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Sustainable resource management coupled to resilient germplasm to provide new intensive cereal–grain–legume–livestock systems in the dry savanna

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Abstract

Sustainable resource management is the critical agricultural research and development challenge in sub-Saharan Africa. The accumulated knowledge on soil management gathered over the last 10 years, combined with solid crop improvement and plant health research at farmers' level, has brought us to a stage where we can now address with confidence the intensification of cereal–grain–legume-based cropping systems in the dry savanna of West Africa in a sustainable and environmentally positive manner.

Two sustainable farming systems that greatly enhance the productivity and sustainability of integrated livestock systems have been developed and implemented in the dry savanna of Nigeria. These are: (i) maize (*Zea mays* L.)–promiscuous soybean [*Glycine max* (L.) Merr.] rotations that combine high nitrogen fixation and the ability to kill large numbers of *Striga hermonthica* seeds in the soil; and (ii) miflet [*Eleusine coracana* (L.) Gaerth] and dual-purpose cowpea [*Vigna unguiculata* (L.) Walp.]. Improvement of the cropping systems in the dry savanna has been driven by the adoption of promiscuously nodulating soybean varieties (in particular TGx 1448-2E) and dual-purpose cowpea. The rate of adoption is very high, even in the absence of an efficient seed distribution system. The number of farmers cultivating the improved varieties increased by 228% during the last 3 years. Increased production of promiscuous soybean has been stimulated by increased demand from industries and home utilization. Production in Nigeria was estimated at 405,000 t in 1999 compared to less than 60,000 t in 1984. Economic analysis of these systems shows already an increase of 50–70% in the gross incomes of adopting farmers compared to those still following the current practices, mainly continuous maize cultivation. Furthermore, increases in legume areas of 10% in Nigeria (about 30,000 ha in the northern Guinea savanna) and increases of 20% in yield have translated into additional fixed nitrogen valued annually at US$ 44 million. This reflects, at the same time, an equivalent increase in land-use productivity, and with further spread of the improved crops, there are excellent prospects for additional economic and environmental benefits from a very large recommendation domain across West Africa.

Keywords: Soybean; Maize; Cowpea; Natural resource management; Intensification

1. Introduction

Agricultural production systems are intensifying across the different agroecological zones in West

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Africa in response to increases in population pressure, demand, and opportunities for product marketing. In the dry savanna, defined as the area with a growing period between 4 and 6 months, cereal and legume cropping systems are being intensified and old crops replaced by new. Maize and soybean are relatively new enterprises in these systems, while sorghum (*Sorghum vulgare* Pers.), millet, cowpea, and groundnut (*Arachis hypogea* L.) are traditional crops. However, the intensification of land-use systems faces increasing biotic and abiotic constraints, including the need to maintain soil fertility and control the parasitic weed *Striga*.

IITA has a long history of sustainable resource and crop management research. In the 1970s, this led to a better understanding of the bush fallow systems and their role in replenishing soil fertility after a cropping cycle of 3–4 years. During the same period, extensive fertilizer studies were undertaken and recommendations for use were developed. Research on mechanical land clearing practices was carried out, showing (for example) that the use of heavy equipment should be avoided. From the early 1980s onwards, following rapid increases in fertilizer prices and increased environmental concern, interest shifted to low external input systems with emphasis on the biological management of soil fertility. Alley farming, cover crops, and zero tillage received major attention and led to further understanding of appropriate resource management opportunities for the generally poor and fragile tropical soils of West Africa (Lal, 1987; Kang et al., 1990). However, the solutions proposed to farmers for the regeneration of soil fertility were adopted in only a limited manner. In the meantime, increased population pressure led to a continuous reduction in the length of natural fallows, and this, combined with low fertilizer use, resulted in further soil degradation. We learned from comparative work under variable conditions in Nigeria and Bènin that soil-improving fallows needed to have a direct economic benefit (Vanlauwe et al., 2001c). It was, for example, found that *Mucuna* fallows in Bénin were adopted by farmers primarily because of their ability to suppress *Imperata* weeds—an effect that is immediately visible and that has economic benefits the next season—rather than because of the restoration of soil fertility that researchers had in mind (Manyong et al., 1996). We have come to think of a grain legume rotation as just such an economically beneficial fallow. Clearly, the benefit from a grain legume rotation is bound to be lower that that from tree-based or herbaceous legume fallows. But the grain legumes are infinitely more adoptable, and this influenced our decision to work on profiting from (and optimizing) benefits to maize from grain legumes.

The increased knowledge base resulting from these research activities has been used in recent years for the development and implementation of sustainable farming systems. The initial focus of the research work for the last 10 years has been on high-intensity food and forage systems such as cereal–legume systems and crop–livestock systems located on degraded and non-degraded soils in the dry savanna benchmark areas. These areas are chosen because they contain the gradients of land-use intensification in West Africa and because they will enhance the scaling up and extrapolation potential, and offer the most favorable opportunities for successful research.

We hypothesized that, in such a setting, sustainable intensification could come from an integrated use of organic inputs, strategic use of fertilizer, and improved resilient germplasm such as drought-tolerant and N-efficient cereals in combination with dual-purpose grain legumes to provide the necessary organic matter, access less available N and P sources, and at the same time provide a good grain yield to the farmer. The entry point for solving the problem of land degradation and natural resource base deterioration has been the choice of resilient and adoptable germplasm.

The objective has, therefore, been to arrest resource degradation caused by land-use intensification, through the widespread adoption of sustainable natural resource management and crop improvement practices by the disadvantaged farming communities of the dry savanna of West Africa. Our aim is to help ensure that the harvests of farmers within the target regions are larger, more dependable and sustainable, generate greater income, and are readily marketable.

2. Materials and methods

2.1. Site description and cropping systems

The dry savanna has a growing season ranging from 4 to 6 months; it has high solar radiation and relatively low pest and disease pressure with the exception of *Striga*. As such, the zone has good production potential for cereals and grain legume crops, provided management practices can be developed to permit economically profitable and sustainable cropping systems. This zone is also very well suited for crop–livestock integration. In recent years, research in developing, improving, and intensifying the cereal and legume systems has been carried out increasingly in the benchmark areas established under the Ecoregional Program for the humid and sub-humid tropics of sub-Saharan Africa. These have been characterized with respect to socioeconomic conditions and agricultural production to allow the extrapolation of results to similar agroecological zones in other West African countries (Manyong et al., 2001). The dry savanna benchmark areas cover villages that have been characterized by IITA, ILRI/IITA (Cowpea Impact Assessment) and ICRISAT.

Over the last two decades, very significant land-use changes have taken place in this agroecoregional zone. Maize has evolved from being a subsistence crop to a major cash and food crop and currently occupies over 40% of the cultivated land (Manyong et al., 2002). Over the last 10 years, soybean production has increased almost fourfold, while sorghum production has continued to go down. In many instances, the land is now under permanent cropping. These changes have occurred, in particular, in places with good market access, as can be seen from the comparison between two different villages in the benchmark area in northern Nigeria, where Kaya, unlike Danayamaka, has good market access and could take full advantage of new technologies available (Manyong et al., 2001).

In the northern part of the Nigerian dry savanna, cropping is cereal-based with sorghum and millet dominating. Intercropping with grain legumes is common in over 90% of the fields; cowpea, and some groundnut are the most common legume components. These crops provide the grain essential for family food and income, as well as crop residues for livestock feed. Livestock, in turn, make an important contribution to crop production through manure and, at times, traction.

2.2. Technology components

2.2.1. Promiscuous soybean

In the early 1970s, IITA identified soybean as an alternate source of inexpensive high-quality protein for improving nutrition and health, and indeed the livelihoods of rural communities in Africa. Agronomic and breeding research were therefore initiated to develop management practices that would optimize yields and varieties that were better adapted to the African environment. IITA breeders faced two main challenges. These were the need to develop varieties that were: (a) capable of producing effective nodules with the indigenous rhizobia in African soils (promiscuous nodulation) to fix atmospheric nitrogen without the need to inoculate seed with purchased rhizobia inoculum which was neither readily available to the resource-poor farmers nor affordable; and (b) able to maintain their seed viability from harvesting at the end of one season to the next planting season, a condition referred to as seed longevity. High-yielding varieties with promiscuous nodulation and enhanced seed longevity were developed and deployed for cultivation by farmers (Kueneman et al., 1984).

From 1987 to 1993, the International Development Research Centre (IDRC) of Canada and the Japan International Cooperation Agency (JICA) funded a project in which IITA, in partnership with a number of Nigerian institutions, developed new recipes using soybean to enhance the nutritional value and taste of traditional Nigerian dishes without increasing cooking time and cost. This has led to increased local consumption of soybean and has stimulated production and industrial processing of the crop in Nigeria (Smith et al., 1993).

In response to rapidly declining soil fertility and resultant low crop yields in sub-Saharan Africa, IITA breeders in the early 1990s focused on developing improved varieties that fix a high proportion of their nitrogen from the atmosphere, and also reduce the threat from the parasitic plant that attacks cereals (*Striga hermonthica*) by inducing suicidal germination of *Striga* seeds. In addition, these varieties produce large amounts of biomass that contribute to improve soil organic matter. This can be spread in the field or fed to livestock and their manure returned to the field. When these new improved varieties are planted in rotation with maize or sorghum, the productivity and sustainability of crop production is enhanced.

2.2.2. Dual-purpose cowpeas

Until the late 1980s, cowpea breeding at IITA focused on the development of new varieties with high grain yield. Farmers have grown these varieties successfully, provided they had access to the necessary inputs, in particular, insecticide sprays. For the majority of the farmers in the dry savanna this was not the case. The limited adoption of these varieties and the increased recognition of the importance of cowpea fodder for animal feeding led to a complete overhaul of our breeding strategy. They aim became to develop so-called dual-purpose cowpea that produced good quantities of both grain and fodder, with minimum insecticide input. Close collaboration was established with the ILRI team in West Africa to address fodder quantity and quality effectively in the breeding and selection program. It has also been shown that intercropping with a dense growth of cowpea can reduce the multiplication of *Striga* seed and slow the buildup of the seedbank (Weber et al., 1995).

2.2.3. Maize

Early efforts were placed on the development of high-yielding open-pollinated (OP) varieties of maize with resistance to the prevailing major diseases in the humid forest and moist savanna of West and Central Africa. Over the last 20 years, IITA has supplied the region with streak-resistant maize germplasm and technology for incorporating resistance into elite adapted materials. At present, all maize germplasm in use in the region is resistant to maize streak virus. Subsequently, a hybrid maize breeding launched by IITA in 1979, with financial support from the Nigerian Government and active participation of NARS, led to the development and release of first-generation inbred lines and hybrids for West and Central Africa in 1983. IITA has also initiated research activities to breed maize for higher N-use efficiency and *Striga* resistance.

High yielding, improved varieties are sometimes not adopted by farmers because they may lack the desired end-use quality for local food preparations. IITA has worked closely with scientists in Benin Republic to develop a variety acceptable to farmers and consumers. Recently, breeding efforts have been initiated to enhance the micronutrient content of maize varieties, to combat the widespread diseases of iron deficiency anaemia and corneal blindness due to Vitamin A deficiency.

2.2.4. Balanced nutrient management

Two promising BNMS technological options aiming at counteracting N and P depletion have been developed and tested on-station and on-farm for their agronomic robustness in Nigeria, Bénin, and Togo since 1997: (i) the combination of organic and inorganic nutrient sources that allow a saving of about 50% of the cost of fertilizer N; and (ii) the use of less available P or rock-P by grain or herbaceous legumes that appear to have more efficient mechanisms than other crops for extracting P from the soil (Vanlauwe et al., 2001b).

2.2.5. Crop–livestock integration

Three Best-Bet (BB) treatments have been implemented on farmers' fields for the past 4 years in Nigeria, Niger, and Mali. These treatments are: (i) BB+: improved cowpea and sorghum, minimum inputs of fertilizer to sorghum and insecticide to cowpea; row arrangement: two rows sorghum, four rows cowpea, livestock feeding with residues from the trial plots, and return of the manure at the start of the cropping season; (ii) BB–: same as for BB+ but with local sorghum; and (iii) Local (L): (farmers own cowpea–sorghum intercrop). It was recognized that the Best-Bet options would differ from region to region within the dry savanna, depending on the dominant crop species and management practices.

2.3. Integration of component technologies into new cropping and livestock systems

System technologies involve the introduction of new, more productive but sustainable cropping systems in which new maize cultivars bred for improved N-use efficiency are rotated or relay cropped with new food/forage legume crops with low harvest indices (e.g. newly bred promiscuously nodulating soybean and dual-purpose cowpea). These allow positive residual soil-N contributions to the following crops while, at the same time, providing the farmers with seeds and fodder for food and feed, as well as income from marketing these farm products. Another option offered to those farmers who have available manure is the combined application of manure and fertilizer to maize. This practice allows farmers to complement the modest fertilizer quantities they can afford, and to benefit from the synergism occurring when combining the two sources of nutrients.

2.4. Research approach

Several steps were taken to address objectives and the implementation of research activities. In a first series of activities, the target areas were characterized in terms of fertilizer use, soil type, nutrient balances, general soil fertility status, livestock integration, and weed/*Striga* constraints. Based upon this information, farmers were grouped into well-defined typologies, that formed the basis for on-farm experimentation. In a second series of activities, technologies aiming at counteracting nutrient depletion and weed/*Striga* constraints were developed in a multilocational mode to generate new knowledge for the efficient design of management practices that would redress deficiencies and increase soil and crop productivity. Thirdly, any promising technologies were then adapted to the prevailing conditions in the research villages and tested under on-farm conditions in researcher- and farmer-managed modes to examine their agronomic robustness and acceptance by farmers. Fourthly, a selection of Best-Bet technologies was tested on-farm by the farming community to test their socioeconomic robustness. Governmental extension services and/or NGOs working in the field are the major partners in implementing this set of activities.

3. Results and discussion

3.1. Resilient germplasm and cropping systems

Surveys on the current use by farmers of different agricultural inputs show that most farmers (97%) in the dry savanna benchmark site use inorganic fertilizers, although application rates are usually low (on average, 40 kg N ha^{-1}) (Manyong et al., 2001). The use of organic materials in situ is very low, whether in the form of animal manure, green manure, or house refuse. While the release of nutrients from organic amendments gives immediate benefits, the improvement of CEC and soil structure, resulting from the buildup of soil organic matter, is a process taking place over a time scale of 5–10 years and longer. Natural fallows and agroforestry systems have indeed been proven to be able to return significant quantities of organic matter to the soil, but their applicability is limited, in particular in areas where continuous cropping is already practiced. In the dry savanna benchmark areas, locally available sources of organic matter are inadequate to meet farmers' requirements. Leguminous cover crops and trees often do not fit into the socioeconomic conditions of the farmers. Thus, the breeding objectives for grain legumes at IITA have been changed and a program was initiated for the development of so-called dual-purpose soybean and cowpea for the maize and millet cropping systems.

The promiscuous soybean and the dual-purpose cowpea lines that are now available produce about 2.5 t ha^{-1} of grain and 2.5–3 t ha^{-1} of forage and there is every indication that further progress can be made. They fix between 44 and 103 kg N ha^{-1} of their total N and have an estimated net N balance input from fixation following grain harvest ranging from −8 kg N ha^{-1} for the traditionally grown variety IAC 100 to +43 kg N ha^{-1} for an improved soybean variety. Results in 1996 and in 1997 showed that maize growing after soybean had significantly higher grain yield (1.2–2.3-fold increase compared to maize after maize). The ^{15}N isotope dilution method was able to estimate the N contribution of promiscuous soybean to maize. The first crop of maize grown after soybean accumulated an average of between 10 and 22 kg N ha^{-1} from the soybean residue, representing 17–33% of the soybean total N ha^{-1}. However, the total amount of N calculated to be contributed by the soybean residue (between 10 and 22 kg N ha^{-1} on average) could not explain the greater yield increase in maize grown after soybean. Hence, the increased yields of maize following soybean were not entirely due to the carry-over of N from the soybean residue and to the soil-N conserving effect but also included other rotational effects. These "other effects" merit further investigations, so the mechanism by which soybean benefits a succeeding maize crop can be better understood (Sanginga et al., 2002a). Vanlauwe et al. (2001a) and Iwuafor et al. (2002) have shown that it is best to supply about half of the recommended amount of N for maize in the form of organic amendments. This means that 2–4 t ha^{-1} dry matter would be needed, dependent on the nutrient content. However, on average, less than 1 t ha^{-1} is currently used. Topping up the cowpea or soybean residue (equivalent to 45 kg N ha^{-1}) with 45 kg urea-N ha^{-1} was shown to give maize yields similar to those obtained after applying 90 kg urea-N ha^{-1} on the poorest fields. On these fields, a positive interaction was observed between cowpea-N and urea-N sources of 200–547 kg ha^{-1} of maize grain. On the richest fields, the effects of applied organic matter were additive.

Results of the livestock integration work show that the quantities of grain and fodder in the BB treatments involving improved dual-purpose cowpea and minimum input were greater than those in the local treatment (L) (Tarawali et al., 2002). The most dramatic difference was for cowpea grain when the BB+ treatment yielded about 16 times more than the L treatment. The data on livestock feeding indicated that animals on the BB+ treatment gained significantly more weight during the last 6 weeks of the 16-week feeding period than those on L. Analysis of the nutrient dynamics shows strong positive balances for N and P for the BB treatments. At the end of the 1999 crop season, BB+ had a net positive balance of 40.5 kg N ha^{-1} and 14.3 17 kg P ha^{-1} compared to a negative balance for L of −28.3 kg N ha^{-1} and 0.67 kg P ha^{-1}.

However, most soils in the moist savanna lack not only N, but are also P-deficient, in particular in the available P that can be accessed by a maize crop. Soil surveys and P-response experiments in the dry savanna benchmark area, as well as in the derived savanna, confirm the lack of adequate amounts of available P (Vanlauwe et al., 2002). In most soils, amounts are below the critical level of 12 ppm. It needs to be emphasized that the P available in the soil for use by plants usually constitutes only a small fraction of the total soil P. Therefore, at IITA we are exploring the use of germplasm of soybean, cowpea, and some herbaceous legumes such as *Lablab* and *Mucuna*, with the ability to access the sources of P not directly available to plants, through mechanisms mediated by mycorrhizal fungi and organic acid secretion. Soybean varieties have now been identified that can indeed access additional soil P (Abdelgadir, 1998). Comparable results have been achieved with cowpea (Sanginga et al., 2002b). Rotational experiments have shown that the cultivation of the new soybean varieties results in a considerable increase in the number of mycorrhizal fungi in the soil (Sanginga et al., 1999). These fungi assist in making additional P available to the roots.

The on-station and on-farm experiments of the project have identified a number of promising technology options. The benefits from a combined application of urea-N and an organic-N source were demonstrated on-station and on-farm (Vanlauwe et al., 2001a; Iwuafor et al., 2002), as explained above. Also, the potential of legumes in making P from rock-P more available to a subsequent maize crop was shown in multilocational trials (Vanlauwe et al., 2000a, b; Lyasse et al., 2002). In order to bring these technologies to a stage where they can be widely adopted by farmers, it is necessary to translate the ideas into real systems, and information (for example) is needed on the choice of the organic-N source to be mixed with urea or the legume, or the fraction of the required N supplied with the organic-N source.

3.2. Fighting *Striga*

Maize in the dry savanna suffers from very serious losses from the parasitic weed *S. hermonthica*. This is the most severe biotic constraint to maize production in this agroecological zone. The total value of damage caused to crop production in Africa by *Striga* is estimated to be around US$ 7 billion per year (Berner et al., 1996). Maize varieties with partial resistance to *Striga* have been developed. However, strain variation in *S. hermonthica* complicates efforts to develop maize cultivars with stable resistance over wide geographic areas and over time. Resistance needs to be combined with other control strategies to attain sustainable control of *Striga*.

The focus of IITA's integrated control strategy for this problem is crop rotation with selected legume cultivars, in particular, soybean. Soybean can bring *Striga* seeds in the soil to premature, so-called suicidal, germination, and thus reduce the pressure on the following maize crop. When an improved variety of soybean was grown in rotation with maize for only one season, the increase in maize yield was from 1.8 to 3.4 t ha^{-1} (Carsky et al., 2000). When farmers rotate these improved varieties of soybean with their cereal crops, they will also have large increases in cereal yield. Farmers in northern Ghana and Nigeria have already seen the advantage of this crop rotation practice and are now able to obtain good yields with maize and sorghum where they had crop failures in the past due to *Striga*. Very significant variation among soybean cultivars has been found with respect to the capacity to cause suicidal *Striga* germination. Substantial variability in the production of *Striga* stimulant has been identified among soybean lines using laboratory assays. Significant additive genetic variation was detected for resistant traits, indicating that resistance can be improved in a breeding program (di Umba, 2000). Therefore, in the breeding program, lines have been developed that show both superior agronomic performance and high rates of stimulant production. Rotation with these soybean cultivars resulted in significant reductions in emerged *Striga* in the subsequent maize crop.

3.3. Economic evaluation of the technologies

Economic assessment of legume–creal rotations in the dry savanna and in the derived savanna (DS) showed that grain and forage legume rotations were highly profitable production systems with a net benefit up to US\$ 1233 ha^{-1} in the DS at Ibadan (2-year grain legume) and US\$ 765 ha^{-1} in the dry savanna at Shika (2-year forage) (Oyewole et al., 2001). In contrast, fallow and green manure rotations were of little economic benefit, despite their positive residual effect on subsequent maize. Continuous maize cultivation was highly productive and economically viable only at Ibadan, the non-degraded site in the DS. At the degraded site at Shika, grain and forage legume rotations were substantially more profitable than continuous maize. Such legume rotations may, therefore, still produce farmer-acceptable yields and net revenues at sites that are no longer suitable for cereal production. At Kaduna, maize yields after *Mucuna* were higher than after cowpea but the latter system was more economically beneficial. It has been estimated that an early-season cowpea contributes 30 kg N ha^{-1} when immediately followed by maize.

Another experiment was carried out with the involvement of the farmers at Kaya village in the dry savanna in Nigeria. Costs and benefits of a maize rotation with an improved promiscuous soybean, with a local soybean, and with the green manure *Lablab purpureus* were compared using partial budgeting. The price of fertilizers, transport cost of fertilizer, and price of soybean varieties and maize were determined through a market survey in the area. Labor was valued at the wage rate of hired farm laborers. The highest net benefits for the two seasons (US\$ 1450 ha^{-1}) were obtained when maize was rotated with the improved soybean variety TGx 1448-2E followed by the rotation with the local variety Samsoy 2 (US\$ 1000 ha^{-1}) (Sanginga et al., 2001). The lowest net benefits (US\$ 600 ha^{-1}) were obtained with *Lablab*. This explains the lack of interest for this green manure, despite its good value for restoring soil fertility as shown by high maize grain yield in plots previously cropped to this herbaceous legume. The application of 45 kg N ha^{-1} to a maize grown after soybean and maize rotation was as attractive as the application of 90 kg N ha^{-1} to the sole maize grown after maize.

An economic evaluation was carried out to compare the costs, returns, and profits between the two BB treatments in the livestock integration experiment. The data collected in Bichi during 2000 showed total revenue of about ₦ 33,000 ha^{-1} for BB+ (US\$ 1 = ₦ 110) and ₦ 17,000 for L. BB+ yielded the highest profit ha^{-1}, about four times that of L (Tarawali et al., 2002). The benefit/cost ratio was as high as 1.77 for BB+ compared to 1.26 for L. The economic superiority of BB+ over L is clearly demonstrated by a marginal return of 1.84. That is an additional 84% of economic gain for farmers who adopt the improved system. A comparative economic analysis over time between the 1999 and 2000 cropping seasons shows an increase in total revenue and profit, and a reduction in production costs for material inputs and labor. Reasons could be positive nutrient balances and the fact that farmers' mastering of the new system had improved over time.

Economic analysis of the above systems showed an increase of 50–70% in the gross income of adopting farmers compared to those following the current practices of mainly continuous maize cultivation (Sanginga et al., 2001). Furthermore, increases in legume area of 10% in the dry savanna, in Nigeria (about 30,000 ha) and increases of 20% in yield have translated into additional fixed N, valued annually at 44 million. This reflects, at the same time, an equivalent increase of land-use productivity and, with further spread, there are excellent prospects for substantial additional economic and environmental benefits. The development of further new improved materials, as well as effective livestock integration, will greatly contribute to the success of these cropping systems and to the improvement of the economic well being of farmers.

A good indication of the positive results achieved is the fact that Sasakawa Global 2000, an NGO that is extensively involved in the introduction of new agricultural technologies, has decided to introduce the above technological options amongst farmers in northern Nigeria. Most importantly, these research results open new opportunities for the sustainable management of the soils in the savannas. Until now, it has been generally accepted that it would be impossible currently in Africa to grow crops continuously on these soils without soil degradation or without the use of inputs at an impracticable or uneconomic level. It was considered that there would still be a need for fallows at all levels of farming. Our results are a positive reflitation of this pessimistic view.

3.4. Development and impact

The development of dual-purpose cowpea and promiscuous soybean varieties that combine high N-fixation, better exploration of soil P, and *Striga* control, as well as the introduction of N-use efficient maize varieties greatly enhance the productivity and sustainability of cropping systems. The benefits to be derived from the above-mentioned characteristics have now been extensively demonstrated under farmers' conditions. However, even though these traits are highly beneficial, they are not the traits that farmers regard as high priority. Farmers are mainly concerned with traits such as high grain and fodder yields that solve their food security problem and increase income.

Increased production of soybean has been stimulated due to increased demand by industries and home utilization. Production in Nigeria was estimated at 405,000 t in 1999 compared to less than 60,000 t in 1984. In addition to these macro-statistics, surveys of villages soybean growing in Benue State, Nigeria, have confirmed that soybean production has increased dramatically. From 1982 to 1984, the total soybean production of a random sample of 70 soybean farmers was less than 5 t, but this increased rapidly to 30.4 t in 1989. In Ghana, soybean production increased from less than 2000 t in 1988 to 20,000 t in 1998. There has been a big increase in the demand for soybean in most of the major cities in Nigeria. An example of this is Ibadan (one of the largest cities in Nigeria). An urban market survey in 1987 revealed that soybean was being sold in only two markets, but by 1990 it was sold in 19 markets. The number of soybean retailers in those markets expanded from a total of 4–419. Several million people in Nigeria, Ghana, Côte d'Ivoire, and other West African countries who had never before heard about it, are now familiar with soybean and its nutritional benefits. A high level of awareness has been created and several African countries have become interested in soybean production and utilization. In particular, more women have been stimulated to venture into producing soybean which was previously a man's crop. There is clear evidence of the acceptance of improved varieties and the importance of soybean as an income-generating crop by both women and men (Sanginga, 1998). Adoption of two high-yielding, promiscuously nodulafing varieties with resistance to Frogeye Leaf Spot (TGx 101 9-2EN and TGx 14482E) released in Nigeria was very high, even in the absence of an efficient seed distribution system; the initial planting was in 2 ha, and the area planted increased to 28 ha in 3 years, giving a multiplication ratio of 1400%. The number of farmers cultivating the improved varieties increased by 228% during the same 3-year period. The second and third-generation adopters were younger men and women (<40 years old).

The same story of the adoption of soybean can be said to be true also for livestock integration where the dual-purpose cowpea has been the driving force for the improvement of the farming system in the dry savanna. Farmers' major reactions to the BB options centred initially on the grain yield, and subsequently on the fodder yield, and perceived quality. The quantities of cowpea grain and fodder in the BB treatments were at least twice as much as those in the L treatment. It should be noted that the productivity of crops and livestock is only one dimension of this research; the implications for human well being and the environment, as well as the interactions between these also need to be considered in the final analyses. The benefits of the two BB options are probably best demonstrated by the fact that the village chief of Bichi recently stated that an estimated 90% of the farmers have now adopted elements of the system on their own.

Adoption of integrated resource management and resilient germplasm technologies developed through this project will improve and stabilize production in existing infertile cropping areas and reduce further degradation. The maintenance of high productivity on more productive soils under continuous cropping will prevent farmers from encroaching onto the more marginal or erosion-prone lands, which are still under natural vegetation. The improved cereal-grain legume rotations not only produce more grain but also more haulms/stover and below-ground biomass per unit of land, compared to the present systems. The resulting higher levels of soil organic matter will also maintain and stimulate the biodiversity of soil microbiological populations and other soil-related flora and fauna.

4. Conclusion and vision

We reject the common belief that intensive continuous cropping is not feasible in the moist savanna zone. On the basis of our accumulated research results, we are now convinced that the future of sustainable agriculture in these zones lies in the use of intensified cropping systems, based on the rotation of N-efficient and *Striga*-resistant cereals and dual-purpose grain legumes, combined with the optimum use of inorganic and organic inputs. For the farmers participating in the trials, the top priority is to produce enough food for the family and, preferably, a surplus to generate income as well. In parallel studies to investigate farmers' perceptions of impact, they clearly indicated that soil fertility and structure were important considerations, as well as an improvement in their ability to keep more livestock. They mentioned that including a legume, such as dual-purpose cowpea and promiscuous soybean, in the system improved the soil. One of the next challenges to be faced is the scaling up of the results and implications from study sites to the moist and dry savanna domain as a whole.

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