1,400	6
Earthing up	2,392	11
Harvesting	4,000	18
Shelling	4,625	21
Total	22,084	100

Table 4. Total costs of production and their relative proportions in the community seed multiplication project conducted in Taraba and Gombe States in Nigeria.

Inputs	Average cost (₦/ha)*	% Total cost of production
Labor	22,084	53
Fertilizer	7,814	19
Seed	5,000	12
Herbicide	6,617	16
Insecticide	300	1
Total cost	41,815	100

*About ₦130=US$1

meet the labor requirement of seed production; therefore, a substantial amount of hired labor was used. The labor costs for the various farm operations are presented in Table 3. An average of ₦22, 084.14/ha was incurred on labor. The cost of harvesting and shelling accounted for about 35% of the total labor costs.

The total variable cost of cultivating one hectare of maize seed was estimated at about ₦41,815.43 (Table 4). Labor costs accounted for about 53% of the total costs while the cost of fertilizer, herbicide and seed constituted about 19, 16 and 12%. Fertilizer was given to farmers on credit at the onset of the project while seed was given to them free of charge by the project. In the subsequent years, however, farmers bought their fertilizers and seeds from local markets and some took seeds from past harvests.

The average seed yield was about 21 bags/ha. At ₦8000/bag, the total revenue (TR) was ₦168,000/ha. Thus, the gross margin (GM), which was estimated as GM=TR–TVC, was ₦126,185 while the return to investment on maize seed production (that is, GM÷TVC) was 3.02. Thus, about ₦3.00 was obtained in return for every Naira invested in maize seed production. Although the farmers had some problem in marketing the seed, about 85% of them eventually sold their seed at the next planting season while 14% stored theirs for planting on their own farms. Therefore, maize seed production was quite profitable for the farmers participating in this project.

Problems and prospects of community-based maize seed production

The maize seed multiplication project has been beneficial to the participating farmers in all the communities. Among other things, the farmers recorded an increase in total farm income from the sale of maize seeds and diffusion of the improved maize seed variety within the communities. The farmers in the communities now have better access to quality seed of improved maize varieties. In addition, the farmers reported that their participation in the project has enhanced their social status and interaction within their communities. They supply other farmers with good quality seed and provide technical advice on maize production. The project has also improved the managerial skills of the farmers, not only on seed multiplication but also on maize grain production.

The major problems encountered by the farmers included financial constraint, high cost of production inputs, particularly, fertilizer, high labor demand, poor market for improved maize seed, and flooding. The farmers complained that the technology was labor-intensive and time consuming, especially for ridging, weeding, harvesting and shelling. The farmers had problems in selling the maize seed because of high prices compared to the ‘‘seed’’ in the open market. The farmers in Gombe State also lost their farms to flood in the third year of the project, but this was not peculiar to maize seed production fields. In spite of these problems, however, farmers made substantial a profit out of seed production.

Conclusion

The community maize seed project has had a significant impact on the availability of good quality seed of extra-early maize varieties in the selected communities. The participating farmers have increased their scale of production while more farmers have been enlisting to participate in the project. The success achieved so far on the project has been attributed to the high profit margin associated with seed relative to grain production. Production and sale of seed has increased the farmers' income and socio-economic status within the communities. The farmers were faced with some problems, including financial constraint, high cost of production inputs, high labor demand, poor market for improved maize seed, and flooding. Therefore sustainability of seed production in the communities studied would depend on farmers' access to credit to minimize the negative impact of the constraints they encountered.

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Economic analysis of quality protein maize (QPM) seed production at community level in Nigeria

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Abstract

This study investigated the profitability of community seed production of Quality Protein Maize (QPM) in Daudawa, Katsina State in northern Nigeria. Nine farmers each planted 0.5 ha of Obatanpa QPM and three farmers each planted 0.25 ha of EV 99, an early maturing QPM variety. The farmers followed the recommended practices for maize production. Using net farm income analysis, the profitability of the production was determined. Results showed that a majority of the farmers had a positive net farm income from the production. The farmers who produced Obatanpa seed made an average net farm income of about ₦63,000/ha; those who produced seed of EV 99 made an average net farm income of about ₦23,000/ha. The major constraints to the community seed production of QPM varieties were inability of the farmers to distinguish between grain and seed for production practices, poor market accessibility and lack of a true spirit of association among the farmers. Farmer awareness campaigns, training in seed production techniques and linkages between community seed producers and seed companies and micro-credit organizations as well as formation of virile farmer cooperatives would enhance the sustainability and profitability of community seed production of QPM varieties.

Résumé

Cette étude a investigué la rentabilité de la production communautaire de semences de maïs QPM a Daudawa, dans l'etat de Katsina au Nigéria. Neuf producteurs ont planté chacun 0,5 ha de Obatampa et trois autre producteurs ont planté chacun 0,25 ha de EV 99, une variété QPM précoce. Les producteurs ont suivi les pratiques recommendées pour la production de mais. En utilisant l'analyse de revenu net a la ferme, la profitabilité de la production a été déterminée. Les résultats ont montré que la majorité des paysans avaient un revenu net de la production qui est positif. Les paysans ayant produit des semences de Obatampa ont eu un revenu net moyen de 63000 naira par ha alors que ceux ayant produit des semences de EV 99 ont eu un revenu net moyen de 23000 naira par ha. Les conraintes majeures à la production communautaire de semences de maïs QPM sont l'inabilité des paysans à distinguer les pratiques de production entre semences et graines, le mauvais accès au marché, et le manque d'esprit d'association entre les paysans. Des campagnes de sensibilisation des paysans, la formation en techniques de production de semences et les liens entre producteurs communautaires de semences et les compagnies semencières, et les structures de la micro-crédit ainsi que la formation de coopérative de producteurs efficaces pourraient améliorer la durabilité et la rentabilité de la production communautaire de semence de variétés QPM.

Introduction

Agriculture is a major occupation in Nigeria and it presently contributes about 35.8% of the total Gross Domestic Product (GDP) with increases in output reaching 6.1% in 2003 (CBN, 2003). Maize (*Zea mays* L.) has made a major contribution to the GDP of the country. Maize is an important food crop in Nigeria, consumed as a staple food by both the rural and urban households either as green maize, roasted or boiled maize, or as dry grain prepared into various local dishes. Maize is also an important component of the cropping system and a cash crop for farmers in most ecological zones of Nigeria. In the industrial sector, maize is used in the production of flour, livestock feed, processed food (such as cornflakes) and beverages, corn oil and starch, sweetners for soft drinks, pharmaceuticals, and malt for brewing beer.

The most striking change in the north-west zone of the country is the emergence of maize from a backyard crop in the 1970s to become one of the most important food and cash crops in the 1990s. Production and expansion of commercial maize production are concentrated in the central part of the northwest zone; specifically, Kaduna State and the southern parts of Katsina State. The factors that favored the rapid expansion include the availability of improved maize varieties that respond to fertilizer application and are, therefore, higher yielding; the ban on the importation of grains (particularly rice and maize) in 1986, which enforced increased local production; an increased demand for maize as an industrial crop used for livestock feeds, production of commercial starch, and brewing; the provision of improved extension services by the State's Agricultural Development Projects (ADPs). A good road network has facilitated easy intra- and inter-zone transportation of produce and people to markets in the country. Using FAO data, Fakorede *et al.* (2003) analyzed maize production trends in several West and Central African countries from 1980 to 2001. Results of the analysis showed that Nigeria had the highest rate of increase, which was about 27.6% per annum, with a total increase of 440% over the whole period under consideration. The Central Bank of Nigeria (CBN 2003) further reported that maize production in Nigeria rose from 6.515 million t in 1999 to 7.020 million t in 2003.

In Nigeria, both the open-pollinated (OPVs) and the hybrid maize varieties are cultivated by farmers. The main sources for OPV seed are the National Seed Service (NSS) and ADPs, both of which are government parastatals. Hybrid maize seed production and distribution has been left exclusively to commercial seed companies, which are owned by private individuals. In recent times, production and sale of OPV seed by the NSS and ADPs has reduced drastically due to limited funding by the government. Similarly, only the Premier Seed Company and few emerging seed companies such as Alheri Seeds and Savanna Seeds remain in the business of hybrid seed production since several other companies have folded up. There is, therefore, an inadequate supply of quality seed in the country. According to Ado *et al.* (2000), one of the most important constraints to maize production in rural areas of Nigeria is non-availability of quality seeds. Farmers tend to use more of seed retained from their previous year's harvest or buy grain from the open market and use as seed. This practice has a serious negative impact on maize production. As observed by Ogunfowora (1996), less than 10% of the maize seed requirement was being met by the domestic production of quality seed. He attributed this to inadequate and untimely provision of improved seeds to farmers as well as insufficient sales promotion and retail outlets to farmers.

The Quality Protein Maize (QPM) was recently introduced to Nigeria through the promotional efforts of the West and Central Africa Collaborative Maize Research Network (WECAMAN) following the success of the QPM variety, Obatanpa, in Ghana where it was developed and released in 1992. According to Sallah *et al.* (2003), WECAMAN had recommended the promotion and release of the variety in member countries and this has led to a high seed demand, which could not be met by Ghana alone.

In Nigeria, the commercial seed of Obatanpa was first produced by Premier Seed Company, Zaria, in 2003. The amount of seed produced could meet the demand of only a small proportion of the farmers who wished to plant the variety. Consequently, WECAMAN initiated projects to promote QPM varieties through community seed production and distribution in many of its member countries as done for the normal endosperm improved varieties of maize in the region. Nigeria is one of the benefiting countries and the community seed project commenced in the country in 2003.

The goal of the QPM community seed project is to make seed available at the community levels at affordable prices without necessarily compromising the seed quality. In the study reported in this paper, an attempt was made to examine the economics of producing QPM seed at the community level in Nigeria. The specific objectives were to (i) determine the costs and returns of QPM community seed production, (ii) determine the level of profitability or otherwise, and (iii) identify the constraints of the scheme.

Methodology

Two varieties of QPM varieties, Obatanpa GH and EV 99, obtained from IITA in 2004 were planted in two community seed production villages established in the two major maize producing States of Nigeria–at Saminaka in Kaduna State and Daudawa in Katsina State–since 2003. In Saminaka, three farmers cultivated 0.5 ha each of Obatanpa GH; in Daudawa, six farmers cultivated 0.5 ha each of Obatanpa GH and three other farmers cultivated 0.25 each of EV 99. The recommended agronomic practices for maize in the study area were applied as follows. Two seeds were planted per hole at an intra-row spacing of 40 cm and inter-row spacing of 75 cm, giving a population density of 66,000 plants/ha. Fertilizer was applied at the rate of 120 kg N, 60 kg P_2O_5 and 60 kg K_2O (Falaki 1999). Although the immediate surrounding farms were either cotton or sorghum fields, an isolation distance of about 400 m was maintained between the seed fields and other maize fields in the neighborhood. Prior to planting the project in the field, seed production training was held for the participating farmers and field days were organized at the community levels.

When the maize was physiologically mature, the stalks were cut and stacked in the field for proper drying as is done with maize in the area. Thereafter, the cobs were removed, cleaned to remove damaged and small grains, and then sorted to seed and grain types. The ears were shelled, weighed and bagged.

The profitability of production was determined using the net farm income analysis; that is:

NFI = Gross margin – explicit fixed costs

where

NFI = Net farm income from the seed farm
Gross margin = Gross income (from seed and grains)-total variable cost (costs of inputs)
Explicit costs = (land rent and family labor using shadow wages and machinery depreciation)

The net farm income is thus equal to gross income minus the total cost of production. Only the seven participating farmers from Daudawa in Katsina State were used for this analysis because only two of the three farms from Saminaka in Kaduna State had good harvests.

Results and Discussion

Cost elements in the community seed production

Land. Except in one farm, land used for the community seed production project was owned by the farmers and, therefore, had no financial cost. For the exceptional case, the land used by the farmer was rented and its rental rate was used in the analysis. The rate was also assumed to represent the opportunity cost of the land used by the other farmers.

Fertilizer. On average, the seven farmers applied about 8 bags of fertilizer, which included NPK for basal application and urea for topdressing. The fertilizer was estimated to cost ₦18,557.

Labor. Sources of farm labor in the communities were the family and hired labor. For the project, most of the participants used both sources; therefore, the actual cost of labor (hired labor plus shadow wages for family labor) were used in the analysis, which, on average, was ₦10,496.

Herbicides. Herbicides were used to minimise the level of weed infestation and number of weedings done in the farm. In this project only one farmer applied herbicides. The actual amount spent to purchase the chemical and for spraying was used in the analysis.

On average, the total cost of production (total variable costs plus explicit costs) was ₦33,770/ha when herbicides were used and ₦28,750/ha for those who used hoe weeding for the production (Table 1).

Seed and grain yields from community seed production

Fields of farmers who followed the agronomic practices and met the required isolation distance were harvested for seed; the others were considered as grain. Furthermore, harvests from water-logged fields, plants used to supply missing stands, and those at edge rows were taken as grain. The seed and grain yields are shown in Table 2. From a total of 4.5 ha of the seed farm planted to Obatanpa GH in the year, 10.62 t of seed and 3.195 t of grain were produced. Table 3 shows the returns made from the seed and grain production by seven of the farmers who participated in Obatanpa GH production in Daudawa (farmers 1–7). The average gross income from seed was ₦115, 320 and that from grain was ₦16, 967/ha.

Table 1. Cost elements (₦/ha) in community seed production of Obatanpa by seven farmers in Nigeria, 2004.

Item of cost	Iliya Ibrahim	Bala Na Auta	Habu Shehu	Awalu Ibrahim	Halilu Turki	Usman Bala	Gambo Garba	Average
Land rent	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
Fertilizer	16,900	33,400	19,600	2, 900	20,400	15, 000	21, 700	18,557
Labor	7,140	13,820	6,040	7,920	14,470	6,540	17540	10, 495
Herbicide	-	-	-	-	-	-	5020	5, 020
Total	28,040	51,220	29,640	14,820	38,870	25,540	48,260	33,770

Source: Field data

Table 2. Farm size, planting date and quantities of seed and grains from community seed production of Obatanpa by nine farmers in Nigeria, 2004.

	Farm size (ha.)	Date planted	Seed yield (kg)	Grain yield (kg)	
Farmer					Remarks
I. Ibrahim	0.5	19-6-04	-	800	Field water-logged
B.N. Auta	0.5	19-6-04	5360	200	
H. Shehu	0.5	20-6-04	200	135	Field water-logged
H. Turki	0.5	14-6-04	2000	100	
A. Ibrahim	0.5	20-6-04	-	960	Field water-logged
U. Bala	0.5	19-6-04	80	250	Field water-logged
G. Garba	0.5	15-6-04	1980	-	The cobs were picked after the field day on the farm
S. Umar*	0.5	16-6-04	-	400	Flooded field
S. S. Birni*	0.5	21-6-04	1000	350	
Total	4.50		10,620	3,195	

* Data from the farmers were not included in the profitability analysis because the farms were located at Saminaka, a different ecology and State. *Source*: Field data

Profitability analysis

The profitability analysis was done by valuing the seeds and grain produced from the seven Obatanpa GH farms used for the analysis. Values of ₦60/kg for seed and ₦40/kg for grain were used as the conservative prices for purposes of the analysis. Table 4 shows that the average total cost was ₦33,770/ha; the average gross income was ₦96,914/ha, while the average net farm income (profit) was ₦63,144 /ha for farmers whose opportunity costs of land and family labor were considered and who also used herbicide. However, looking at Table 4 critically, five of the seven farmers made a profit but two produced at a loss. Three of the farmers made profits over and above the average profit but they were also the farmers who invested more in the production process. Indeed, these farmers invested more than the average total cost of production, an indication that they used a higher management level, which resulted in a good seed yield and, therefore, a higher income. The two farmers who made net losses had a relatively poor management and a low investment in fertilizers.

Economics of EV 99 QPM production

Only three farmers produced seed of EV 99 during the year of the study. The cost of production was derived as shown in Table 5. The average total cost of production was ₦39, 853/ha. About 2.5 t/ha of seed and 900 kg/ha grain were produced/ha (Table 6). Table 7 shows the gross income from EV 99 seed production. An average gross income of ₦62, 533/ha was made. Two of the three farmers made a profit while one made a loss (Table 8). The average profit was ₦22680/ha and the two farmers' profits were each above this average. The loss experienced by the other farmer was attributable to flooding.

Constraints to community seed production of QPM varieties

The basic constraints to community seed production of QPM varieties were identified as follows:

Inability of farmers to distinguish between seed and grain in the application of production practices. Farmers could not understand why they needed standard isolation distances when their farms were located between or close to other farms.

Flooded fields. In years of heavy rainfall, the fields could be flooded or water- logged and this could affect the quality and quantity of seed produced. Proper drainage and good seedbed preparation were suggested to farmers who could not relocate their fields away from areas prone to flooding.

Table 3. Gross income (₦/ha) from community seed production of Obatanpa by seven farmers in Nigeria, 2004.

Source of Income	Iliya Ibrahim	Bala Na Auta	Habu Shehu	Awalu Ibrahim	Halilu Turki	Usman Bala	Gambo Garba	Average
Seeds*	-	321,000	12,000	-	120,000	4,800	118,800	82,371
Grain**	32,000	12,000	5,400	38,400	4,000	10,000	-	14,543
Total	32,000	333,000	17,400	38,400	124,000	14,800	118,800	96,914

* Seed was valued @ N60/kg; ** Grain was valued @ N40/kg; 1US$ =₦130
Source: Field data

Table 4. Profitability analysis (₦/ha) of community seed production of Obatanpa by seven farmers in Nigeria, 2004.

Item	Iliya Ibrahim	Bala Na Auta	Habu Shehu	Awalu Ibrahim	Halilu Turki	Usman Bala	Gambo Garba	Average
Gross income	32,000	333,000	17,400	38,400	124,000	14,800	11,8800	96, 914
Total costs	28,040	51,220	29,640	14,820	38,870	25,540	48,260	33, 770
Profit/Loss	3,960	281,780	–12240	85,130	85,130	–10,740	70,540	63, 144

Source: Field data

Table 5. Cost elements (₦/ha) in community seed production of EV 99 by three farmers in Daudawa, Nigeria, 2004.

	Halilu Turki	Auwalu Ibrahim	Alh. Usman Bala	Average
Item of cost				
Land rent*	4,000	4,000	4,000	4,000
Fertilizer	15,200	23,000	32,800	23,667
Labor (family and hired)	12,040	9,040	15,480	12,187
Total costs	31,240	36,040	52,280	39,853

*Shadow price for rent. *Source*: Field data

Table 6. Farm size, planting date and quantities of seed and grains from community seed production of EV 99 by three farmers in Daudawa, Nigeria, 2004.

Farmer	Farm size (ha.)	Date planted	Seed yield (kg/ha)	Grain yield (kg/ha)	Remarks
H. Turki	0.25	15-6-04	1,200	400	
A. Ibrahim	0.25	22-6-04	1,200	-	
U. Bala	0.25	19-6-04	100	540	Flooded
Total	0.75		2,500	940	

Source: Field data

Table 7. Gross income (₦/ha) from community seed production of EV 99 QPM by three farmers in Daudawa, Nigeria, 2004.

Source of Income	Halilu Turki	Auwalu Ibrahim	Alh. Usman Bala	Average
Seeds*	72,000	72,000	6,000	50,000
Grain	16,000	-	21,600	12,533
Total	88,000	72,000	27,600	62,533

*Seed was valued @ ₦60/kg; and grain @ ₦40/kg; 1US$= ₦130

Source: Field data

Table 8. Profitability analysis (₦/ha) of community seed production of EV 99 QPM by three farmers in Daudawa, Nigeria, 2004.

Item	Halilu Turki	Auwalu Ibrahim	Alh. Usman Bala	Average
Total income	88,000	72,000	27,600	62,533
Total costs	31,240	36,040	52,280	39,853
Profit/Loss	56,760	35,960	–24,680	22,680

Source: Field data

Market accessibility. There was no ready access to market for the produced seed as the crop was new in the community.

However, efforts were made to link the farmers to the seed companies and the Agricultural Development Projects in the two States in an effort to improve marketing of seed. The open days held in the two locations have improved awareness of other farmers in the communities of the availability of the seed. Indeed, many farmers had requested seed from the farmers before harvesting.

Lack of a true spirit of association. Farmers are working as individuals even though they are in associations. This affects their production and market access and bargaining power.

Conclusion and Recommendations

The production of QPM seed at the community level has resulted in farmers being aware of the new maize variety and its quality for food. Hitherto, QPM was not known in these communities but through the open days, it has now been popularised even beyond the two communities. The economic analysis showed that, on average, the production of both Obatanpa GH and EV 99 QPM varieties were profitable. The following recommendations should, therefore, be considered to enhance sustainability of QPM seed production beyond the project phase:

i. Farmers' training and awareness campaigns are needed to overcome the basic technical problems of seed production techniques, which the farmers lacked. Publicity campaigns using extension leaflets, demonstrations and mass media are needed to reach out to more maize farmers.

ii. Effective demand for the QPM seed could be created if the farmers or their groups could be linked to the existing seed companies so that they could serve as contract growers. This will be an incentive, as the producers will be assured of the market.

iii. The farmers should come together to form strong and virile QPM Farmers' Associations to facilitate better access to extension services and and establish strong linkages with seed companies, the ADPs and markets.

The individual profit level shows that those who invested in improved crop management practices, such as recommended fertilizer rates, had higher profits.

Farmers should be linked to sources of farm credit/input supply companies or micro-credit organizations for easy access to financial and physical inputs to ensure sustainability of the community seed project beyond the project phase.

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Effets de la rotation et de l'association culturales Maïs-Pois d'angole sur l'amélioration des rendements du maïs en zone de savane du Burkina Faso

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Résumé

Le but de l'expérimentation était de mettre en évidence un effet éventuel de la rotation ou de l'association culturale du maïs avec le pois d'angole combiné ou non à l'application des phosphates naturels du Burkina Faso. Cette étude a été conduite dans la zone maïsole du Burkina Faso sur deux sites appartenant à la même zone climatique pendant cinq ans (site de Farako Ba) et quatre ans (site de Sidéradougou). On peut noter les points suivants: Sur le site de Farako Ba : Les rendements déclinent très rapidement et à un rythme régulier en monoculture de maïs. L'effet précédent pois d'angole (avec ou sans apport de phosphate naturel) est pratiquement nul. L'association maïs/pois d'angole améliore les rendements du maïs par rapport à une culture pure de maïs. Les rendements peuvent être multipliés par trois. La présence du phosphate naturel du Burkina appliqué une année avant l'association ne change pas les résultats. Cette association a permis de relever les rendements jusqu'au niveau atteint au début de l'expérimentation. Les différents traitements n'ont pas entraîné une différence dans les stocks de carbone du sol. Par contre le taux de phosphore total est plus élevé sur le traitement comprenant un amendement en phosphates naturels. La présence du pois d'angole seul améliore les réserves en phosphore du sol par rapport au témoin en monoculture de maïs. Sur le site de Sidéradougou : la monoculture de maïs enregistre les rendements les plus bas également. L'addition de phosphates naturels améliore les rendements en situation de monoculture de maïs mais à partir de la deuxième année d'application. L'effet du Burkina phosphate est plus marqué en présence de pois d'angole. Dans ces conditions l'effet du Burkina phosphate démarre à partir de la deuxième année. La simple présence du pois d'angole dans le système de culture améliore les rendements. Au vu de ces résultats on peut recommander l'utilisation du pois d'angole dans les systèmes de culture de la zone maïsicole du Burkina Faso en association culturale avec une application de Burkina phosphate une fois tous les deux ans à la dose de 400 kg.ha^{-1}.

Abstract

The objective of this experiment was to determine the effect of maize-pigeon pea rotation or intercrop or sole with the application of Burkina Faso natural phosphates. This study was conducted for 5 years at Farako Ba and 4 years at Sidéradougou in the maize producing zone of Burkina Faso. At Farako Ba, there was a consistent, rapid decline in maize yield when planted as a sole crop. Relative to sole maize, intercropping maize and pigeon pea trippled maize yield. The application of natural phosphates one year before intercropping had no effect on the results. The different treatments did not affect organic matter content of the soil. On the contrary, the total amount of phosphorus was higher in the treatment amended with natural phosphates. Pigeon pea increased the phosphorus reserves in the soil compared to the sole maize control. At Sidéradougou, sole maize had very low grain yield but addition of natural phosphates improved the yield as from the second year of application. The Burkina phosphate was more effective when pigeon pea was planted. Based on these results, the use of pigeon pea with the application of 400 kg ha^{-1} of Burkina phosphate once every two years, could be recommended in cropping systems in the maize producing zone of Burkina Faso.

Introduction

La zone ouest du Burkina représente plus de 75 % de la zone maïsicole du pays, le restant étant disséminé sur l'ensemble du territoire et concerne principalement des champs de case, des terres irrigables ou des bas fonds (Wey 1998). Les sols de cette zone sont pour la plupart pauvres en matière organique et présentent une carence naturelle en phosphore et azote (Hien 1990). Le taux de cette matière organique chute rapidement dès la mise en culture et affecte fortement les rendements des cultures.

La faible utilisation des engrais minéraux et organiques dans un contexte où la jachère qui était le moyen traditionnel de restauration de la fertilité des sols est de moins en moins pratiquée (en raison d'une demande en terres de plus en plus élevée) a entraîné dans plusieurs terroirs villageois une chute remarquable de la fertilité des sols et une réduction progressive de la réponse des cultures aux engrais chimiques. Face à une telle situation il s'est avéré indispensable de mettre au point des technologies permettant d'inverser la tendance.

Il est généralement admis qu'un précédent cultural de légumineuse agit positivement sur le rendement des plantes des autres espèces cultivées dans la rotation. Or dans les systèmes de culture de la zone ouest du Burkina, la présence de légumineuses (arachide, niébé) est courante dans les exploitations où elles sont en rotation ou en association avec les céréales (sorgho et maïs). La présence des légumineuses dans

Tableau 1. Caractéristiques physico-chimiques des sols de Farako Ba.

Caractéristiques physico-chimiques	Horizon 0-20 cm
Argile (%)	7
Limons (%)	19
Sables (%)	74
PHeau	6,5
PHkcl	5,6
Carbone total (%)	0,61
Matière organique (%)	1,1
C/N	13,7
N total (mg/kg)	409
P Bray I (mg/kg)	5,6
P total (mg/kg)	69,8
K total (mg/kg)	531
Ca échangeable (C.mol+/ kg sol)	1,08
K échangeable (C.mol+/ kg sol)	0,02
Mg échangeable (C.mol+/ kg sol)	0,46
ECEC (C.mol+/ kg sol)	1,82
Acidité d'Echange (C.mol+/ kg sol)	0,08
Saturation en bases (%)	96

les systèmes de culture est une opportunité pour améliorer la fertilité des sols et les rendements des cultures. Par leur capacité à fixer l'azote de l'atmosphère grâce au processus de la fixation symbiotique, les légumineuses peuvent améliorer le bilan de l'azote dans les systèmes de cultures (Bado 2002).

L'objectif de cette étude est d'évaluer la contribution d'une légumineuse comme le pois d'angole dans l'amélioration de la production du maïs dans le cadre d'une rotation ou d'une association culturale avec le maïs en présence des phosphates naturels du Burkina.

Matériel et Méthodes

Caractéristiques des sites d'expérimentation

La position géographique des essais. Les expérimentations ont été réalisées dans la zone ouest du Burkina Faso sur deux sites : le site de Farako Ba et le site de Sidéradougou. L'essai de Farako Ba est implanté à la station de Recherches Agricoles de Farako Bá qui est située à 10 km au sud-ouest de Bobo Dioulasso tandis que celui de Sidéradougou est à 80 km au sud de Bobo Dioulasso.

Le climat. Les deux essais sont situés dans la zone sud-soudanienne La pluviométrie annuelle moyenne varie entre 950 de 1100 mm.

Les sols. Les sols de Farako Bâ sont de type faiblement ferralitique. Ils sont de texture sableuse en surface (0-20 cm). Le tableau donne les caractéristiiques physico-chimiques d'un sol de Farako Ba.

Tableau 2. Caractéristiques physico-chimiques d'un sol de Sidéradougou (Horizons 0–10 et 10–20 cm).

Caractéristiques physico-chimiques	Horizon 0-10 cm	Horizon 10-20 cm
Argiles (%)	9.70	13.40
Limons fins (%)	2.50	3.10
Limons grossiers (%)	3.30	4.60
Sables fins (%)	20.50	16.80
Sables grossiers (%)	64.00	62.10
pHeau	6.50	6.25
pHkcl	6.25	5.75
Carbone total (%)	0.55	0.48
Matière organique (%)	0.95	0.83
C/N	12.66	11.83
N total (mg/kg)	434.36	405.66
P Olsen (mg/kg)	8.66	6.66
Ca échangeable (C.mol+/ kg sol)	2.61	1.92
Mg échangeable (C.mol+/ kg sol)	0.51	0.57
K échangeable (C.mol+/ kg sol)	0.17	0.15
Na échangeable (C.mol+/ kg sol)	0.06	0.09
Mn (C.mol+/ kg sol)	0.04	0.06
Al (C.mol+/ kg sol)	0.00	0.00
H (C.mol+/ kg sol)	0.00	0.00
S (C.mol+/ kg sol)	3.36	2.73
CEC (C.mol+/ kg sol)	3.41	2.80
Saturation en bases (%)	99.00	97.00

Les sols de Sidéradougou sont du type ferrugineux tropical, de texture sableuse à sablo-argileuse en surface (0-20 cm). Une analyse d'un échantillon de sol donne les résultats consignés dans le Tableau 2.

Le matériel végétal : les variétés de maïs utilisées sont la SR21 sur le site de Farako Ba et la FBC6 sur le site de Sidéradougou. Le pois d'angole semé est une variété locale.

Les engrais : la fertilisation minérale a été assurée par un engrais complexe N-P_2O_5-K_2O-S-B_2O_5 de formules 14-23-14-6-1 ou 15-15-15-6-1, de l'urée et par le Burkina phosphate (BP) dont la composition chimique est donnée dans le Tableau 3.

Le dispositif expérimental

Le dispositif expérimental est un dispositif en blocs de Fisher.

Site de Farako Ba. Le dispositif comprend trois traitements et six répétitions; l'expérimentation a commencé en 2000. Le Tableau 4 donne la succession des cultures au cours des cinq années d'expérimentation.

Tableau 3. Composition chimique du phosphate naturel du Burkina.

Eléments	Teneurs en %
P_2O_5	25.50
K_2O	0.23
CaO	34.5
MgO	0.27
SiO_2	26.24
CO_2	1
Al soluble HCl	3.1
Fe_2O_3 soluble HCl	3.4
F	2.5
Na_2O	0.11
S	0.04

Tableau 4. Succession des cultures au cours des cinq années d'expérimentation. Site de Farako Ba.

N° du traitement	Traitement	Année 2000	Année 2001	Année 2002	Année 2003	Année 2004
T1	mm	maïs	maïs	maïs	maïs	maïs
T2	Pam	PA	maïs	PA	PA2 + maïs	PA + maïs
T3	*PAmBP*	PA+BP	maïs	PA+BP	PA2 + maïs	PA + maïs

NB :
PA : culture pure de pois d'angole
BP : Burkina phosphate (application à la dose de 400 kg.ha^{-1}).
PA + maïs : association maïs/pois d'angole de première année
PA2 + maïs : association maïs/pois d'angole de deuxième année

Le pois d'angole de deuxième année (PA2) correspond à une culture de pois d'angole à laquelle on associe le maïs en deuxième année. Le pois d'angole de première année (PA) correspond à une culture de pois d'angole à laquelle est associée le maïs dès la même année. Dans les deux cas et sur les deux sites le maïs est semé entre les poquets de pois d'angole sur les lignes. Les deux cultures sont semées à la même densité : 0.80 m x 0.40 m, deux plantes par poquet.

En cas d'association maïs/pois d'angole ou de culture pure de maïs, la parcelle reçoit une fertilisation minérale modeste de 100 kg ha^{-1} d'engrais complexe NPK et 100 kg ha^{-1} d'urée (46%). Le NPK est appliqué au premier sarclage soit environ 10 jours après semis et l'urée à 30 jours environ après semis.

Les feuilles de pois d'angole sont fauchées lorsque leur développement est important au point de gêner la croissance normale du maïs et étalées au sol. Elles sont alors enfouies soit par un léger sarclage soit par un buttage. L'opération se répète au moins trois fois au cours de la saison culturale.

Tableau 5. Succession des cultures au cours des quatre années d'expérimentation. Site de Sidéradougou.

Traitement	Année 2001	Année 2002	Année 2003	Année 2004
T1	maïs	maïs	maïs	maïs
T2	maïs +BP	maïs	maïs	maïs
T3	PA	PA+maïs	maïs	maïs
T4	PA + BP	PA+maïs	maïs	maïs

Lorsqu'il s'agit d'une culture pure de pois d'angole, il n' y a pas d'apport d'engrais. Toutefois l'essai de Farako Ba avait reçu en première année une application uniforme de NPK à la dose 100 kg.ha^{-1} compte tenu du très faible développement des plantes en relation avec le faible niveau de fertilité du sol de l'essai.

Site de Sidéradougou : le dispositif expérimental comprend quatre traitements en cinq répétitions. Les quatre traitements résultent d'une combinaison factorielle comportant deux niveaux pour chaque facteur (Tableau 5) :

- Présence ou absence de pois d'angole dans le système de culture
- Avec ou sans apport de Burkina phosphate (400 kg.ha^{-1}). Les parcelles élémentaires mesurent 72 m^2.

Analyse de sol

Un prélèvement de sol a été réalisé en janvier 2005 sur l'horizon 0-20 cm de l'essai de Farako Ba pour des analyses de carbone et de phosphore total. L'analyse a été faite au laboratoire de la station de Kamboinsé de l'INERA.

Analyse statistique des données

L'analyse de variance des résultats a été réalisée avec le logiciel GENSTAT 5.32.

Résultats et Discussions

Essai de Farako Ba

Evolution des rendements en fonction de l'âge de mise en culture. La Figure 1 et tableau 6 montre l'évolution des rendements en maïs-grain de 2000 à 2004 sur le témoin qui est une culture continue de maïs.

Le premier constat que l'on peut faire c'est que le rendement obtenu en première année est tout de même bas malgré une pluviométrie acceptable (moyenne de l'année : 1073.5 mm) : 1684 kg.ha^{-1}. Ce rendement est en deçà des rendements potentiels de la variété SR21. Le bas niveau de rendement obtenu peut être attribué au bas niveau de fertilité de ce sol plusieurs fois exploité dans le cadre

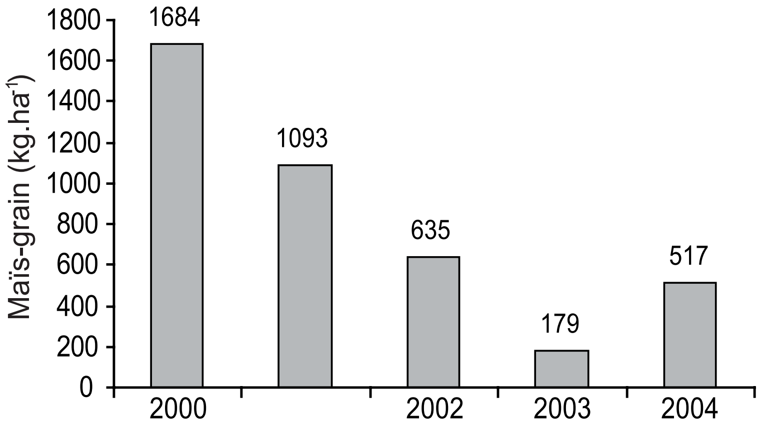

Figure 1. Evolution des rendements du maïs-grain de 2000 à 2004 en culture continue de maïs à la station de Farako Ba.

Tableau 6. Evolution des rendements du maïs-grain en culture continue de maïs. Site de Farako Ba.

Année	Grain (kg,ha^{-1})
2000	1684
2001	1093
2002	635
2003	179
2004	517
F	51.63
Probabilité	<0.001
lsd	239.3
CV%	24.2

des expérimentations agronomiques. Mais cette situation est souhaitée afin de pouvoir mesurer l'impact de la nouvelle technologie que l'on veut mettre au point sur l'amélioration de la fertilité des sols.

Le deuxième constat que l'on peut faire c'est la tendance nette à la baisse significative des rendements du maïs d'une saison à l'autre comme le montre le tableau d'analyse de variance (Tableau 7). En deuxième année 35 % du rendement initial est perdu, en troisième année 62 %, en quatrième et cinquième années respectivement 89 et 69 % malgré les apports d'engrais.

D'une manière générale, la chute rapide de la fertilité des sols tropicaux à la suite de leur mise en culture est bien connue. Mais il faut noter que dans le cas présent le faible niveau initial de fertilité de ce sol est la raison principale du déclin rapide des rendements.

Effet du précédent cultural pois d'angole sur les rendements du maïs à Farako Ba. En deuxième année d'essai (2001) on a comparé les rendements obtenus sur les parcelles portant en première année soit le pois d'angole soit le maïs. Le Tableau 7 rassemble les résultats

Tableau 7. Successions culturales et rendements du maïs sur le site de Farako Ba.

Successions culturales à Farako Ba					
Traitements	Année 2000	Année 2001	Année 2002	Année 2003	Année 2004
1	maïs	maïs	Maïs	maïs	maïs
2	PA	maïs	PA	PA2 + maïs	PA + maïs
3	PA+ BP	maïs	PA+ BP	PA2 + maïs	PA + maïs
Rendement en maïs-grain (kg.ha^{-1}) à Farako Ba					
1	1684	1093 a	635	179 a	517 a
2	**	1307 a	**	675 b	1561 b
3	**	1461 a	**	925 c	1672 b
Probabilité		0.159		0.001	0.013
Lsd		391		327	767

NB :
- PA : culture de pois d'angole
- BP : Burkina phosphate
- PA + maïs : association maïs/pois d'angole de première année
- PA2 + maïs : association maïs/pois d'angole de deuxième année
- Sur la même colonne les chiffres portant la même lettre ne sont pas différents au seuil *P* = 0.05.

d'analyse de variance et les moyennes des traitements. Ces données sont illustrées sur la figure 2. On peut noter ceci :

– l'absence de différence significative entre les trois traitements.
– Une tendance des systèmes avec pois d'angole à procurer des rendements plus élevés (différence arithmétique).
– L'effet du burkinaphosphate n'est pas également observé.

Ces résultats peuvent être attribués à la faible croissance du pois d'angole de l'année précédente (en 2000). Cette faible croissance étant liée à la pauvreté du sol de l'essai de Farako Ba.

Effet de l'association maïs-pois d'angole sur les rendements du maïs à Farako Ba en 2003 et 2004. En 2003 et 2004, il a été analysé l'effet de l'association pois d'angole-maïs sur les rendements du maïs (Figure 3).

L'analyse de variance est consignée dans le Tableau 7. On peut faire les observations suivantes :

– L'association maïs/pois d'angole améliore toujours les rendements du maïs.
– En 2003 le traitement 2 (maïs+PA) est 3 fois que le témoin et le traitement 3 cinq fois plus élevés. Mais le niveau général des rendements est bas.
– En 2004, l'association avec ou sans burkinaphosphate procure des rendements équivalents mais trois fois supérieurs au rendement obtenu sur le témoin. L'effet de l'apport du phosphate naturel du Burkina est pratiquement nul.

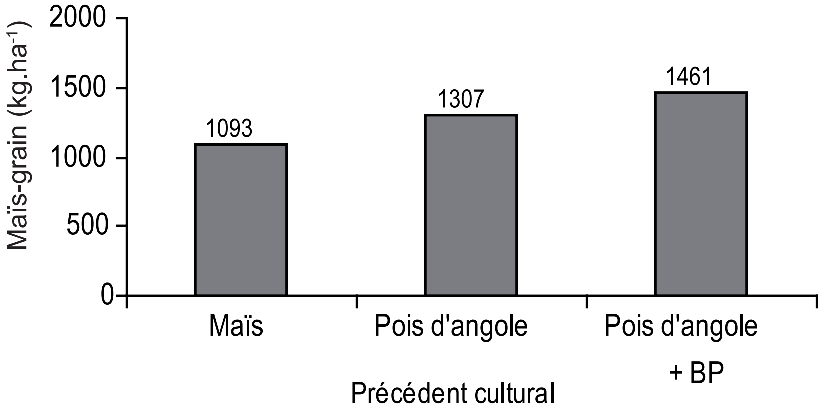

Figure 2. **Effet du précédent cultural sur le rendement du maïs sur le site Farako Ba (année 2001).**

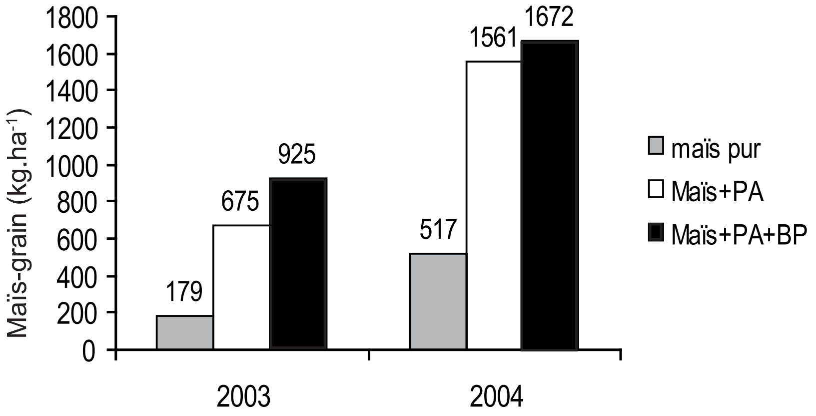

Figure 3. **Effets de l'association Maïs/Pois d'angole sur les rendements du maïs à Farako Ba.**

Effet des traitements sur la teneur du sol en carbone et en phosphore total. Le taux de carbone n'est pas sensiblement différent entre les traitements (Tableau 8). Par contre la teneur en phosphore totale discrimine bien les trois traitements. Le traitement T3 qui avait eu un apport de BP en 2000 et en 2002 à la dose de 400 kg.ha-1 a la plus forte teneur en phosphore suivi par le T2. Le traitement T1 enregistre la plus faible réserve en phosphore.

Conclusion sur le site de Farako Ba:

i. Les rendements déclinent très rapidement et à un rythme régulier en monoculture de maïs.
ii. L'effet précédent cultural « pois d'angole seul » ou « pois d'angole combiné au burkina phosphate » est pratiquement nul.
iii. L'association maïs-« pois d'angole seul » améliore les rendements du maïs par rapport à un témoin en culture pure de maïs.

Tableau 8. Effet des traitements sur le carbone et le phosphore total du sol de Farako Ba.

Traitements		C (mg.g^{-1})	Phosphore (mg.kg^{-1})
mm	T1	2,710	126,39
PA+m	T2	2,685	153,33
PA+m+BP	T3	2,572	166,81

iv. Les rendements peuvent être multipliés par trois. L'effet du Burkina phosphate en présence de pois d'angole est pratiquement nul.
v. Les différents traitements n'ont pas entraîné une différence dans les stocks de carbone du sol.
vi. Par contre le taux de phosphore total est plus élevé sur le traitement comprenant un amendement en phosphates naturels.
vii. La présence du pois d'angole seul améliore les réserves en phosphore du sol par rapport au témoin en monoculture de maïs.

Essai de Sidéradougou
L'expérimentation a une durée de quatre ans. Le dispositif expérimental a permis:

- d'étudier l'évolution des rendements de 2001 à 2004 (quatre ans) en culture continue de maïs avec ou sans apport de phosphates naturels du Burkina;
- d'apprécier les effets résiduels des traitements appliqués en première (2001) et deuxième année (2002) sur les rendements du maïs-grain en 2003 et 2004. Les résultats sont rassemblés dans le Tableau 9**.**

Evolution des rendements du maïs-grain en monoculture de maïs. L'évolution des rendements du témoin avec ou sans phosphates naturels (appliqués seulement en première année) indique une relative stabilité des rendements contrairement à ce qui a été observé à Farako Ba (Figure 4). Cette faible variabilité est mieux observée sur le témoin avec BP notamment les trois premières années de l'expérimentation. On pourrait attribuer le maintien des rendements sur ce site à la fertilité du sol relativement plus bonne par rapport au sol de Farako Ba.

Effet du Burkina phosphate sur les rendements du maïs en culture pure. L'analyse de variance montre que le BP appliqué en 2001 n'a aucun effet sur les rendements en maïs grain dans la même année. Par contre on peut observer un effet résiduel à partir de la deuxième année jusqu'à la quatrième année. Il faut néanmoins noter que les accroissements de rendements sont tout de même modestes : 13 et 14 % en 2002 et 2003. Par contre en 2004 l'arrière-effet du BP a été particulièrement important : 46 %. Ces résultats peuvent être attribués à la faible solubilité des phosphates naturels du Burkina.

Tableau 9. Successions culturales et rendements du maïs sur le site de Sidéradougou.

Facteur 1	Facteur 2		*Successions des cultures à Sidéradougou*			
			Année 2001	Année 2002	Année 2003	Année 2004
Absence de PA	Sans BP	T1	M	M	M	M
	Avec BP	T2	M+BP	M	M	M
Présence de PA	Sans BP	T3	PA	PA2+M	M	M
	Avec BP	T4	PA+BP	PA2+M	M	M
Rendements du maïs-grain (kg.ha^{-1}) à Sidéradougou						
Absence de PA	Sans BP	T1	1945 a	1422 a	1338 a	1913 a
	Avec BP	T2	1728 a	1611 b	1524 b	2785 b
Présence de PA	Sans BP	T3	**	1515 a	1682 a	2440 a
	Avec BP	T4	**	2056 b	2498 b	3140 b
		Effet PA	**	NS	S	S
				(*P*=0.104)	(*P*=0.010)	(*P*=0.051)
		Effet BP	NS	S	S	S
				(*P*=0.034)	(*P*=0.037)	(*P*=0.002)

NB :

- PA : culture de pois d'angole
- BP : Burkina phosphate
- PA + maïs : association maïs/pois d'angole de première année
- PA2 + maïs : association maïs/pois d'angole de deuxième année

pour chaque niveau du facteur 1 (pois d'angole), les traitements (T1 et T2 d'une part, T3 et T4 d'autre part) portant la même lettre sur la même colonne ne sont pas différents au seuil $P = 0.05$

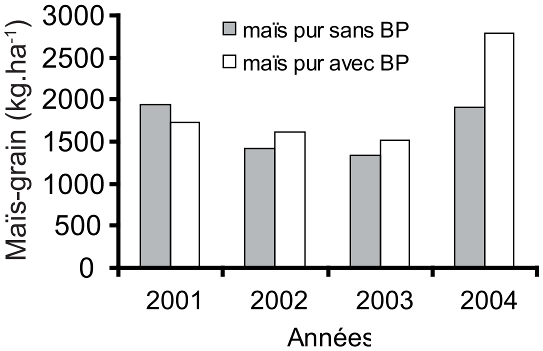

Figure 4. Evolution des rendements du maïs en culture continue avec où sans apport de phosphates naturels.

Effet du Burkina phosphate sur les rendements du maïs venant après une culture de pois d'angole amendé avec le Burkina phosphate. La culture de pois d'angole de 2001 avait reçu un apport de 400 kg.ha^{-1} de BP. La saison qui a suivi (en 2002) a été planté du maïs entre les poquets du pois d'angole qui était donc à sa deuxième année. Le sol n'a pas donc été labouré. La biomasse foliaire du pois d'angole a été régulièrement fauchée et déposée sur les interlignes puis enfouie légèrement. Les rendements obtenus (traitements T3 et T4 du Tableau 9) sont dans l'ensemble faibles. Ces résultats pourraient s'expliquer par le fait que ce système de culture qui consistait tout simplement à semer directement le maïs entre les pieds de pois d'angole de deuxième année ne valorise pas suffisamment la biomasse foliaire du pois d'angole qui est fauchée et déposée sur les interlignes sans enfouissement conséquent. De plus le sol n'a connu aucune préparation avant le semis (semis direct). La croissance des plantes est alors moins bonne. C'est seulement le traitement T4 (pois d'angole avec BP) qui a enregistré le meilleur rendement en 2002 (2056 kg.ha^{-1}) et montre un effet positif du BP. L'accroissement de rendement est de 36 % (par rapport au T3). L'effet du pois d'angole ainsi que l'interaction pois d'angole x Burkina phosphate ne sont pas significatifs.

En 2003 et 2004, on peut apprécier les effets résiduels des traitements. Ainsi l'analyse de variance montre un effet du BP significatif sur les rendements du maïs. L'accroissement de rendement dû au BP appliqué en 2001 (T4) est de 48 % en 2003 et de 29 % en 2004. A l'instar des traitements sans pois d'angole (T1 et T2), les effets du BP se manifestent les années qui suivent l'apport. Toutes fois en présence de pois d'angole l'effet du BP est plus important.

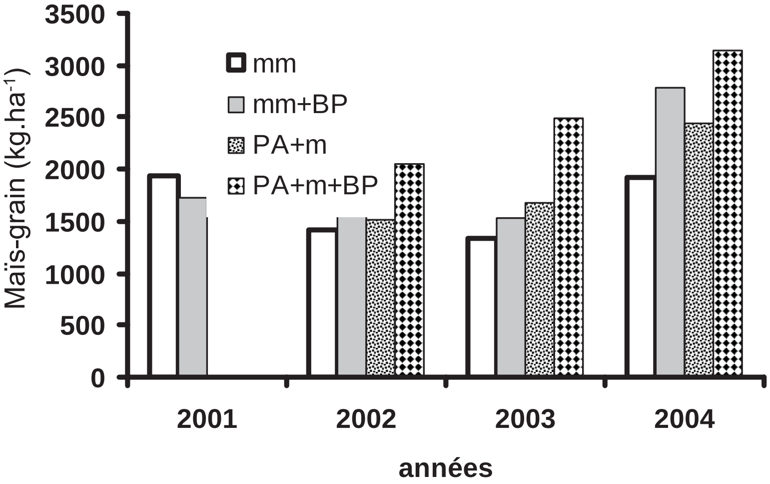

Figure 5. Effet des traitements sur les rendements du maïs-grain à Sidéradougou.

Conclusion sur le site de Sidéradougou :

i. La monoculture de maïs enregistre les rendements les plus bas.

ii. L'addition de phosphates naturels améliore les rendements en situation de monoculture de maïs mais à partir de la deuxième année d'application.

iii. L'effet du Burkina phosphate est plus marqué en présence de pois d'angole dans le système de culture (Fig. 5). Dans ces conditions l'effet du Burkina phosphate démarre à partir de la deuxième année.

iv. La simple présence du pois d'angole dans le système de culture améliore les rendements du maïs.

Conclusion Générale

Au bout de ces cinq années d'expérimentation on peut tirer ces conclusions partielles :

Sur le site de Farako Ba :

Les rendements déclinent très rapidement et à un rythme régulier en monoculture de maïs. L'effet précédent pois d'angole (avec ou sans apport de phosphate naturel) est pratiquement nul en 2001.

L'association maïs/pois d'angole améliore les rendements du maïs par rapport à une culture pure de maïs. Les rendements peuvent être multipliés par trois. La présence du Burkina phosphate appliqué une année avant l'association ne change pas les résultats. Cette association a permis de relever les rendements jusqu'au niveau atteint au début de l'expérimentation. Les différents traitements n'ont pas entraîné une différence dans les stocks de carbone du sol. Par contre le taux de phosphore total est plus élevé sur le traitement comprenant un amendement en phosphates naturels. La présence du pois d'angole seul améliore les réserves en phosphore du sol par rapport au témoin en monoculture de maïs.

Sur le site de Sidéradougou :
La monoculture de maïs enregistre les rendements les plus bas également. L'addition de phosphates naturels améliore les rendements en situation de monoculture de maïs mais à partir de la deuxième année d'application. L'effet du Burkina phosphate est plus marqué en présence de pois d'angole dans le système de culture. Dans ces conditions l'effet du Burkina phosphate démarre à partir de la deuxième année. La simple présence du pois d'angole dans le système de culture améliore les rendements.

Au vu de ces résultats on peut recommander l'utilisation du pois d'angole dans les systèmes de culture de la zone maïsicole du Burkina faso en association culturale avec une application de Burkina phosphate une fois tous les deux ans à la dose de 400 kg.ha^{-1}. La rotation culturale pois d'angole-maïs est par contre difficile à recommander dans le contexte actuel de saturation de l'espace agricole et de divagation des animaux.

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Section 5

Postharvest and Utilization

Evaluation of amylase-rich flour for cereal-based infant formulas from improved Cameroonian maize cultivars

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Abstract

The effect of cultivar and malting conditions on some biochemical and functional factors of maize (*Zea mays* L.) flour was studied. The experiment was a 3x4x5 factorial with 3 hydration levels (50%, 75%, 100%), 4 maize cultivars (CMS 8501, CMS 8704, Kassaï, 88094xM131xExp24) and 5 germination times (0, 1, 2, 3, 4 days). Grain samples were malted using a micro-malting method and evaluated for their water absorption capacity, physico-chemical composition and germination activity. Flours (control and malted) were analysed for amylase activity, soluble sugars and least gelatinisation concentration. Results showed that cultivars and malting conditions had significant effects ($P<0.05$) on the parameters studied. The maximum water uptake varied between 54.34% and 58.82%. The time needed for 50%, 75% and 100% hydration level (HL) varied between 4.00 and 4.50 h; 12.50 and 14.17h and 36.00 and 40.50 respectively. The peak of germination activity was attained on the second day at 50% HL. The amylase activity reached maximum values of 0.27 and 0.28 mg/ml on the second day with little or no increase thereafter. An inverse relationship was observed between the concentrations of soluble sugars and least gelatinisation. Amylase-rich flour with the best properties was obtained from 88094xM131xExp24 followed by CMS 8704.

Résumé

L’effet du cultivar et des conditions de maltage a été étudiée sur quelques facteurs biochimiques et fonctionnels des farines de maïs. Un dispositif factoriel 4x3x5 soit 4 cultivars de maïs (CMS 8501, CMS 8704, Kassaï, 88094xM131xExp24), 3 niveaux d’hydratation (50%, 75%, 100%) et 5 temps de germination (0, 1, 2, 3, 4 jours) a été utilisé. Les grains de maïs malté en utilisant une micro-méthode de maltage ont été analysés pour leur composition globales, capacité d’absorption d’eau et degré de germination. Les farines (maltées et control) ont été examinées pour les activité amylasique, teneur en sucres solubles et plus petite concentration gélifiante. Les résultats montrent l’existence une influence significative ($P<0{,}05$) des variables sur les paramètres analysés. Les valeurs maximales d’eau absorbées par les grains varient entre 54,34 et 58,82%. Les périodes requises pour 50%, 75% et 100% d’hydratation varient entre 4h00′ et 4h30′; 12h30′ et 14h13′ et 36h00′ et 40h30′ respectivement. Les pics de taux de germination (92,0-92,67%) ont été observé au 2^{e} jour pour 50% d’hydratation. L’activité amylasique atteint des valeurs optimales de 0,27 et 0,28 mg/ml au 2^{e} jour et ne présente plus une évolution significative. Une tendance inverse est observée avec les sucres solubles et plus petite concentration gélifiante. Sur la base des résultats obtenus, les grains maltés de 88094xM131xExp24 suivie de CMS 8704 produisent des farines amylolytique dotées des meilleures propriétés.

Introduction

Most traditional weaning foods made from cereals are low in nutritional values due to the fact that cereals do not have high contents of micro- and macro-nutrients (WHO, 1998). For example, during the process of cooking to make porridge, the starch from the cereal binds water, thus requiring a considerable amount of water to bring the consistency of the porridge to a level suitable for feeding children, and this lowers the energy and nutrient density of the porridge considerably. This high volume/high viscosity characteristic, referred to as dietary bulk, makes it difficult to satisfy the nutrient requirements for infants fed on these gruels, and this is considered a major source of the problem of malnutrition in areas where cereal staples are the main food (Ljungqvist *et al.* 1981; WHO 1998).

Recently, more attention has been directed towards the attainment of protein energy requirements because of the widespread occurrence of protein energy malnutrition and linear growth retardation of infants in developing countries. Observations on child feeding practices in Northern Cameroon revealed that the weaning period usually starts 3–6 months after birth and one in every three children is malnourished (Seumo and Abdouraman 1990; Rogeaux *et al.* 1991; Njongmeta *et al*. 2003). Similar observations have been reported in many other sub-Saharan African countries (Simondon *et al.* 1991; Dubernet *et al.* 1991; WHO 1998). Although the energy/nutrient density of transitional foods can be increased by the addition of oil, fat, sugar, milk, honey, etc., these are too expensive for an average family in North Cameroon. A viable alternative is to enhance the nutritional status of cereal porridge through processing. Germination of the cereal before processing is considered the best way to enhance the nutritional status of the porridge, since dietary bulk reduction results from the formation of amylases that break down starch in the germinated cereal seed. In addition to bulk reduction, germination increases the thiamine, riboflavin, niacin, folic acid, ascorbic acid, and iron contents as well as the biological value of cereals. Also it reduces the antinutritional and flatus-producing factors (WHO 1998). The extent to which germination affects the grain quality depends on the material used and the malting conditions. The amylase activity in maize malts is lower than in sorghum malts (Traore 2004).

Few studies have been conducted on the improvement of cereal malting properties (Wang and Fields 1978; Matilda *et al.* 1993). Reports on the use of maize malts in infant formulas, as have been done for sorghum, are even fewer. There is a need to assess the changes in grain properties during maize malting. The research reported in this paper was carried out to determine the effect of malting conditions on some biochemical and functional determinants in maize grain. The goal was to obtain information that could be used to define suitable malting conditions necessary for the production of amylase-rich flours.

Materials and Methods

Maize grain samples

Grain samples from four maize cultivars (CMS 8501, CMS 8704, Kassaï, 88094xM131xExp24) evaluated in this study were obtained from the Agricultural Research Institute for Development (IRAD) in Garoua, Cameroon. These cultivars were grown under the same environmental conditions and crop management practices.

Physico-chemical analysis

The samples were cleaned and sorted, and 1000 grains were weighed. Analysis of moisture, proteins, lipids and ash contents was carried out using official methods of analysis (AOAC 1990). Total carbohydrate was obtained by difference (Egan *et al.* 1981).

Hydration kinetics

The grain samples were put in plastic containers and steeped with distilled water (20% w/v) at 30 °C. The hydration process was monitored by weighing the grains placed in a tray on a sensitive balance (Sartorius, Prodilab, France, 0.001g) at different intervals until a constant weight was attained. The surface of each sample was dried by blotting with absorbent paper before weighing. The percentage of water absorption was defined as:

$$A=(M'-M) \times 100/M + A_o \qquad (1)$$

where A_0 represents the initial sample moisture, M and M′ are the weight of the dry solids and the weight of the hydrated samples. The hydration runs were carried out in triplicate and measurements taken were used to construct the hydration curves. In this study it was assumed that the internal resistance to water diffusion in grain samples controlled the rate of water uptake and hence the internal mass transfer coefficients, k_1 and k_2. The coefficient of water transfer from the grain surface to the center was defined after Peleg (1988) as:

$$M_t=M_0+t/(k_1+k_2t) \qquad (2)$$

where M_t and M_0 represent the total water content per unit weight of dried sample at time t and 0; k_1 and k_2 are hydration kinetics constants. According to this model, the maximum water absorbed is $Mw=M_0+1/k_2$ and time to reach half-saturation is $t_{50\%}= k_1/k_2$. The linear absorption equation of the relation in equation (2) is

$$t/(M_t-M_0)= k_1+k_2t \qquad (3)$$

Malting studies

The effects of cultivar and malting conditions on grain properties were investigated in a 3 x 4 x 5 factorial experiment with three hydration levels (50%, 75% and 100%), four maize cultivars (CMS 8501, CMS 8704, Kassaï and 88094xM131xExp24) and five germination times (0, 1, 2, 3 and 4 days) as the factors. Maize grains were malted using a micro-malting method (Demuyakor and Ohta 1992). After sterilisation (water: ethanol, 30:70 v/v), each grain sample was steeped in distilled water (1:5 w/v, 30 °C) to reach the required hydration level (HL). Random samples placed in batches in disposable plates lined with absorbent paper were allowed to germinate in the dark at 30 °C in an oven (Memmert, Germany) with wetting done twice a day. Duplicate batches were taken out at various intervals and dried at 50°C for 48h. Rootlets were rubbed by hand and separated by sieving. The ungerminated (control) and germinated grains were ground in a laboratory mill (SAMAP, Type F100, France) so that they could pass through a 0.5 mm sieve. The flour samples were stored in sealed plastic bags in a dessicator until needed for analyses. In a parallel study, 100 grains from the steeped samples were germinated on filter paper in petri dishes and the germination activity was recorded (Beta *et al.* 1995).

Malted and raw flour analysis

The water soluble sugars and proteins were extracted according to Oshodi and Ekperigin (1989). Each flour suspension (distilled water, 1:50

w/v) was shaken and centrifuged at 5600 rpm for 30 minutes. Sugars and amylase activity in the supernatant were determined as described by Ogbonna *et al.* (2001). The least gelatinisation concentration was determined on suspensions ranging from 2 to 60% (w/v) by the modified method of Coffmann and Garcia (1977).

Statistical analysis

All measurements were replicated three times and the data subjected to the analysis of variance to test for the effects of the different factors on the measured properties. Duncan Multiple Range Test was used to separate the means. Statistical analyses were carried out using the SPSS (1993) statistical package.

Results and Discussion

Physicochemical properties of maize grains

The physicochemical properties of the maize grains are presented in Table 1. The 1000 grain weight varied between 197.2 and 268.5g. Similar results have been reported by several earlier workers (Bressani and Mertz 1958; FAO 1993). The results indicated significant ($P<0.05$) cultivar differences in grain composition. Generally, the grains had high carbohydrate content relative to low amounts of lipids and ash. On a comparative basis, the protein content of CMS 8704 grain was significantly ($P<0.05$) lower than the other varieties, but this was higher lipid content, this normally varies between 3 and 18% among maize genotypes (FAO 1993).

Water absorption kinetics

The water absorption kinetics for the grain samples at 30°C are shown in Figure 1a. There was a rapid increase in grain moisture within the first hour, thus indicating the strong influence of steeping time on this parameter. The patterns of the different curves are similar with a tendency to converge towards the maximum point of water uptake, Mw. It is evident from the hydration parameters (Table 2) that Mw is dependent on cultivar and steeping time. The time required to reach Mw ranged from 65 to 96 h. The maximum hydration level (100% HL) was similar for CMS 8501 and 88094 x M131 x Exp24 but significantly ($P<0.05$) higher than that observed for CMS 8704 and Kassai. Solomon *et al.* (1987) and Ilori *et al.* (1990) reported a 37 to 48% water uptake after steeping sorghum between 16 and 48 h. The difference between their reports and this work might be related to the genetic material used. The rate of water uptake (Rw) ranged from 11.79%/h to 14.13%/h. In each maize cultivar, Rw was higher for samples of lower grain weight. This observation is in agreement with

Table 1. Physicochemical composition (% w/w) of the grains of four maize varieties assayed in Cameroon.

Cultivars	Properties* CHO**	Moisture	Proteins	Lipids	Ash	1000 grain wt (g)
CMS 8501	77.8±1.4^{cd}	10.6±0.5^{a}	6.03±0.2^{b}	4.3±0.0^{a}	1.3±0.0^{b}	197.2±3.2^{a}
CMS 8704	77.1±1.9^{c}	11.0±0.3^{b}	5.77±0.1^{a}	5.0±0.0^{d}	1.1±0.0^{a}	268.5±3.1^{d}
Kassaï	74.9±1.5^{b}	11.0±0.0^{b}	8.35±0.3^{c}	4.4±0.0^{b}	1.3±0.1^{b}	262.5±1.1^{c}
88094xM131xExp24	74.2±1.5^{a}	11.1±0.1^{b}	8.79±0.2^{d}	4.8±0.0^{c}	1.1±0.1^{b}	212.2±6.6^{b}

* Means with the same letters within the same column are not significantly different at the 0.05 level of probability

** Carbohydrates.

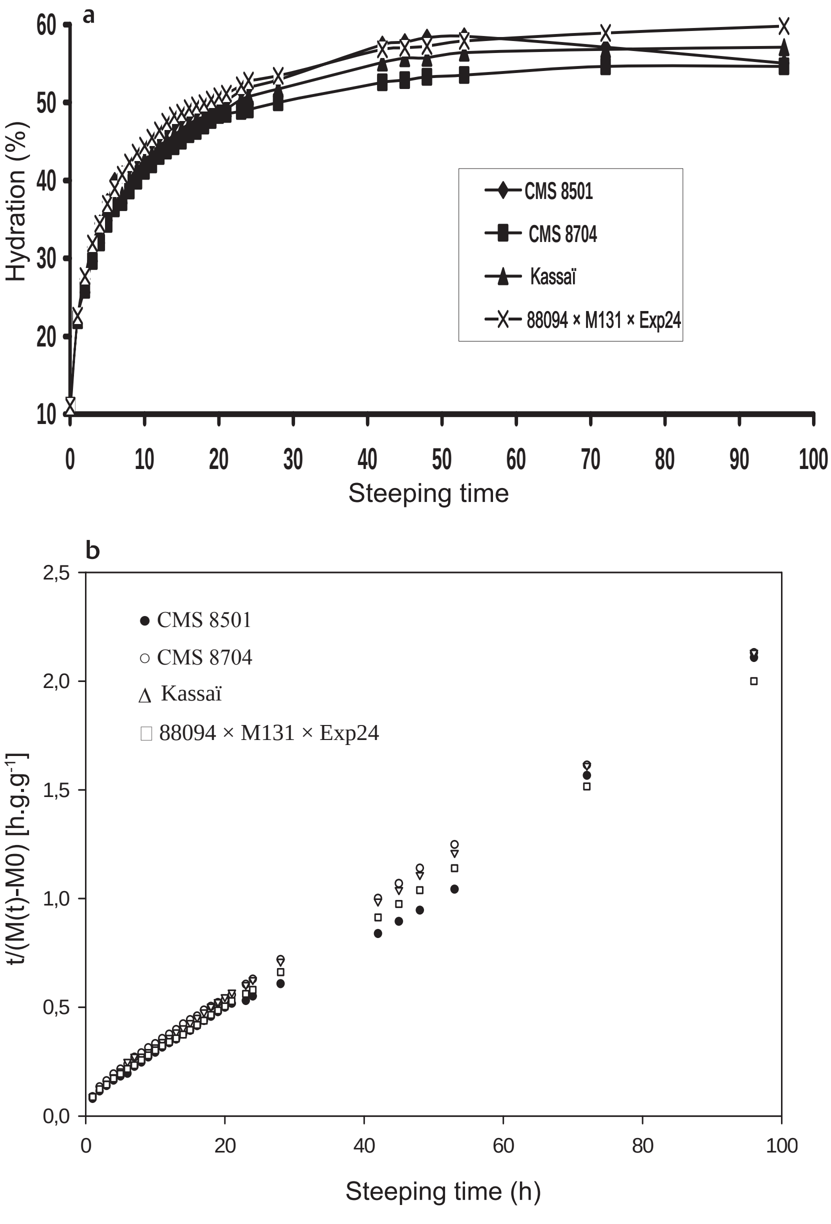

Figure 1. Variation in (a) hydration curves and (b) linear moisture absorption curves of maize grains as affected by steeping time and cultivars.

previous reports in sorghum (Ilori *et al.* 1990; Demuyakor and Ohta 1992). The grain hydration curves for each cultivar, plotted according to the Peleg (1988) model are presented in Figure 1b. The linear regression of the overall hydration process on steeping time produced a perfect fit ($R^2 = 0.99$).

Similar results were reported by Njingtang *et al.* (2003) for taro flour and Thuram *et al.* (2002) for peas.

Table 2. Steeping time and varietal effects on hydration parameters of the grain of four maize varieties assayed in Cameroon.

Cultivars		Properties*								
		$T_{50\%}$(h)	$T_{75\%}$ (h)	$T_{90\%}$(h)	$T_{100\%}$(h)	Mw (%)	Rw (%/h)	k_1	k_2	R²
CMS 8501	Cal.	4.0 ± 0.5^{a}	12.5 ± 1.5^{a}	36.0 ± 4.5^{a}	65.6 ± 11.0^{a}	59.6 ± 1.6^{bc}				
	Exp.	3.4 ± 0.2^{a}	10.2 ± 0.6^{ab}	30.5 ± 1.8^{a}	nd	58.5 ± 0.9^{b}	14.1 ± 3.8^{b}	0.071	0.021	0.994
CMS 8704	Cal.	$4.3\ \pm0.3^{bcbb}$	13.5 ± 2.6^{ab}	39.0 ± 2.6^{abc}	80.0 ± 13.8^{b}	54.8 ± 1.4^{a}				
	Exp.	$3.7\ \pm0.1^{ab}$	11.0 ± 0.2^{ab}	33.0 ± 0.7^{ab}	nd	54.3 ± 0.3^{a}	11.8 ± 3.9^{a}	0.085	0.023	0.990
Kassaï	Cal.	4.2 ± 0.3^{ab}	14.1 ± 1.0^{b}	37.5 ± 2.6^{ab}	96.0 ± 0.0^{c}	57.1 ± 1.5^{b}				
	Exp.	3.8 ± 0.4^{b}	11.5 ± 1.2^{b}	34.6 ± 3.6^{abc}	nd	56.7 ± 2.4^{ab}	11.9 ± 4.2^{a}	0.084	0.022	0.992
88094xM131xExp24	Cal.	4.5 ± 0.0^{ab}	13.3 ± 0.6^{ab}	40.5 ± 0.0^{c}	96.0 ± 0.0^{c}	59.8 ± 0.8^{c}				
	Exp.	3.8 ± 0.0^{ab}	11.4 ± 0.1^{ab}	34.1 ± 0.2^{c}	nd	58.8 ± 6.6^{b}	12.6 ± 4.2^{a}	0.079	0.021	0.996

* Means (calculated or experimental) with the same letters along the same column are not significantly different at the 5% level of significance

$T_{50\%}$, $T_{75\%}$, $T_{90\%}$, $T_{100\%}$= Time to reach 50, 75, 90 and 100% water absorption by maize grain; Mw = Maximum water absorption (%) by maize grain; Rw = Rate of water absorbtion (%/h) by maize grain; k_1, k_2 = water absorption kinetic constants; Cal. = Calculated value;

Exp.= Experimental value; nd = not determined.

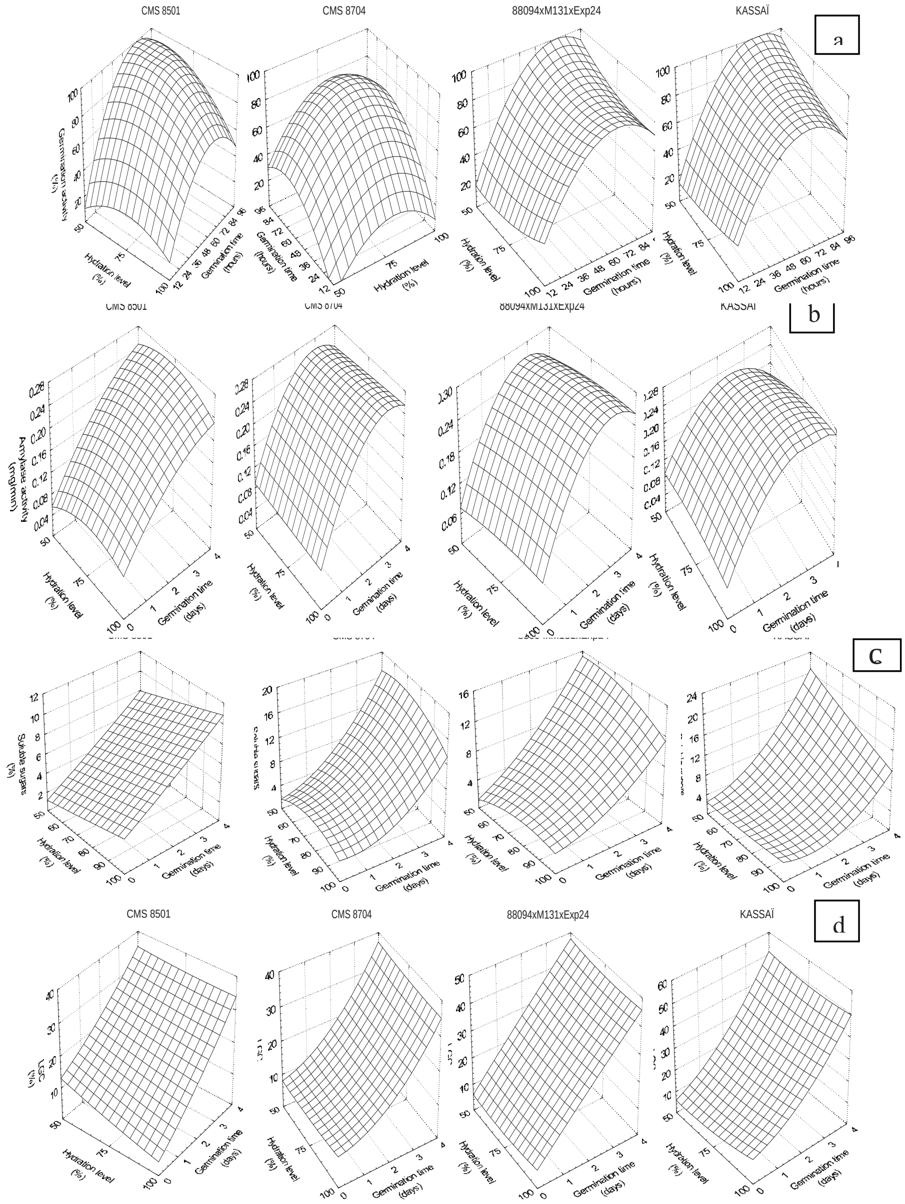

Figure 2. Response surface plot of the effects of grain hydration level and germination time on (a) germination activity (b) amylase activity (c) soluble sugars and (d) least gelatinisation concentration (LGC) of four maize cultivars (CMS 8501, CMS 8704, Kassaï and 88094 x M131 x Exp24) assayed in Cameroon.

Variation in germination activity

The germination activities (GA) of the maize cultivars are shown in Figure 2. Hydration level significantly (*P*<0.05) affected GA, which varied among the maize cultivars from 0.0 to 92.0%, 2.67 to 89.67% and 8.0 to 79.67% at 50%HL, 75%HL and 100%HL respectively. Appreciable variation among the cultivars was found on the first day of germination. In general, the peak of GA occurred on the second day at 50%HL with samples from 88094 x M131 x Exp24 and Kassai. There was no significant increase in GA after the second day regardless of the HL. Previous studies on maize revealed peaks of GA of 80, 70 and 60% at 25, 30 and 35°C respectively on third or fourth day (Wang and Fields 1978). At a constant temperature, sorghum showed peaks of GA of 25, 30 and 20% respectively between the second and fourth day. Kumar *et al.* (1992) found for 26 sorghum cultivars, peaks of GA between 33 and 100% after the third day. The study by Ilori *et al.* (1990) showed maximum GA varying between 85 and 96% after 18 h for sorghum. The differences between the results of these earlier workers, especially those involving maize, and those found in the present study may be due to differences in the genetic material and/or processing method.

Variation in amylase activity

Amylase activity (AA) is the most important factor affecting malt quality. During germination this enzyme is produced and acts on the starch to alter its properties. The AA of the malt obtained from the maize cultivars used in this study is presented in Figure 2b. The AA increased from 0.06 mg/ml in unmalted maize grain to maximum values of 0.27 and 0.28 mg/ml on the second day of germination at 75% HL for CMS 8704 and 88094 x M131 x Exp24, respectively. A longer germination period (3-4 days) was required for optimum AA of the remaining HL and for the other varieties. Thus, both HL and cultivar had significant ($P<0.05$) effects on the AA of maize. Malted flour from 88094 x M131 x Exp24 at each HL, followed by those of Kassai and CMS 8704 at 100%HL had the highest AA. CMS 8501 had the least AA at all HL and germination periods. The AA decreased significantly ($P<0.05$) after the fourth day for all the HL and cultivars except for CMS 8704 at 100% HL. This indicates that prolonged germination beyond 3 days may reduce the enzyme activity. These data suggest that AA development during germination varied with different hydration level, steeping duration and cultivar, thus corroborating previously reported results obtained for sorghum (Olaniyi and Akinrele 1987; Subramanian *et al.* 1992; 1995; Iwuoha and Aina 1997). Contrary to the earlier reports on sorghum, however, the correlation coefficient between AA and GA ($r = 0.72$) in the present study was positive and statistically significant.

Iwuoha and Aina (1997) obtained maximum AA on the second day and a peak of GA on the fifth day. Beta *et al.* (1995) observed no correlation between AA and GA after three day of germination of sorghum. These authors found that sorghum kernels with higher test weights retained more density and solids after malting; however, their malts had lower α-amylase activities. In the present study, 88094 x M131 x Exp24 followed by CMS 8704 appeared to possess the potential to serve as source populations for amylase-rich flour to be used for specific purposes such as formulation of infant formulas.

Variation in soluble sugar content

The effect of malting conditions on the soluble sugar (SS) contents of the different cultivars is shown in Figure 2c. The SS was significantly ($P<0.05$) influenced by the experimental factors. The SS content of the ungerminated grain varied from 1.73 to 4.01%. The SS values increased as the length of the germination period increased. CMS 8501 had the lowest SS values for all the HL. On the fourth day of germination, this cultivar showed maximum SS contents of 7.26, 10.94 and 9.74% at 50% HL, 75% HL and 100% HL, respectively. For the same period, 88094 x M131 x Exp24, CMS 8704 and Kassaï had maximum SS content of 17.77, 21.34 and 25.23% at 50% HL, 75% HL and 50% HL, respectively. These differences in SS percentage may be explained on the basis of the fact that AA increased with length of germination, producing more soluble extracts (sugars and proteins) as previously described for maize and sorghum (Ilori *et al* 1990; Aniche and Palmer 1990). During cereal germination, the solubilisation of endosperm reserve protein is accompanied by increased accessibility and invariably increased susceptibility of the reserve starchy material to the action of endogenous amylase (Palmer 1989). Starch undergoes modifications characterized by partial conversion into maltose and other sugars. This mechanism is more important with the development of endogenous enzymes (Marero *et al*). Indeed, the correlation coefficient between SS and AA content was r=0.51. Similar results were reported for maize and sorghum by earlier workers (Palmer and Bathgate 1976; Okolo and Ezeogu 1996), although the results contradict those reported for sorghum by Subramanian *et al.* (1992).

Variation in least gelatinisation concentration

The least gelatinisation concentration (LGC) is an index of the gelling tendency of flour, which is an important characteristic in the processing of weaning food since there is only a partial conversion of starch during germination. The effect of malting conditions on LGC is presented in Figure 2d. The LGC values varied from 5.19 to 46.13% and 8.09 to 52.15% for 88094 x M131 x Exp24 and Kassai, respectively. The maximum LGC on the fourth day were obtained at 50% HL. The results indicate a significant ($P<0.05$) effect of the experimental factors on LGC. The LGC increased with germination time, with that of 88094 x M131 x Exp24 and Kassai being higher on the fourth day and at 50% HL. The results suggested that strength of the gel formed after cooking of maize malted flours decreased with the duration of germination. Among the factors, germination time had the largest influence on the variation of LGC. The increase in LGC had a negative relationship with starch, but positive relationships with AA (r=0.70) and SS (r=0.80) during germination. Starch has been recognized as the major substrate responsible for the gelatinisation of products under hydrothermal treatments (Cabrera *et al.* 1984; Ngoddy and Onuoha 1985; Tatsadjieu 1997). Njingtang and Mbofung 2003). This effect of enzymatic hydrolysis has previously been reported (Lasekan and Lasekan 2000; Traore *et al.* 2004).

Conclusion

Effects of malting conditions were studied in order to define suitable processing conditions necessary to develop amylase-rich flours from agronomically improved Cameroonian maize cultivars. The results from the study showed that germination is a principal factor influencing the improvement in the nutritional value of maize. The extent of improvement is conditioned by the hydration level, maize cultivar and duration of germination. Germination time had the greatest effect and brought about increased amylase activities and soluble nutrient contents through the degradation of storage reserves in the grain. The soluble sugar value as well as least gelatinisation concentration increased with germination time in all cultivars. These factors are of equal importance in influencing properties of the nutritional and functional profile of malted flours. Grain samples from 88094 x M131 x Exp24 and CMS 8704 produced amylase-rich flours with the best properties and are, therefore, potential sources of good ingredients for the production of weaning foods commonly made from whole maize flours. The performance of the amylase-rich flours in the preparation of gruels is currently being evaluated.

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Effects of wheat flour replacement, maize cultivar and fermentation time on the characteristics of *Makala*, a Cameroonian fried dough product

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Abstract

The objective of this study was to investigate the possibility of using Cameroonian varieties of maize (*Zea mays* L.) to develop composite flour for the production of *Makala*, a deep fat-fried, fermented dough. The study was a 4 x 5 x 5 factorial with four maize cultivars (CMS 8806, CMS 8501, CMS 9015 and CMS 8704), five levels (0, 10, 20, 30 and 40%) of replacement of wheat (*Triticum aestivum* L.) flour with maize flour and five fermentation periods (0, 30, 60, 90, 120 min). The flour samples were analysed for physico-chemical and functional properties; the dough samples were kneaded as commonly practiced in Cameroon, manually molded into balls and divided into two groups. One group was fermented and later evaluated for dough swelling capacity. The other group was fried after 90 min of incubation and analysed for physical (weight, diameter and density) and sensory (color, taste, flavor, firmness and overall acceptability) properties. Results of the study showed that all the properties were significantly ($P<0.05$) affected by the three factors. Proteins, lipids and ash contents of the composite flour reduced significantly as the maize flour proportion increased. Similarly, dough swelling capacity and *Makala* density decreased with increased maize proportion in the composite flour, regardless of the fermentation time and maize variety. In contrast, water absorption capacity of the composite flour increased as the proportion of maize flour increased. The *Makala* produced from the composite flour had overall acceptability scores of 4.2 to 2.8 on a five-point hedonic scale, with the *Makala* prepared from CMS 8806 and CMS 8704 having the highest sensory scores.

Résumé

Cette étude a été menée afin d'évaluer la possibilité d'utiliser une ressource locale (le maïs) pour développer une farine composée adéquate pour la fabrication de *Makala* (beignet de pâte fermentée). Un dispositif factoriel 4x5x5 soit 4 cultivars de maïs (CMS 8806, CMS 8501, CMS 9015, CMS 8704), 5 degrés de substitution (0, 10, 20, 30, 40% de maïs) et 5 temps de fermentation (0, 30, 60, 90, 120 min) a été utilisé. Les propriétés physico-chimiques et fonctionnelles des farines ont été analysées. Les pâtes obtenues par pétrissage ont été modelées en patons puis réparties en deux lots. Un lot a servi au suivi du gonflement pendant la fermentation. Le second lot a été soumis à la friture après 90min d'incubation. Les *Makala* produits ont été analysés pour leur propriétés physiques (masse, diamètre et densité) et sensorielles (couleur, goût, odeur, texture et acceptabilité générale). Les résultats montrent l'existence d'une influence significative ($P<0,05$) des variables sur les paramètres étudiés. Les teneurs en protéines, lipides et cendres sont réduites dans les farines composées après addition de farine de maïs. Une tendance inverse a été observée pour la capacité d'absorption d'eau. Le gonflement des pâtes composées est ralenti pour les niveaux de substitution croissants, indépendamment des variétés et temps de fermentation. Les *Makala* composés présentent des notes d'acceptabilité entre 4,2 et 2,8 sur une échelle hédonique à 5 points. Les *Makala* contenant les farines de CMS 8806 et CMS 8704 ont obtenu les meilleures notes sensorielles.

Introduction

The method used to produce indigenous foods can contribute significantly to the improvement of the nutrition and well-being of the population, especially when the end product has high acceptability, good storage characteristics and low cost. One such food product is *Makala,* a deep fat-fried, fermented dough, which is widely eaten by children as well as adults in West and Central Africa, especially in Cameroon (Lopez 1996). It is produced by women, using simple methods. It has high acceptability and desirable functional and storage characteristics, but is made from imported wheat flour, which is expensive and hardly affordable by the rural dwellers. Consequently, village women have developed composite flour for *Makala* production. Several studies have been conducted on the characteristics of bread produced from composite flour (Mpongo 1987; Tiekoura 1990, 1994; Keregero and Mtebe 1994; Iwuoha *et al.* 1997; Carson *et al.* 2000) but not on *Makala*. Research aimed at producing composite flour from wheat and local cereals to be used as a suitable starting ingredient for *Makala* preparation could greatly contribute to improve the food variety and accessibility, resolving the food insecurity problem posed by postharvest and importations.

In north Cameroon, maize (*Zea mays* L.) production has increased tremendously and presently accounts for over 65% of cereal consumption (Abraao 1994). The quality of maize grain varies considerably and this is attributable to genetic factors, environmental influences, level of agronomic practices during production (for example, fertilizer application), degree of milling and storage conditions (FAO 1993). With the continuous release of maize cultivars, by research stations, it is essential to determine the quality characteristics of new cultivars in order to assess their potential for domestic, small-scale and industrial uses. Several reviews of the literature on cereal flour production have been published (Watson 1984; Munck 1995 *inter alia*) and wet-milling has been found to be the most frequently used processing technique in northern Cameroon. Maize flour obtained by this semi-mechanized method is usually processed into couscous (semolina or thick paste) and porridges (Ndjouenkeu *et al.* 1989). Although different types of fried dough products consumed daily in Cameroon (such as *Makala, Cen-cen, Taara-pott-en, Wardi, Wayna*) have been described (Lopez 1996), information on use of composite flours in the preparation of these products are lacking. The objectives of this study were to evaluate the effects of (i) wheat flour replacement by maize flour and (ii) differences among flours made from Cameroonian improved maize cultivars on the properties of *Makala*.

Materials and Methods

Maize grain and wheat flour source

Grain samples from four maize cultivars (CMS 8806, CMS 8501, CMS 9015 and CMS 8704), obtained from the Institute of Agricultural Research for Development (IRAD) in Garoua, Cameroon, were analyzed in this study. These cultivars were grown under the same environmental conditions and fertilizer rates. Commercial baker's wheat flour (12% protein), sugar, salt and vegetable oil were purchased from the local market.

Pre-treatment of grains and production of maize flours

Flours were produced from the maize cultivars as illustrated in Figure 1a (Ndjouenkeu *et al.* 1989). Dry grains were cleaned of debris, washed using clean tap water and dehulled (Engelberg type dehuller, France). Dehulled grains were then soaked in clean tap water (4 h, 1:3 w/v) and partially sun-dried for 4 h. The grains were milled using a hammer mill (Manucycle, Cameroon). The resulting whole flours were sun-dried for 6 h, passed through a 400µm sieve and then mixed thoroughly with wheat flour to form composite flour, using a bakery mixer (Bonnet, Villefranche Sur Saône, Type 450A34, France). For the purpose of the study, the composite flour was mixed in the ratios 90:10, 80:20, 70:30 and 60:40 w/w wheat:maize flours. Wheat flour was used as the control. The composite dough samples were later prepared as commonly done in Cameroon.

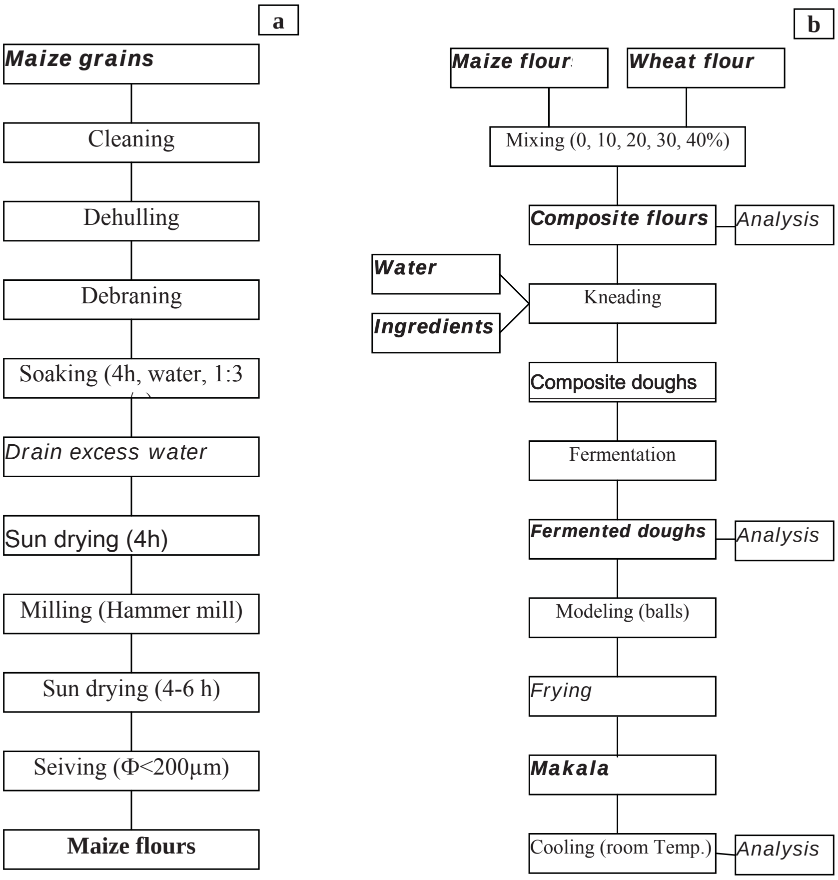

Figure 1. **Flow diagram for the production of (a) maize flour and (b) composite *Makala*.**

Dough kneading, fermentation and frying

The processes for the preparation of batter for the doughnuts are illustrated in Figure 1b. The dough ingredients were 13.5% sugar, 0.5% instant bakers' yeast and 0.3% iodised salt. Prior to dough preparation, the ingredients were mixed with clean tap water for 3–5 minutes. The water absorption capacity was determined as described by Phillips *et al.* (1988) and the amount of water (53.3 to 65.3%) was adjusted accordingly. An appropriate mass of flour was then moistened with the above solution and kneaded for 2-3 min. The dough was finely whipped for 10 min using a fork mixer (Bonnet, France). The dough samples were manually shaped into balls of 40 g and divided into two groups. One group was subjected to various fermentation periods of 0, 30, 60, 90 and 120 min in graduated glass cylinders placed in an oven (Memmert, Germany) set at 30°C. The other group was fried for 5 min in vegetable oil (*Diamaor*, Sodecoton, Cameroon), after 90 min of incubation in stainless steel plates. Fermentation periods were selected on the basis of assays conducted by a local processor. The resulting products (flours, dough and *Makala*) were analyzed for their physico-chemical, functional and sensory properties.

Physico-chemical and functional analysis

The dehulling and milling rates of the maize samples were calculated as follows:

$$\text{Dehulling rate} = \frac{\text{(weight of dehulled grains)} \times 100}{\text{(weight of whole grain)}}$$

$$\text{Milling rate} = \frac{\text{(weight of milled flour sifted to 400 µm)} \times 100}{\text{(weight of dehulled grain)}}$$

The weight of 1000 grains was taken after which whole and composite flours were analyzed for moisture, proteins, lipids and ash contents, using standardized methods of analysis (AOAC 1990). Total carbohydrate was calculated by the difference method (Egan *et al.* 1981). Water absorption capacity (WAC) was determined according to Phillips *et al.* (1988). The dough swelling capacity (DSC) was measured according to the modified method of Delhaye *et al.* (1984).

Physical and sensory analysis

The weight and diameter of the fried products were measured and their density calculated. Sensory evaluation was conducted by a 12-member panel randomly drawn from the staff members of the Institute in Garoua, who were familiar with the taste of *Makala* prepared from conventional wheat flour. The selected panelists underwent a training course on how to evaluate the organoleptic characteristics of *Makala* samples. Five sensory attributes were evaluated, including flavor, color, taste, firmness and overall acceptability. The intensity of each attribute was scored on a scale of 1 (extremely disliked) to 5 (extremely liked). About 40 g of each product was presented to each panelist in coded white disposable plates without any additional ingredient. Water was provided to the panelists for rinsing their mouths between samples. Whole wheat *Makala* samples were used as control for comparison.

Statistical analysis

All measurements were replicated three times and the data obtained were subjected to the analysis of variance to test for the effects of the experimental factors on the measured properties. Duncan Multiple Range Test was used to separate the means. Statistical analyses were carried out using the SPSS (1993) statistical package.

Results and Discussion

Physico-chemical characteristics

The physico-chemical composition of the maize and wheat flours is presented in Table 1. The maize cultivars were significantly different for 1000 grain weight as well as dehulling and milling rates. These traits are recognised as indexes of the technological efficiency of grains. The observed variability for the traits was influenced by both genetic and environmental effects thus confirming earlier reports (FAO 1993). On a comparative basis, there was no significant difference ($P>0.05$) between moisture and protein contents of the maize flour. The protein values obtained in the present study were lower than the 7.5% obtained for the maize flour in the study reported by Ndjouenkeu *et al.* (1989), perhaps because of different genotypes used in the two studies. Maize flours are usually low in lipid and ash contents. Incorporation of maize flour into wheat flour significantly ($P<0.05$) reduced the protein, lipid and ash contents of composite flours as the level of maize substitution increased. Similar results were reported for *bro*, the bread made from composite flour containing 40% maize (Tiekoura 1990; 1994).

Water absorption capacity

For most flours, the quantity used in food preparation depends to a large extent on their water absoption capacity (WAC) during the process of hydration. Water absorption capacity plays a major role in the food preparation processes. Figure 2 shows the values of WAC of the composite and wheat flours in this study. The lowest values were obtained for the wheat flour whereas those obtained for composite flours involving CMS 8806 were the highest, followed by CMS 8704. These results compare very well with previous reports (Enwere 1998), and confirm that, with these products, starch rather than proteins played a more important role in water absorption contrary to what was reported by Mbofung *et al.* (2002). Many other authors reported that, at room temperature or during cereal heat treatment, proteins in flours are mainly responsible for the bulk of water uptake and to a lesser extent the starch and cellulose (Sefa-Dedeh and Osei 1994; Sefa-dedeh *et al*. 2001; Martin and Fitzgerald 2002).

In the present study, flour hydration appeared to be affected by genotypic differences in starch properties and flour particle size as observed in sorghum by Fliedel *et al.* (1989). Njingtang *et al.* (2001) noted that flour of finer particle size would be expected to have a larger surface area in contact with water. Grain moisture during milling is also an important factor affecting flour particle size index (Fliedel *et al*. 1989). Njouenkeu *et al.* (1989) reported that for grain moisture contents ranging from 15.9 to 20.5%, the amount of maize flour passing through 500µm sieve decreased from 50% to 25%.

Table 1. Physico-chemical properties of maize and wheat flour (means±sd)*.

Cultivars	Properties							
	Dehulling yield (%)	Flour yield (%)	1000 Grain weight (g)	Carbohydrates (%MS)	Moisture (%MS)	Proteins (%MS)	Lipids (%MS)	Ash (%MS)
CMS 8806	72.1±1.5^{c}	57.3±1.2^{b}	188.4±0.9^{a}	78.5±0.3^{b}	13.9±0.0^{c}	4.1±0.3^{a}	2.5±0.2^{a}	0.7±0.0^{b}
CMS 9015	70.8±2.0^{a}	63.3±2.1^{c}	287.6±2.2^{c}	79.1±0.1^{bc}	13.5± 0.4^{b}	4.6±1.0^{a}	2.4±0.0^{a}	0.5±0.0^{a}
CMS 8501	71.3±1.1^{b}	57.1±1.1^{b}	305.8±3.1^{d}	78.6±0.3^{b}	14.1± 0.1^{c}	4.1±0.1^{a}	2.7±0.1^{a}	0.3±0.0^{a}
CMS 8704	72.7±1.5^{c}	49.2±1.9^{a}	271.7±0.4^{b}	78.4±0.2^{b}	13.1±0.0^{b}	4.7±0.4^{a}	3.4±0.1^{b}	0.4±0.1^{a}
Wheat	-	-	-	70.4±0.1^{a}	12.9±0.1^{a}	12.0±0.1^{b}	3.8±0.1^{c}	0.8±0.0^{c}

* Means in the same column with different superscripts are significantly different at the 0.05 probability level.

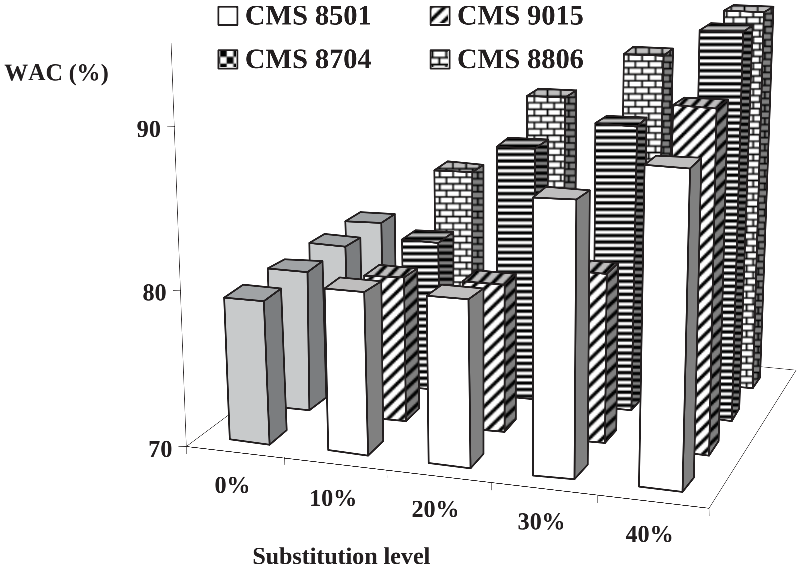

Figure 2. Variation in water absorption capacity (WAC) of wheat (0%) and composite flours from Cameroonian maize varieties.

Dough swelling capacity during fermentation

The interaction of fermentation time and proportion of maize flour substitution on dough swelling capacity (DSC) are presented in Figure 3. The two factors significantly ($P<0.05$) influenced the properties of the fermented dough. Generally, the DSC decreased as the incubation time and maize flour proportion increased. Composite dough from CMS 8806 showed the lowest decrease in DSC while higher decreases were obtained with CMS 8704 and CMS 9015. Decreases in DSC could be attributed to lower gluten content as the level of maize flour substitution increased in the composite flour, as earlier reported by Tiekoura (1990). It has also been reported that fermentation is strongly related to the dough composition (Pyler 1979; Delhaye *et al.* 1984) and that dilution of the gluten network affects dough volume and gas retention, thus resulting in lower dough rising at high substitutions (He and Hoseney 1991). In sorghum, however, an inverse trend was observed for composite dough with the addition of vital wheat gluten to reinforce the gluten network and gas retention, resulting in higher volume (Cheong and Sun 1998; Carson *et al.* 2000).

Makala *physical and sensory attributes*

The sensory analysis used in this study provided a basis for determining the sensory characteristics important for acceptance of *Makala* and was an aid in identifying the effect of maize variety and substitution level in the composite doughnut. The physical properties of *Makala*

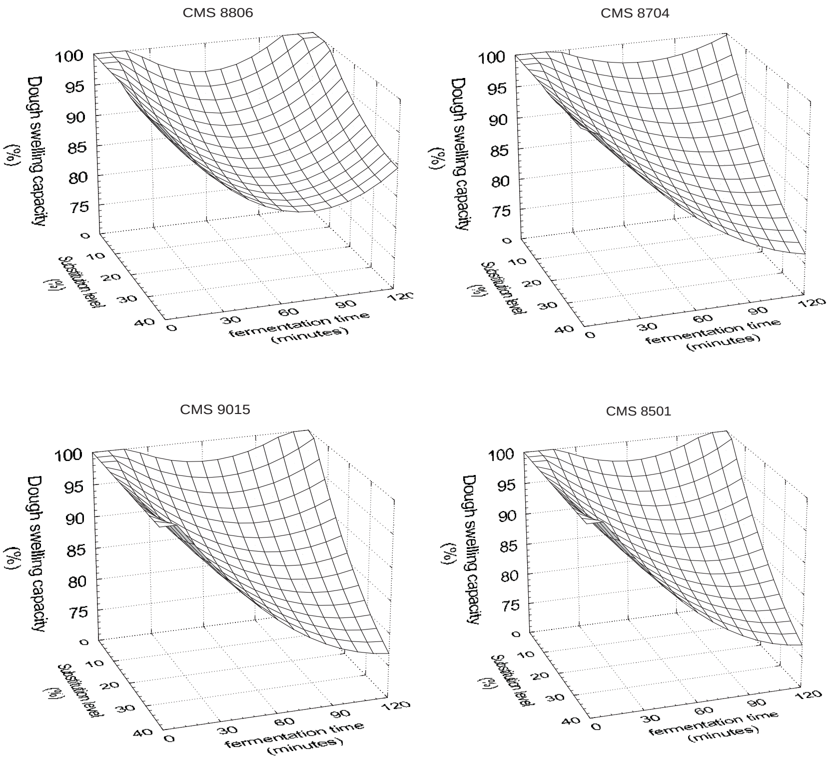

Figure 3. **Variation in dough swelling capacity as affected by flour substitution level, fermentation time and maize cultivar.**

are presented in Figure 4 and the sensory scores are shown in Table 2. Analysis of variance showed significant ($P<0.05$) effects of the experimental variables on the properties measured. The effect of proportion of substitution appeared to be more important than the effect of maize cultivar, although substitution level had no effect on the weight of the composite *Makala*. Relative to the control, there was a slight but significant increase in the weight of the composite *Makala*.

As the level of maize substitution increased, the density and sensory attributes tended to decrease. In general, *Makala* containing 10% and 20% maize received similar scores as the control (data not shown). Comparable results were reported on 20% and 30% sorghum composite bread (Foda *et al.* 1987; Iwuoha *et al.* 1997). At 30% substitution level, the doughnuts made from CMS 8806 and CMS 8704 composite flours had similar scores. *Makala* containing 40% maize flour received a low rating from all the panellists due to its flavor and firmness. A similar observation was made with 40% sorghum composite bread by Keregero and Mtebe (1994), who concluded that bread with 40% or less sorghum flour ranked above 70% in acceptance relative to the standard 100% wheat bread. More than 40% replacement of wheat flour by composite flour resulted in

Table 2. Sensory scores of *Makala* samples containing 0%, 30% and 40% flour from four Cameroonian maize varieties.

	0%	30%				40%			
Sensory score	Wheat	CMS 8806	CMS 8501	CMS 8704	CMS 9015	CMS 8806	CMS 8501	CMS 8704	CMS 9015
Color	4.11	3.98	3.20	3.86	3.90	3.64	3.11	3.42	3.06
Firmness	3.99	3.90	3,00	3.85	3,10	3.87	2.18	3.58	2.05
Taste	4.22	4.00	3.66	4.01	3.83	3.24	2.46	2.86	2.81
Flavor	4.11	4.02	3.78	4.00	3.61	3.10	2.60	2.92	2.45
Overall acceptability	4.33	4.10	3.02	3.96	3.12	3.11	2.80	2.98	2.86

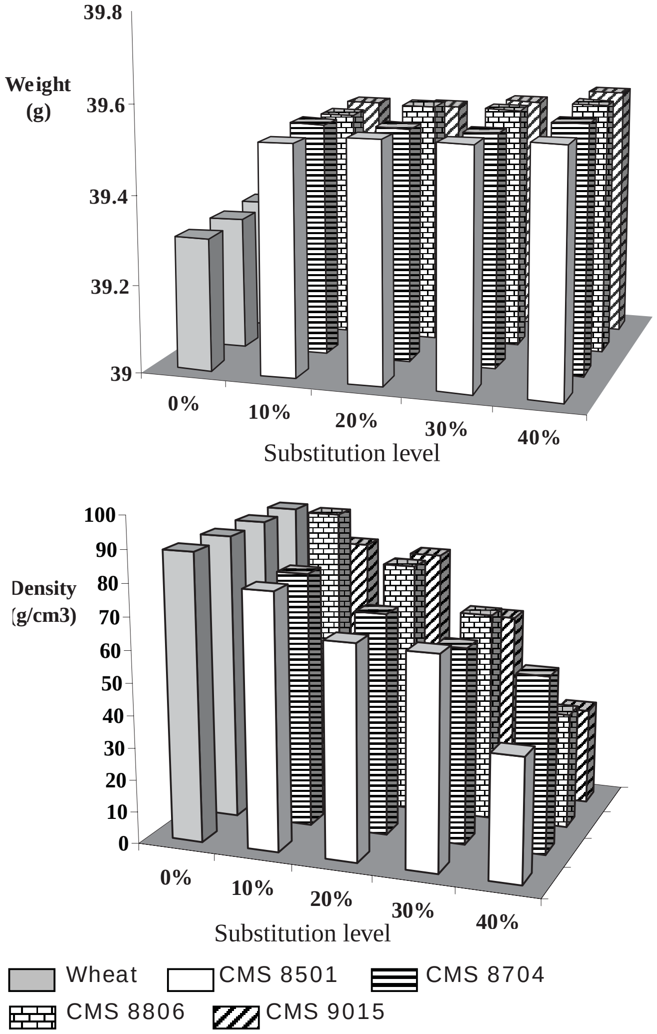

Figure 4. Variation in weight and density of *Makala* as affected by substitution level.

unacceptable products with less than 62% acceptance due to the low density of the products. Carson *et al.* (2000) produced bread from 50% sorghum composite flour. The product was given a general acceptability mean score of 6.9 on a nine-point hedonic scale. The *Makala* from maize composite flour in the present study received an overall acceptability scores between 2.8 and 4.2 on a five-point hedonic scale. Therefore, *Makala* made from composite flour containing maize, to a large extent, is satisfactory to the consumers in Northern Cameroon.

Conclusion

Improved maize cultivars from Cameroon were used to prepare composite flours for *Makala* production and the effects of cultivar and processing methods on flour properties were evaluated. Substitution level affected the product properties more than cultivar differences.

Sensory evaluation results showed that the *Makala* from all cultivars and maize flour substitution levels were acceptable to consumers, although the *Makala* with best sensory properties was obtained from CMS 8806 and CMS 8704. Therefore, replacing wheat flour with up to 40% maize flour is acceptable for *Makala* production in Cameroon.

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Adaptation et utilisation de variétés de maïs riches en protéines (QPM) en zone de forêt de Côte d'Ivoire : bilan de deux années d'expérimentation

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Résumé

Les variétés de maïs Obatanpa, DMR-ESR-W et EV99-QPM ont été introduites chez une trentaine d'agriculteurs durant la petite saison des pluies dans la zone forestière humide de la région de Gagnoa. Ces tests avaient pour objectifs d'évaluer les performances agronomiques et la préférence des consommateurs. Aucune différence significative en rendement grain n'a été obtenue entre Obatanpa (2.5 t /ha) et la variété locale (2.65 t /ha). Les rendements des variétés précoces DMR-ESR-W et extra-précoce EV99-QPM variaient entre 0.5 t /ha à 2 t/ha. Les rongeurs, les foreurs de tiges et les brûlures de feuilles dues au champignon *Helminthosporium* ont constitué les principales contraintes à la production du maïs QPM. Les agriculteurs ont montré leur préférence pour les variétés QPM, d'une part à cause leur goût sucré et la qualité de leur farine, et d'autre part pour leur cycle relativement court et les bonnes perspectives de débouchés qu'elles offrent. La marge bénéficiaire par hectare était de 35100 FCFA et la marge par kilogramme de 60 FCFA. Le ratio bénéfice/coût était de 25%. Par ailleurs, l'introduction du QPM dans l´alimentation des poulets de chair a permis d'observer un gain en poids de 120 g au bout de 7 semaines par rapport au maïs ordinaire. Les modèles de régression de la croissance des volailles ont montré une supériorité de l'aliment renfermant la variété Obatanpa. Ces premiers résultats montrent de bonnes perspectives d'adaptation et d'adoption des variétés de maïs QPM dans la zone forestière de Côte d'Ivoire.

Abstract

Three improved varieties of maize (*Zea mays* L.), Obatanpa, DMR-ESR-W and EV99-QPM were introduced to about 30 small-scale farmers during the short rainy season in the humid forest zone of the Gagnoa region of Côte d'Ivoire. The objective was to evaluate the agronomic performance and consumer preference of the varieties. No significant difference was obtained between the grain yield of Obatanpa (2.5 t /ha) and the local variety (2.7 t /ha), which was used as the check. Grain yield of the early variety DMR-ESR-W and the extra–early variety EV99-QPM varied between 0.5 t /ha and 2 t/ha. Rodents, stem borers and rust disease incited by *Helminthosporium*, constituted the main constraints to the production of QPM maize varieties. Farmers showed preference for QPM because of its sweet taste, the quality of its flour, its relatively short growth cycle and the good market prospects. The profit margin from growing QPM was 35100 FCFA per ha and 60 FCFA per kg. The cost/benefit ratio was 25%. Relative to normal endosperm maize, a weight gain of 120g was obtained 7 weeks after the introduction of QPM into broiler chicken feeds. The regression models of chicken growth showed a nutritional superiority of the food containing QPM variety, Obatanpa. These preliminary results indicate good prospects for the adoption of QPM varieties in the forest zone of Côte d'Ivoire.

Introduction

Le maïs est la céréale la plus cultivée à travers le monde après le blé et le riz. En Afrique occidentale et centrale, il occupe 21% des terres cultivables et fait partie des aliments de base des populations, avec une consommation moyenne par habitant de 28 Kg/an (World maize facts and trends, CIMMYT 1999/2000). Le maïs est aussi utilisé dans l'alimentation des animaux et comme matière première dans les industries. C'est une excellente source d'énergie pour les hommes et les animaux. Selon les estimations, le besoin en maïs dans les pays en développement devrait atteindre 504 millions tonnes en 2020 (FAOSTAT 2004).

En Côte d'Ivoire, le maïs est la deuxième céréale la plus cultivée après le riz. La production annuelle estimée à 600 000 t est destinée à 68% pour l'alimentation humaine. Environ 10% de la production est utilisée dans l'alimentation animale. Pendant longtemps, le maïs était principalement cultivé dans les régions du Nord où il constitue la base de l'alimentation de la population. Avec les mouvements inter-régionaux des populations, la culture du maïs s'est répandue vers le centre-ouest, le centre et le sud du pays. La zone Centre Ouest représente 50 % des quantités de maïs commercialisées où les aliments de volaille constituent la principale demande (Fusillier 1994). La disponibilité en terre, l'installation des populations du nord ayant le maïs comme aliment de base, le développement rapide du secteur privé pour sa collecte et sa complémentarité dans les systèmes de production avec les plantes pérennes comme le café et le cacao ont fortement contribués à l'expansion rapide de cette culture en zone forestière (Fusillier 1994).

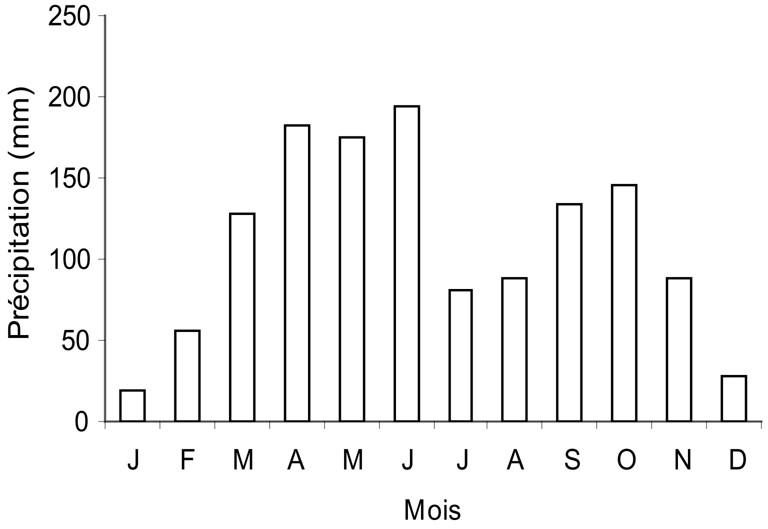

Figure 1. Distribution mensuelle des pluies à Gagnoa (moyenne de 2003 et 2004) .

Depuis 2000, le Quality Protein Maize (QPM) à grains blancs, vulgarisé au Ghana sous le nom de Obatanpa a été introduit en Côte d'Ivoire pour répondre aux besoins des éleveurs. Ce maïs riche en protéines possède un taux élevé en lysine et tryptophane par rapport au maïs ordinaire (NRC 1988). Des tests variétaux et des essais d'utilisation de ce type de maïs ont été initiés en deuxième cycle dans la zone forestière, au centre ouest du pays, en 2003 et en 2004. Cette étude vise donc à déterminer les caractéristiques agronomiques de ces variétés de maïs, définir les critères de leur appréciation par les paysans pour sa culture et sa consommation, et démontrer l'importance du QPM dans l'alimentation animale.

Materiéls et Méthodes

Zone d'étude

L'étude a été conduite dans la région de Gagnoa (latitude : 06 08'N ; longitude : 05 57' ; altitude : 205m). Les caractéristiques géographiques, climatiques et pédologiques de cette région sont celles de la moyenne Côte d'Ivoire pré-forestière. Le climat est tropical humide. L'humidité moyenne est de 85% avec de fortes variations saisonnières. La température varie entre 19 et 33°C avec une moyenne de 27°C. Le régime pluviométrique est bimodal avec une grande saison des pluies d'avril à juillet et une petite saison des pluies de mi-septembre à mi-novembre. Les précipitations oscillent entre 1400 mm et 1600 mm (Figure 1).

Dans cette région, la forêt primaire a fortement régressé laissant la place à une jachère essentiellement constituée de dicotylédones avec une dominance de *Chromolena odorata* (Ndabalishe 1995). Les sols sont de type ferralitique. L'horizon humifère est peu épais mais riche en matière organique. Les sols ont en général une bonne fertilité avec cependant des risques de carence en phosphore par endroit.

Au plan socio-économique, l'agriculture de plantation est dominée par les allochtones venus des régions du Centre et du Nord de la Côte d'Ivoire et des allogènes venus des pays limitrophes (Burkina Faso, Mali). La main-d'œuvre agricole salariée est essentiellement composée d'allogènes. La densité de la population est très élevée dépassant 70 habitants/m^2.

Les systèmes de production agricole sont diversifiés. Les cultures d'exportation (café, cacao, banane) coexistent avec les cultures vivrières (maïs, igname, banane, riz, manioc, cultures maraîchères). L'encadrement des paysans est assuré par l'Agence Nationale pour le Développement Rural (ANADER) et certaines Organisations Non Gouvernementales.

Tests agronomiques

Une trentaine d'agriculteurs sélectionnés en collaboration avec les services de vulgarisation intervenant dans la région ont participé à l'expérimentation au champ pendant deux années. Chez chaque agriculteur, un dispositif en bandes parallèles contiguës a été adopté. Les variétés de maïs (Obatanpa, EV99 QPM, DMR, témoin local) ont été fertilisées avec 200 kg/ha d'engrais NPK suivi de 50 kg/ha d'azote sous-forme d'urée au 45$^{\text{ième}}$ jours. La densité de semis était de 0,8m entre les lignes et 0,5m sur la ligne avec deux grains par poquets. Les semis se sont déroulés en septembre et les récoltes en décembre. Le niveau d'attaque des maladies et des insectes a été relevé en utilisant une échelle de 1 à 5 (1 pas d'attaque et 5 forte attaque). La hauteur d'insertion des épis et la taille maximale des plants ont été mesurées à maturité. Le rendement grain a été estimé à partir du poids des épis et le taux d'humidité. Les analyses statistiques ont été effectuées à l'aide de procédures dans Genstat (2003)

Tests d'utilisation du QPM dans l'alimentation des animaux

Sur la volaille. Les animaux d'expérience étaient de 300 poussins chair d'un jour, répartis en 2 lots de 150 animaux chacun. Chaque lot a reçu l'un des aliments proposés (lot témoin : aliment à base de maïs ordinaire, lot QPM : aliment à base de maïs à protéines de qualité). En station, les animaux consommant chaque type d'aliment sont répartis en 3 sous lots, à raison de 50 bêtes par sous lot, pour minimiser les variations de consommation au sein des mangeoires. Chez le paysan les deux lots ont été maintenus. Les animaux étaient pesés chaque semaine. L'essai a duré 49 jours. Il a comporté une phase de démarrage d'une durée de 28 jours, suivie d'une phase de croissance. A chaque phase correspond une formule alimentaire donnée. Un programme de prophylaxie sanitaire a été observé. Les quantités et le mode d'administration des aliments ont été conformément aux pratiques en vigueur chez les éleveurs et en fonction de la période de démarrage et de croissance-finition.

Sur les porcins. Les animaux d'expérience étaient composés de 16 porcelets sevrés, de même âge, issus de deux portées et répartis en 2 lots de 8 animaux. Chaque lot a reçu l'un des aliments proposés (lot témoin : aliment à base de son de maïs ordinaire ; lot QPM : aliment à base de maïs QPM où le son de maïs a été remplacé par le maïs QPM). La ration était servie aux animaux selon la technique à la ferme. Elle se faisait à l'aide d'une boîte servant de mesures des ingrédients constitutifs de l'aliment. Ces différentes mesures ont été pesées afin d'établir la correspondance en proportion d'aliments. Les ingrédients se composaient de son de maïs, de son de riz, de la farine de poisson, de sel et de prémix. L'essai a duré 3 mois. Les mesures ont débuté après une phase d'adaptation de 5 jours. Avant de lancer l'expérimentation, les animaux ont été regroupés, pesés, et des numéros leur ont été attribués au hasard. La ration alimentaire était distribuée chaque matin à 9 heures après le nettoyage des loges et l'après midi à 15 heures. Les animaux disposaient d'eau à volonté et les pesées étaient faites une fois par semaine, le matin du même jour avant la distribution des repas.

Aspects socio-économiques

Les enquêtes sur la production du maïs QPM ont été réalisées auprès de 12 agriculteurs à Boutroclo et à Onytabré dans la region de Gagnoa. De même pour l'étude de la consommation, les données ont été collectées auprès de douze personnes au terme d'une séance de dégustation de mets préparés à partir du maïs QPM. La méthodologie de collecte de données a été par des enquêtes à passage unique et des enquêtes à passages répétés. Les données relatives à la production se rapportent aux éléments démographiques (ethnie, âge, sexe, niveau d'instruction, profession, etc) ; aux entrées et sorties (charges fixes et variables, production, prix, vente, autoconsommation) ; aux modes de financement et de règlement de transaction ; aux actifs et passifs à court, moyen et long terme ; aux cycles et réseaux de commercialisation ; aux motivation ; à la réceptivité à l'innovation et aux contraintes.

Pour l'étude de la consommation, les données se rapportent aux éléments démographiques (origines, âge, sexe, niveau d'instruction, profession) ; aux critères de choix des variétés, au degré d'appréciation du maïs QPM, à la fréquence de consommation et aux projections de consommation future de maïs QPM. Des données primaires ont été au besoin complétées par des données secondaires contenues dans les études précédentes. Pour l'identification des opérateurs et des systèmes de production et de consommation, les calculs de proportion ; moyenne; écart-type ; tests de Student ont été utilisés.

Les performances économiques des exploitations ont été appréciées par l'analyse de ratio tirés des comptes d'exploitation, bilan, temps des travaux. L'évaluation de la productivité des facteurs et du degré d'intensification est faite par le calcul des ratios d'intensité d'utilisation et de productivité des facteurs suivants. C/T (Intensité capitalistique), C/S (Intensité d'utilisation du capital), T/S (Intensité d'utilisation du travail), P/T (Productivité physique du travail), P/C (Productivité physique du capital), P/S (Rendement à l'hectare), VP/L (Productivité monétaire du travail), VP/C (Productivité monétaire du capital), VP/S (productivité monétaire de la terre). Avec : C : le capital, T : le travail, S : la superficie, P : la production, V : la valeur monétaire. L'évaluation de la rentabilité est faite par le calcul de divers ratios que sont le bénéfice net d'exploitation, la marge par kg, le ratio bénéfice/coût et des ratios de valorisation des facteurs. Les ratios de valorisation des facteurs sont exprimés par:

$$TRT = (BNE - I) / T$$
$$TRF = (BNE - COT) / FP$$

Avec TRT (le taux de rémunération journalière du travail), TRF (le taux de rémunération des fonds propres), BNE (le bénéfice net d'exploitation), I (l'intérêt sur les fonds propres), COT (le coût d'opportunité du travail), FP (les fonds propres), T (le temps de travail).

L'intérêt (I) est calculé en appliquant aux fonds propres un taux d'intérêt (i) correspondant au coût d'opportunité du capital diminué du taux de croissance annuelle de la valeur des fonds propres. Le coût d'opportunité du capital est le taux accessible en investissant dans des secteurs alternatifs ayant des risques comparables. Le coût d'opportunité des fonds propres est estimé au taux d'intérêt sur la forme d'épargne bancaire la plus généralisée (i = 3 %). Le coût d'opportunité (COT) est calculé en appliquant au travail familial ou du comité un taux r correspondant au taux moyen de salaire agricole dans la région (r = w.d/n, avec w le taux de salaire en période de demande d'emploi agricole salarié ; d la durée de la période de pointe agricole, n le nombre de jours ouvrables pour le travail agricole dans l'année).

Resultats et Discussions

Tests agronomiques

Le Tableau 1 présente les caractéristiques agronomiques des différentes variétés. Une bonne croissance a été observée en général. La variété Obatanpa et DMR ont un cycle semis maturité de 106j et 95j, avec une période de 53j et 50j pour la floraison femelle respectivement. La variété EV99 est la plus précoce avec un cycle de 90 jours et 46 jours pour la floraison femelle. Les variétés témoins sont des maïs jaunes de 120 jours. La hauteur maximale des variétés QPM est sensiblement plus réduite et le niveau d'insertion de l'épis significativement plus bas (< 1m du sol) par rapport aux variétés locales. Au niveau parasitaire, des attaques d'insectes (niveau d'attaque : 2) ont été observées sur les épis dont les extrémités étaient partiellement recouvertes par les spathes. De même, des brûlures de feuilles provoquées par le champignon *Helminthosporium* (niveau d'infection : 3) et la rouille (niveau d'infection : 2), ont également été observés. Cependant, ces attaques n'ont pas eu d'effets très néfastes sur les rendements. Sur les deux années, les rendements de 2.5 t/ha (Obatanpa), 2.3 t/ha (DMR) ne sont pas significativement différent de la variété locale (2.6t /ha). Des dégâts de rongeurs (Aulacodes) ont été observés principalement sur les parcelles QPM. Ces résultats ne montrent pas de grandes variations du cycle végétatif de la variété Obatanpa qui est estimé à 105 jours (Twumasi *et al.* 1997).

Utilisation du maïs QPM

Croissance des poulets de chair. Les compositions des aliments utilisés sont indiquées dans le Tableau 2. Aucune analyse bromatologique de ces aliments n'a été effectuée. Néanmoins, les valeurs calorifiques des aliments proposés ont été estimées en tenant compte des données existantes sur les ingrédients constitutifs (INRA 1978). Ainsi, l'aliment démarrage dose 21% de protéines brutes pour une teneur en énergie métabolisable de 2793 kcal /kg. Pour l'aliment croissance, sa valeur azotée est estimée à 19 % des Matières Azotées Totales (MAT), pour une dose de 2906 kcal/kg d'énergie métabolisable.

En station, il a été observé un taux de malformations anormalement élevé (plus de 10%) parmi nos oiseaux en expérimentation, ce qui a eu une incidence sur leur évolution normale. L'analyse montre une différence non significative entre les deux lots d'animaux (Tableau 3). Néanmoins, au bout des 7 semaines, l'évolution des poids moyens des animaux consommant le maïs QPM affiche un surplus de près de 120 g par rapport à leurs congénères du lot maïs ordinaire. Cette différence de poids ne peut être due qu'au maïs QPM, puisque tous les

Tableau 1. Caractéristiques agronomiques moyennes des variétés de maïs cultivées chez des paysans en zone forestière de Côte d'Ivoire.

Variétés	*Nbre* de paysans	Cycle (jours)	Floraison femelle (jours)	Floraison mâle (jours)	Hauteur plants (cm)	Hauteur épis (cm)	Rendement grains (kg/ha)
Année 1	12						
Obatanpa		105-108	53	56	263 (11.3)*	108 (8)	2565 (561)
Témoin local		120-122	60	57	298 (19.6)	139 (12)	2832 (489)
Année 2	18						
Obatanpa		106	52	56	211 (16.5)	101 (6)	2375 (662)
EV99-QPM		90	46	43	160 (14.3)	60 (4)	1955 (320)
DMR-ESR-W- QPM		95	50	49	154 (8.6)	77 (5)	2322 (196)
Témoin local		120	59	58	304 (6.8)	142 (20)	2632 (404)

* les valeurs entre parenthèses représentent l'écart type

Tableau 2. Proportions des ingrédients de différents aliments offerts aux poulets de chair.

Ingrédients	Aliment de démarrage (%)	Aliment de croissance (%)
Maïs*	58	60
Tourteau de coton	14.5	12
Tourteau de coprah	3	5
Son de blé	9.5	11
Farine de poisson	12	10
Coquillage	1.5	1.1
CMV	0.5	0.5
Sel	0.3	0.4
Total	100.00	100.00

* Maïs ordinaire ou maïs QPM
Pour l'aliment de démarrage :
Valeur azotée estimée = 21 % MAT
Valeur énergétique estimée = 2793 kcal /kgMS (EM)
Pour l'aliment de croissance :
Valeur azotée estimée = 19 % MAT
Valeur énergétique estimée = 2906 kcal /kgMS (EM)

Tableau 3. Evolution du poids moyen de deux lots de poulets chair dont l'une reçoit une alimentation à base de maïs QPM et l'autre du maïs ordinaire (MO).

Age (jours)	QPM (g)	MO (g)	QPM – MO (g)
1	36.6	36.6	0
7	92,7	86,8	5.9
14	190,2	174,6	15.6
21	373,8	315,3	58.5
28	532,2	480,5	51.7
35	707,2	670,6	36.6
42	985,3	891,0	94.3
49	1229,2	1111,1	118.1

autres ingrédients sont identiques dans les deux formules alimentaires comparées. En fait, le maïs ordinaire et le maïs QPM dosent tous environ 10% de protéines ; la différence entre ces deux aliments vient de ce que le second est plus riche en lysine et en tryptophane (CRI 1996), deux acides aminés essentiels dont les volailles ont le plus grand besoin.

La supériorité de l'aliment à base de maïs QPM est aussi mise en evidence par son indice de consommation qui est plus faible que l'aliment à base de maïs ordinaire (Tableau 4). La comparaison de l'indice de consommation observé dans le lot QPM avec ceux rapportés par Osei (1994a et 1994b) montre que notre formule est plus efficace.

Tableau 4. Indices de consommation de deux lots de poulets chair dont l'une recevait une alimentation à base de maïs QPM et l'autre du maïs ordinaire

	Lot QPM			Lot maïs ordinaire		
	S/lot 1	S/lot 2	S/lot 3	S/lot 4	S/lot 5	S/lot 6
Indice de consommation (IC)	2,31	2,39	2,60	2,95	2,88	2,70
IC moyen		2,43			2,84	

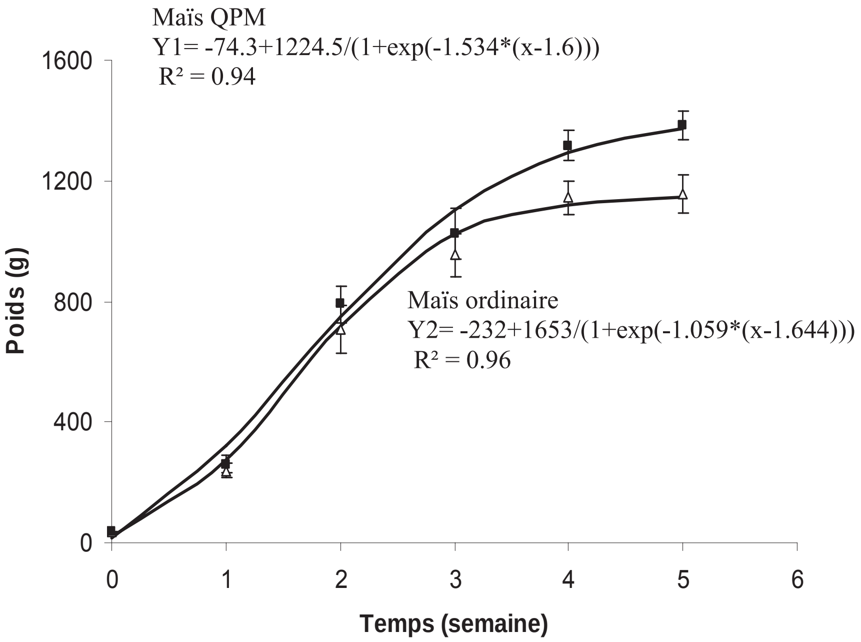

Figure 2. Evolution du poids en fonction de l'age des poussins.

En milieu paysan, un gain en poids plus rapide des oiseaux nourris au maïs QPM a été également observé (Figure 2). Ce gain peut être raisonablement décrit par une fonction logistique en fonction du temps avec un coefficient de correlation superieur a 0.94. Ainsi donc au bout de 35 jours, les poulets nourris au QPM avaient un poids (1.4 kg) significativement différent de celui des poulets nourris au maïs normale (1.1 kg).

Chez les porcins

Les compositions des aliments utilisés sont indiquées dans le Tableau 5.

Après 2 semaines, les poids moyens des animaux dans les deux lots montrent un gain de poids de 380 g pour le maïs QPM contre 260 g pour le maïs ordinaire. Ceci indique que le taux de croissance initial des animaux nourris au QPM est plus élevé que celui de ceux

Tableau 5. Composition de l'aliment offert aux lots expérimentaux de porcins.

Ingrédients (%)	Lot I (témoin)	Lot II
Son de maïs	48,7	-
Maïs QPM	-	48,7
Son de riz	48,7	48,7
Farine de poisson	2	2
Sel	0,35	0.35
Prémix	0,25	0.25
Total	100,00	100,00

Tableau 6. Les indices de consommation observés chez les porcs nourris avec du maïs QPM et ceux recevant une alimentation à base de maïs ordinaire.

	Lot maïs ordinaire	Lot maïs QPM
Gains de poids (kg)	0,670	0,710
Aliment consommé (kg)	3,890	3,96
Indice de consommation	5,81	5,58

nourris au maïs normal. Cette différence due au maïs QPM confirme la qualité nutritionnelle de l'aliment contenant cet ingrédient puisque tous les autres ingrédients sont identiques dans les deux formules alimentaires. La supériorité de l'aliment à base de maïs QPM est aussi reflétée par un indice de consommation plus faible (5,58) que dans l'aliment à base de maïs ordinaire (5,81) (Tableau 6).

Caractéristiques socio-économiques des exploitants

La dimension socio-économique des exploitants comprend les éléments démographiques, l'expérience, le niveau d'instruction, la profession, et les motivations.

Eléments démographiques

De manière générale, les exploitants (chefs d'exploitation) sont exclusivement des hommes (100%) autochtones (100%). L'âge moyen est de 40 ans ce qui représente 57% des exploitants à Boutroclo et 75% à Onytabré.

Niveau d'instruction et catégories socio -professionnelles

Les exploitants sont en majorité des lettrés (91%). 73% ont le niveau d'études secondaires. Presque tous ont une longue expérience en matière de culture de maïs local blanc et de maïs jaune vulgarisé par l'ANADER. Ils pratiquent l'agriculture de rente (café/cacao) et l'agriculture vivrière (riziculture pluviale, manioc, maïs, etc.).

Systèmes d'organisation

Les exploitants de Boutroclo sont regroupés au sein d'une organisation collective mise en place pour l'entraide dans le travail. Dans les deux localités la taille moyenne d'un ménage est de 7 personnes dont 1 seul actif adulte homme et 1.5 actives adultes femmes. Très peu de jeunes participent aux activités pour cause de scolarisation.

Critères d'identification et de choix des variétés

Généralement, les paysans ont deux principaux critères d'identification des variétés: la couleur des grains (blanc et jaune) et la forme des épis. Ensuite viennent la taille du plant et la forme des feuilles. Le choix des variétés est fait par les paysans selon la durée du cycle, les rendements élevés et les perspectives de débouchés.

Contraintes en facteurs de production

Les contraintes au développement de la culture du maïs évoquées par les producteurs sont le travail, le capital et la présence des ravageurs (rats palmistes et autres). La terre n'est pas considérée comme un facteur limitant par les exploitants qui sont tous des propriétaires terriens cultivant eux-mêmes leurs terres.

Contrainte en capital

L'autofinancement est la règle dans le secteur. Le capital constitue le facteur limitant qui entraîne l'inaccessibilité des intrants agricoles et des équipements modernes de production à la majorité des petits agriculteurs.

Contrainte en travail

Les exploitants utilisent majoritairement la main-d'œuvre familiale sur les fermes paysannes. Pour les essais, l'essentiel du travail est fait par le groupe des exploitants. Le travail salarié est utilisé en appoint pour les activités les plus pénibles. La rémunération est de 1 000 FCF F/jour pendant la période du labour. Le travail est contraignant pour des raisons de main-d'œuvre. La main-d'œuvre familiale est souvent insuffisante pour exploiter de grandes superficies. De plus, la scolarisation entraîne une raréfaction de ce type de travail. La contrainte en capital circulant limite les possibilités d'accès à la main-d'œuvre salariée. L'offre de travail salarié est de plus en plus limitant.

Systèmes de culture

La culture du maïs est une activité traditionnelle dans la zone d'étude. Les systèmes de culture sont très diversifiés. En général, le maïs est cultivé en association avec le riz pluvial. Certains agriculteurs pratiquent la monoculture en rotation avec le riz. Le maïs blanc se cultive essentiellement pour l'autoconsommation. Elle se fait en association

Tableau 7. Coûts financiers de production du maïs QPM et du maïs jaune.

Indices	Maïs QPM Essai à Boutroclo (0.25 ha)		Maïs jaune Ferme paysanne à Boutroclo (1.5 ha)	
	Montant	%	Montant	%
Coûts variables	30 100	87	30 000	62
Main d'oeuvre		45		62
Intrants		42		0
Coûts fixes	4 625	13	18 500	38
Total	34 725	100	48 500	100

avec le riz pluvial. La culture du maïs jaune pour la commercialisation date de 1994 dans la région avec l'encadrement de l'ANADER. Les agriculteurs pratiquent la monoculture. La culture du maïs QPM est en essai en milieu paysan depuis 2003. Pour cette phase de pré vulgarisation, les paysans pratiquent la monoculture.

Réseaux de commercialisation primaire

La production de maïs jaune est entièrement écoulée sur le marché de Gagnoa par les intermédiaires commerciaux qui viennent s'approvisionner bord champ.

Performances économiques

Les coûts de production de maïs QPM s'élèvent à 30 100 FCFA soit, en extrapolant dans l'hypothèse de fixicité des coefficients techniques de production, 120 400 FCFA/ha (Tableau 7). Ils sont majoritairement composés de coûts variables (87%) dont 42% sont des intrants et 45% de la main-d'œuvre rémunérée. La faiblesse des coûts fixes (13%) s'explique par le fait que le travail se fait manuellement avec un équipement modeste (machettes, dabas et limes).

Intensité d'utilisation et productivité des facteurs

Comme cela ressort du Tableau 8, la productivité des facteurs est faible alors que les facteurs de production sont abondamment utilisés sur la parcelle de l'essai. Par contre, on remarque une forte productivité des facteurs et une faible intensité capitalistique sur la ferme paysanne.

L'inexpérience des opérateurs dans la culture de la variété de maïs QPM explique en partie la faible productivité constatée car l'expérience personnelle est un facteur déterminant dans la maîtrise de nouvelles méthodes productives. La contrainte en facteurs de production est manifeste. Rappelons que la croissance soutenue de la production agricole ivoirienne qui a permis de se hisser au rang de premier producteur mondial de cacao et troisième producteur mondial de café en quelques décennies a été rendue possible pour l'essentiel par une

Tableau 8. Ratios d'intensité d'utilisation et de productivité des facteurs.

Indices	Maïs QPM Essai à Boutroclo (0.25 ha)	Maïs Jaune Ferme paysanne (1.5 ha)
C/T (FCFA/Jour)	516	182
C/S (FCFA/ha)	138 900	32 333
T/S (jours/ha)	269	177
P/T (kg/jours)	2.15	5.8 (²)
P/C (kg/ FCFA)	0.004	0.03 (²)
P/S (kg/ha)	580	1026 (²)
VP/T (FCFA/jour)	647	1 056
VP/C	1.25	5.8
VP/S (FCFA/ha)	174 000	187 300

C/T : intensité capitalistique, C/S : intensité d'utilisation du capital, T/S : intensité d'utilisation du travail, P/T : productivité (physique) du travail, P/C : productivité (physique) du capital, P/S : rendement à l'hectare, VP/T : productivité monétaire du travail, VP/C : productivité monétaire du capital, VP/S: productivité monétaire de la terre Avec,

C : le capital investi (34 725 FCFA pour l'essai et 48 500 FCFA pour la ferme paysanne), T : le travail (67.25 journées pour l'essai et 266 pour la ferme paysanne), S : la superficie (0.25 ha pour l'essai et 1.5 pour la ferme paysanne), P (²) : la production (145 kg de grains secs pour l'essai et 1 540 pour la ferme paysanne). Pour la ferme paysanne, en plus des grains, il faut comptabiliser aussi les 3 000 épis vendus frais, VP : la valeur monétaire de la production (43 500 FCFA pour l'essai dont les grains sont vendus à 300 FCFA/kg de QPM et 281 000 FCFA pour la ferme paysanne dont les grains sont vendus à 150 FCFA/kg de maïs jaune).

augmentation des superficies exploitées et non une réelle mutation technologique. Aujourd'hui, tous ces facteurs sont contraignants avec une particulière acuité dans la zone d'étude en raison de son importance relative dans l'économie cacaoyère. La pression foncière est forte avec des densités de population atteignant 100 hab./km² par endroits. Le capital aussi est contraignant de sorte que l'intensité capitalistique est faible. Le travail se révèle être le principal facteur de différenciation sociale et le principal déterminant du choix des combinaisons productives. Or, le facteur travail est lui aussi contraignant, notamment du fait de la raréfaction de la main d'oeuvre allogène. L'acceptation d'une innovation dépend aussi bien de son accessibilité et donc de son adéquation avec les contraintes des paysans que de sa rentabilité. En effet, en matière de choix technologique, le meilleur système est celui qui utilise intensément le facteur abondant et augmente la productivité du facteur rare. Les taux de valorisation des facteurs obtenus sur les essais en milieu paysan se comparent défavorablement avec les coûts d'opportunité de ces facteurs.

Le facteur terre

Théoriquement, la valeur économique de la terre peut être estimée au coût de référence puisque dans cette zone le marché du foncier est relativement développé. Aussi, le prix du marché reflète-t-il la disposition des demandeurs à payer et est de ce fait une bonne estimation de la valeur économique. On peut aussi déterminer la valeur économique de la terre à la valeur nette des productions réalisables par unité de superficies. Si elle est estimée au coût de référence, le prix d'achat est d'environ 100 000 FCFA/ha dans cette zone, ce qui correspondant à trois années de bénéfices de production de maïs QPM. Si c'est la valeur nette des productions réalisables par unité de superficies qui est retenue, nous pouvons estimer la valeur économique de la terre au produit monétaire net d'un ha de cacao qui est de l'ordre de 40 000 FCFA/ha/an (le produit monétaire brut d'un ha de cacao est actuellement de 160 000 FCFA (400 kg/ha × 400 FCFA/kg) et le coût de production est d'environ 120 000 FCFA/ha (300 FCFA/kg × 400 kg/ha)). Ce montant n'est pas statistiquement différent de celui obtenu avec le maïs QPM.

Le taux de rentabilité du travail familial obtenu (130 FCFA/j) est inférieur au taux accessible par la main-d'œuvre agricole. Ce taux est de 1000 FCFA/j pendant 3 mois de plein emploi du travail agricole salarié, soit un taux annuel de 320 FCFA/j. Sur les fermes de production de maïs jaune, les paysans obtiennent une rémunération de 760 FCFA/j.

Déterminants de la consommation

La dimension socio-économique des consommateurs montre que les consommateurs sont issus de diverses aires socio culturelles et de diverses catégories socio professionnelles. On enregistre une grande diversité de préférences et une variabilité de la consommation selon les origines ethniques. Elle porte sur le goût, l'état, la finesse et l'odeur de la farine. De manière générale, les consommateurs préfèrent acheter le maïs frais braisé ou la pâte (tô). Cette dernière forme de cuisson est particulièrement appréciée par les consommateurs allochtones du nord de la Côte d'Ivoire et les allogènes. Le maïs QPM est très apprécié par les consommateurs. 40% lui trouvent un goût bon, et 50% un goût excellent. Le maïs figure au menu quasi quotidien de nombreux consommateurs, notamment la pâte (tô) régulièrement consommée par 63% des personnes enquêtées (Tableau 9). La consommation est occasionnelle pour les autres formes de cuisson (épis braisés ou bouillis, et bouillie). Cependant, la volonté des personnes enquêtées est de consommer quotidiennement ou quasi quotidiennement du maïs QPM sous divers formes de cuisson (Tableau 9). Comparé au maïs normal, les consommateurs, dans leur grande majorité, lui trouvent un goût excellent. Les perspectives de débouchés sont donc très bonnes.

Tableau 9. Distribution des consommateurs selon la fréquence de consommation actuelle de maïs en général (en %) et selon la fréquence de consommation souhaitée de maïs QPM (en %).

	Epis braisés	Epis bouillis	Pâte (tô)	Bouillie	Yaourt	Gâteau	Poudre
Consommation actuelle							
Quotidien	18	-	36	-	-	-	-
Plusieurs fois par semaine	-	-	27	-	-	-	-
Occasionnellement	27	18	-	-	-	-	-
Rarement	9	9	9	100	-	-	-
Pas de consommation	46	73	28		-	-	-
Total	100	100	100	100	-	-	-
Consommation désirée de QPM							
Quotidien	36		36	18	9	-	-
Plusieurs fois par semaine	64	100	27	27		-	-
Occasionnellement	-	-	37	55	81	100	100
Pas de consommation	-	-	-	-	-	-	-
Total	100	100	100	100	100	100	100

Conclusion

Notre étude montre que les maïs QPM peuvent convenir au deuxième cycle de culture dans la zone forestière. La pression parasitaire n'est pas forte et les rendements sont équivalents au maïs jaune déjà vulgarisé dans la zone et provenant probablement de la population 28.

Au niveau de l'alimentation animale, les résultats obtenus indiquent une supériorité du maïs QPM sur le maïs ordinaire. En effet, en plus des gains de poids plus élevés enregistrés avec cet aliment, les indices de consommation (IC) montrent que l'aliment à base du maïs QPM est plus efficace que l'aliment à base de maïs ordinaire. Par ailleurs, les IC obtenus dans les deux rations, comparés à ce qui est rapporté dans la littérature, indiquent que ces rations sont très efficaces. Toutefois, il a été noté en station une fréquence anormalement élevée de malformations au niveau des pattes des volailles. Ce phénomène est certainement lié à un apport insuffisant de l'aliment en minéraux ; dans les essais à venir, nous tenterons d'y remédier.

Au niveau socio-économique, il est impératif de prendre en compte les préférences des consommateurs, les contraintes et les motivations des producteurs dans la définition des systèmes à vulgariser.

En outre, les essais devraient se réaliser sur des parcelles individuelles où l'effort de travail est plus manifeste. Sur les fermes collectives en effet, en l'absence d'un système d'incitations sociales ou économiques appropriées, il se développe un phénomène de resquillage. Dans la zone d'étude, près de 91% des exploitants sont lettrés avec un age moyen de 40 ans. Les critères de choix des paysans pour la réalisation d'un champ de maïs sont la disponibilité en maïs de cycle court, les rendements élevés et l'existence de débouchés. L'étude a aussi montré que le maïs est acheté au champ et acheminé à Gagnoa qui est un centre urbain de plus de 400.000 habitants. Le coût de production est élevé à cause de la main d'œuvre, mais la production de maïs demeure une activité rentable. Des efforts doivent être faits pour créer plus de débouchés surtout qu'il existe aujourd'hui en milieu péri - urbain et en milieu rural une réelle dynamique de développement.

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Report and Recommendations

Report and Recommendations on the Fifth West and Central Africa Biennial Regional Maize Workshop held at IITA-Bénin, Cotonou, 3–6 May 2005

Preamble

The Fifth Biennial West and Central Africa (WCA) Maize Workshop took place at the IITA-Bénin Station, Calavi, Cotonou, Benin Republic 3-6 May 2005. About 50 participants from 12 countries attended the Workshop. WCA countries represented included Bénin, Burkina Faso, Cameroon, Côte d'Ivoire, Ghana, Guinea, Mali, Nigeria, Senegal, Tchad, and Togo. One participant came from Kenya and another from Mozambique. In all, 49 scientific/technical papers and several other reports were presented. A Merit Award Ceremony was held to honor members who had made immense contributions to the progress of the Network.

A breakdown of the scientific/technical papers is as follows:

Theme	5
Breeding	7
Agronomy and Physiology	9
Seed Systems and Statistics	2
Integrated Pest Management	7
Economics and Extension	11
Postharvest and Utilization	8

Creating a new section on Seed Systems and Statistics was a welcome idea. In the previous Workshops, this new section had been subsumed in the Breeding Section. Similarly, in line with the terminology in vogue, the Network changed Plant Protection to Integrated Pest Management.

Generally, the presentations were well prepared, well presented, informative, thought provoking and they generated a lot of lively discussion. All presenters used Power Point in preparing their papers and used the LCD projector for the presentation. In sum, the subregion has made further progress in improving maize production and productivity.

Theme Papers

An overview of the activities of the Network for nearly 20 years revealed that considerable progress was made in most subject-matter areas in each of the member countries. It was concluded that the Network had proceeded in the right direction and this should be sustained to raise maize production in the subregion.

Breeding, Seed Production and Statistics

Recommendations from previous workshops

1. More research should be done to determine the factors that influence tolerance of maize varieties to stresses such as acidity, drought and low N.
2. GIS should be used to re-demarcate the ecological zones in the subregion.
3. Efforts should be made to establish at least one biotechnology laboratory in the subregion.
4. Exchange of scientific visits must be encouraged among scientists of the various NARS.
5. The network must call for proposals for research to address recommendations that are yet to be implemented.
6. Need to show much more interest in breeding nutrient-dense varieties.
7. Terminology used in drought stress research needs to be well defined and agreed upon.
8. Morphological traits and their managements in stress breeding need to be investigated.
9. Breeders' rights and farmers' interests vis-à-vis seed production and adoption of improved varieties must be considered.
10. There is the need to simplify the naming of maize varieties.

Advances

1. Significant progress has been made in identifying and developing maize varieties (OPVs, inbred lines and hybrids) with varying levels of tolerance to *low N, soil acidity* and *drought*.
2. Mode of tolerance of maize to soil acidity (Al tolerance) has been identified as both additive and non-additive with predominance of non-additive.
3. The level of *Striga* tolerance in cultivars (OPVs, inbred lines and hybrids) in different maturity groups has been enhanced.
4. The use of herbicide tolerant maize varieties (IR-Maize) has been developed and tested successfully against *Striga hermonthica*.
5. *Quality Protein Maize (QPM)* varieties with varying maturity have been developed and are being disseminated to farmers.
6. Genotypes (inbred lines and landraces) with high *iron, zinc* and *β-carotene* contents have been identified for further breeding work.
7. Training on *QPM* seed identification, production and dissemination has been conducted.

Lessons

1. Maize genotypes resistant to *Striga* are currently in use in some member countries.
2. Member countries are continuing to adopt *QPM* varieties.

3. The community-based seed production scheme has been a very valuable tool in the promotion and dissemination of *QPM* varieties.
4. The importance of seed source on seed quality and productivity of maize has been highlighted.
5. The defects of Genotype x Environment (G x E) interaction can be overcome via a good statistical model.

Challenges

1. Can drought tolerant traits be used for the selection of genotypes under *low N* with special emphasis on stay-green attributes?
2. Could genotypes with *broad-based adaptation for stresses* in the region be identified through the regional varietal screening?
3. Could other reliable criteria (such as the black layer formation, degree-days, milk-layer, etc.) be used to classify maize into different maturity groups more accurately than days to silk?
4. The problems of mycotoxins and storage insects continue to pose challenges in the subregion.
5. Would the establishment of biotechnology laboratories and the use of genetic markers speed up breeding for abiotic and biotic stress tolerance?

Recommendations

1. Breeders must be actively involved in extension and socio-economic studies and impact assessment.
2. Breeding for varieties that are tolerant to storage pests (including insects and microorganism) is needed.
3. Farmer participation in research planning and implementation and evaluation should be encouraged.
4. Farmers and technicians involved in the community-based seed multiplication scheme must be trained in the techniques of seed production, processing and storage.
5. These farmers must be trained to initiate small and medium-scale seed enterprises for sustainability of the scheme.
6. Demonstrations on *QPM* and other nutritionally dense maize varieties should be conducted directly on human beings now that they have been adequately demonstrated on livestock and birds.
7. Capacity of NARS scientists in biotechnology should be further developed through collaboration with IITA.
8. Capacity of NARS scientists in appropriate statistical packages must be further developed through collaboration with IITA.

Agronomy and Crop Physiology

Recommendations from previous workshops

The following tasks from the previous workshops are yet to be fully implemented by member countries.

1. Propose approaches/innovations to enhance farmer-researcher collaboration on-station and result in crop management practices, appropriate to farmers and hence facilitating adoption.
2. Design regional adaptive trials such as maize legume rotations for the control of *Striga* and soil fertility improvement.

Advances

In crop rotation and intercropping schemes, late maturing *Striga* tolerant maize following soybean, cowpea, pigeon pea, groundnut or intercropped reduced the *Striga* menace and produced higher maize yields than sole cropping/farmers' practices.

In low input and nutrient deficient systems, application of organic nutrients (cow dung, *mucuna,* etc.) or rotation with legumes (soybean, cowpea, *centrosema* etc.) and application of inorganic fertilizers could sustain soil fertility and increase maize yields.

Inoculation with mycorrhiza and the use of low doses of inorganic fertilizer can sustain maize production in acid soils of Cameroon.

The better performance of drought tolerant genotypes under sub-optimal N conditions suggests that the selection for drought tolerance may confer tolerance to N deficient conditions.

The identification of P efficient and high N fixing soybean genotypes may interact with other rotation effects to improve yields of subsequent maize. However, there is the need for improved methodology for estimating the nutrient benefits and/or other rotation effects.

There is wide promotion of adoption of maize hybrids and *QPM* among member countries.

Challenges

1. Understanding the dynamics of N and P in cereal–legume rotation.
2. Developing and testing *Striga* tolerant early and extra-early maize varieties.
3. Developing fertilizer management practices.
4. Developing agronomic practices for the dissemination of hybrids and *QPM* technologies.

Recommendations

1. Crop improvement in N fixation by legumes.
2. Crop improvement in legumes response to P.
3. Development of methodologies that better estimate nutrient benefits and other rotation effects.
4. Training of farmers on fertilizer management (type, method, quantity and time of application).
5. The dissemination of hybrids and *QPM* technologies should be incorporated in legume–maize systems. The use of legume species with high N fixing potential should be encouraged.

6. Development and testing of *Striga* tolerant early and extra-early maize varieties.
7. Introduction and testing of IR-maize for *Striga* management.

Economics and Extension

Recommendation from previous workshop

The following recommendation from the previous workshop was yet to be executed.

1. Exchange of socio-economists among WECAMAN member countries.

Lessons learned

1. Existence of viable women farmers' groups, seed producer. groups has been established.
2. Spatial distribution of farm plots and enterprise recombination are identifies as tools for the determination of extent of maize adoption.
3. The main trade/marketing problems are inadequate/poor infrastructure, insecurity and postharvest technologies.
4. Preliminary perceptions indicate high demand for early extra-early *QPM* maize varieties
5. Factors influencing fertilizer adoption have been identified.
6. Factors influencing farmer efficiency in improving hybrid maize production have been identified.
7. Community-based maize seed production is being promoted as a profitable in technology generation could undermine the acceptability and hence adoption of technologies.

Challenges

1. Scaling up of viable women-farmer groups and seed producer groups.
2. Operationalizing linkage between research, extension, input supplies, farmers and other stakeholders.
3. Lack of empirical evidence of adoption (impact) of these varieties in West and Central Africa.
4. Ensuring the sustainability of community-based seed production schemes.

Recommendations

1. More work to scale up viable women-farmer and seed producer groups.
2. There should be a strong linkage between all stakeholders (researchers, extentionists, farmers, input agencies, policy makers, etc.) in the agricultural development system to facilitate sustainability. Suggested strategies are: participatory problem

identification, planning and implementation involving policy makers, researchers, extensionists, input agencies, NGOs and developing NGOs

3. (a) Comprehensive adoption and impact studies are needed; (b) country case study results of previous adoption and impact studies should be presented at WECAMAN workshop.
4. Capacity building (training) of seed producers.
5. Need for greater involvement of farmers (women, youth, marginal, etc.) in technology regeneration and dissemination.
6. Need for research into the role of women in maize production, processing and marketing.

General recommendation

For better publicity, local media should cover WECAMAN workshops.

Postharvest and Utilization

Recommendations from the previous workshop

The following recommendations from the previous workshop were yet to be executed.

1. Each steering committee member should be assigned the responsibility of implementation and monitoring of one of the broad programs of WECAMAN.
2. Identification of appropriate and cost-effective drying and storage methods for effective dissemination in the humid areas.
3. Promotion and extension activities in drying and storage to reduce infection and mycotoxin of grain need to be stepped up to increase maize production.
4. Industrialists, paramedical staff and processors must be invited to future workshops to enhance transfer of technology and effective collaboration.

On the other hand, some progress has been made towards achieving the following recommendations.

1. Early *QPM* varieties should be promoted in low rainfall and marginal areas when they become available.
2. Breeders should consider nutritional enhancement by improving protein, zinc and iron contents and quality. Yellow QPM must be developed and promoted to support accelerated development of the poultry and livestock industries. Work is in progress in that yellow *QPM* is being developed and tested across countries.
3. Physico-chemical and proximate analyses must be conducted for promising varieties for industrial use. In this regard, breeders

should work closely with food technologists, industrialists, and consumer groups in varietal development programs. Value-added production will enhance maize utilization. Work in this line has started in Cameroon and Nigeria and should be continued.

Advances

1. Composite flour for dough product (30% substitution) is now available. Production of amylase-rich flour has been developed and is now available to interested individuals and industrialists.
2. Production process of starch granules is also now available.
3. Use of essential oils in the storage of maize.

Lessons

1. The traditional local agroprocessing items of equipment are not efficient in producing good quality food products.
2. There has been a great demand for yellow *QPM*.
3. There was little or no information on newly developed end-use products.

Challenges

1. The need to make yellow *QPM* varieties available for commercial production.
2. Involvement of industrialists and processors in technology development and dissemination.
3. Building NARS capacity for practical and quick tryptophane analysis.

Recommendations

1. Organize and encourage farmers to have access to various items of equipment for maize production and processing.
2. Identify appropriate and cost-effective drying and storage methods for effective dissemination in the humid areas.
3. Promote further research in the characterization of essential oil in maize storage.
4. Promote *QPM* varieties in all agroecological zones for the use of farmers and industrialists.
5. Breeders should consider nutritional enhancement by improving protein, zinc and iron contents and quality. Yellow *QPM* must be developed and promoted to support accelerated development of the poultry and livestock industries.
6. Physico-chemical and proximate analyses must be conducted for promising varieties for industrial use. In this regard, breeders should work closely with food technologists, industrialists and consumer groups in varietal development programs. Value-added production will enhance maize utilization.