Plant and Soil **228:** 61–71, 2001.

Nitrogen management in 'adequate' input maize-based agriculture in the derived savanna benchmark zone of Benin Republic

B. Vanlauwe[1,4], K. Aihou[2], P. Houngnandan[2], J. Diels[1], N. Sanginga[1] & R. Merckx[3]
[1] *International Institute of Tropical Agriculture, Ibadan, Nigeria, c/o Lambourn, Carolyn House, 26 Dingwall Road, Croydon CR9 3EE, UK;* [2]*Institut National des Recherches Agricoles du Bénin, BP 884, Cotonou, Benin Republic;* [3] *Laboratorium voor Bodemvruchtbaarheid en Bodembiologie, K Mercierlaan 92, 3001 Heverlee, Belgium.* [4]*Corresponding author*[*]

Key words: agroforestry, cowpea, cut-and-carry systems, herbaceous legumes, organic matter, urea

Abstract

Although the West-African moist savanna zone has a high potential for crop production, yields on farmers' fields are, on average, far below this potential, mainly due to the low use of external sources of nutrients. Since the mid-1990s, it has become clear that in order to upgrade crop production to levels needed to sustain the growing population without further degrading the soil resource base, inorganic fertilizers are required. Due to the physico-chemical nature of these soils and the relatively high cost of inorganic fertilizers, a general consensus exists in the research and development community that these inorganic inputs need to be complemented with organic matter. Here, we explore options to produce organic matter *in-situ* and evaluate the impact of combining inorganic and organic sources of N on maize yields, focusing on the densely populated derived savanna (DS) benchmark of Benin Republic. Although most of the farmers (93%) in this benchmark use inorganic fertilizer, applications rates are low (on average, 27 kg N ha^{-1}). A significant response to N was observed for 96% of the studied farmers' fields.

Grain and herbaceous legumes were observed to produce between 383 and 8700 kg dry matter ha^{-1} in the benchmark area. Inoculation with *Rhizobia* and inorganic P additions were shown to significantly improve biomass production on sites with low contents of *Rhizobia* and P. Although maize grain yield was observed to increase significantly following a legume compared with following a maize crop or natural fallow, these increases were insufficient in the case of a cowpea crop or were obtained at the cost of leaving the field 'idle' for a whole year in the case of a herbaceous *Mucuna* fallow. Topping up a cowpea haulms equivalent of 45 kg N ha^{-1} with 45 kg urea–N ha^{-1} was shown to give maize yields similar to the yields obtained after applying 90 kg urea–N ha^{-1} on the poorest fields. Moreover, on these fields, a positive interaction between cowpea–N and urea–N sources of 200 kg grain ha^{-1} was observed. On the richest fields, the effects of applied organic matter and fertilizer were additive.

Agroforestry systems are alternative cropping systems that produce organic matter *in-situ*. As tree roots go down below the rooting depth of food crops, sub-soil fertility was observed to influence tree biomass production. Yield increases in tree-crop intercrop systems – such as alley cropping – in the absence of inorganic inputs are often reduced by the occurrence of tree-crop competition. In cut-and-carry systems, where tree prunings are harvested from a field adjacent to the crop land, increases in maize grain yield caused by addition of those prunings were observed to be on the low side. Mixing these residues with urea, however, was shown to lead to added benefits of about 500 kg grains ha^{-1}, relative to the treatments with sole inputs of organic matter or urea. Although residue quality was shown to affect maize N uptake in a pot trial, its impact under field conditions was minimal for the range of considered residue qualities. In an alley cropping trial, maize yield was shown to be sustained on a non-degraded site and enhanced on a degraded site, when a minimal amount of mineral fertilizer was added with the prunings, whereas fertilizer application alone failed to do so in both cases.

[*] FAX No: +44-234-22-41-22-21. E-mail: b.vanlauwe@cgiar.org

Although the discussed cropping systems have a large potential to improve crop production in the DS benchmark and beyond, the rate and extent of adoption of those technologies by the farmer community will determine their agronomic and socio-economic robustness.

Abbreviations: DS – Derived Savanna; EPHTA – Ecoregional Program for the Humid and Sub-Humid Tropics of Sub-Saharan Africa; LISA – Low Input Sustainable Agriculture; NGS – Northern Guinea Savanna; SGS – Southern Guinea Savanna; SSA – Sub-Saharan Africa

Introduction

Although the West-African moist savanna zone has a high potential for crop production, maize yields obtained by farmers are generally around 30% of the yields obtained on research farms (Tian et al., 1995). One of the main causes for this discrepancy is the low use of external inputs, leading to negative balances for N, P and K (Rhodes et al., 1996).

In the 1970s, technologies dealing with soil fertility issues were developed following the first paradigm in tropical soil fertility research: "overcome soil constraints to fit plant requirements through purchased inputs" (Sanchez, 1994). A logical consequence of this paradigm was the introduction of subsidies on mineral fertilizers in many countries in Sub-Saharan Africa (SSA) (Smaling, 1993). Sanchez (1976) stated that when mechanization if feasible and fertilizers are available at reasonable cost, there is no reason to consider the maintenance of organic matter as a major management goal. Although the application of the first paradigm proved to be very successful in Asia and Latin America, only minor achievements were made in SSA because of the lack of an impending crisis caused by stagnant food production, the lack of the availability of new agricultural technologies in terms of improved crop varieties and crop management practices, and the lack of existing farming systems able to support relatively intensive food production over long periods of time (Spencer et al., 1992).

Between the mid-1980s and early-1990s, the environmental degradation resulting from the application of the first paradigm and the abolition of the fertilizer subsidies in SSA, imposed by structural adjustment programs, led to the development of farming systems where inputs of mineral fertilizers were minimized or even avoided and to intensified research on the biological management of tropical soil fertility (Swift, 1985). Alley cropping and live-mulch legume systems are examples of such minimal or zero input technologies. Several soil-fertility regenerating low input techniques, based on the production of organic matter have been tested in the derived savanna benchmark area in Southern Benin by Versteeg et al. (1998). Although it is widely accepted that organic matter additions are essential to maintain the soil physico-chemical health in the mainly sandy topsoils with low activity clays, it is doubtful whether organic inputs alone will be able to deal with the continuous removal of N from the soil. Vanlauwe and Sanginga (1995) observed a low recovery of *Leucaena leucocephala* derived N by maize crops in alley cropping systems in the DS. Vanlauwe et al. (1998a, b) observed that even after 120 days a significant part of the *Leucaena*-N was found in the soil organic matter pool, leading to poor synchrony between the release of N from organic residues and the crop's need for N.

Based upon similar observations, Sanchez (1994) enunciated a second paradigm in tropical soil fertility research: "overcome soil contraints by relying more on biological processes by adapting germplasm to adverse soil conditions, enhancing soil biological activity and optimizing nutrient cycling to minimize external inputs and maximize the efficiency of their use". Recent publications have emphasised the role of both inorganic and organic inputs in sustaining soil fertility (Buresh et al., 1997, Renard et al., 1998) and support the belief that 'no-input' or 'low-input' agriculture is not a sustainable form of agriculture. The one-time popular term 'Low Input Sustainable Agriculture' (LISA) has been proven to be a *contradictio in terminis* for the majority of Sub-Saharan African farms. The focus on research on N cycling in the DS and indeed the whole of Africa should be aimed at 'adequate-input' agriculture. In this context, 'adequate' refers to 'enough to at least replenish the amount of plant available nutrients removed by the harvested products'.

The lowland moist savanna has been subdivided into the Derived Savanna (DS), Southern Guinea savanna (SGS) and Northern Guinea Savanna (NGS) sub-zones, each characterized by a specific range of lengths of growing period (Jagtap, 1995). The DS has a length of growing period between 211 and 270 days. Past research in the region has been carried out without taking into account the variability found between fields, villages and ecoregions. Therefore, extrapolation of research results and consequently adoption of promising technologies proved difficult. Due to the heterogeneous biophysical and socio-economic character of the sub-zones, the Ecoregional Program for the Humid and Sub-Humid Tropics of Sub-Saharan Africa (EPHTA) has identified benchmark areas in each of the sub-zones, in which impact-oriented research and development activities should be concentrated (EPHTA, 1996). Benchmark areas contain all the biophysical and socio-economic gradients found in the total agro-ecozone and as such enable the extrapolation of technologies developed and tested in the benchmarks to the complete agro-ecozone. The benchmark area for the DS has been located in Southern Benin (Figure 1) and most of the data presented in this paper were obtained in this zone. The Mono province of Benin, which constitutes a significant part of the DS benchmark area, has a high population density of 200–250 persons km^{-2} (Manyong et al., 1996). Pinstrup-Andersen et al. (1997) estimated that over the next 20 years, the demand for cereals will increase by 120% in Sub-Saharan Africa. Although this increase in production can potentially be obtained by expanding the cultivated area or by intensifying the existing cultivated area, only the latter option is a realistic one in the DS benchmark and indeed in many regions in Sub-Saharan Africa, because of their high actual population densities.

This report reviews recent data obtained from trials addressing soil fertility replenishment issues in the DS benchmark of Benin with the following objectives: (i) to evaluate the impact of combining organic matter and fertilizer N inputs on maize yield in the DS benchmark area, (ii) to explore the potential of selected annual and perennial species to produce the needed organic matter to be combined with the inorganic N, and (iii) to identify factors which may hinder the achievement of this potential. Initially, some data related to fertilizer use and the N status of the soils in the target area are given.

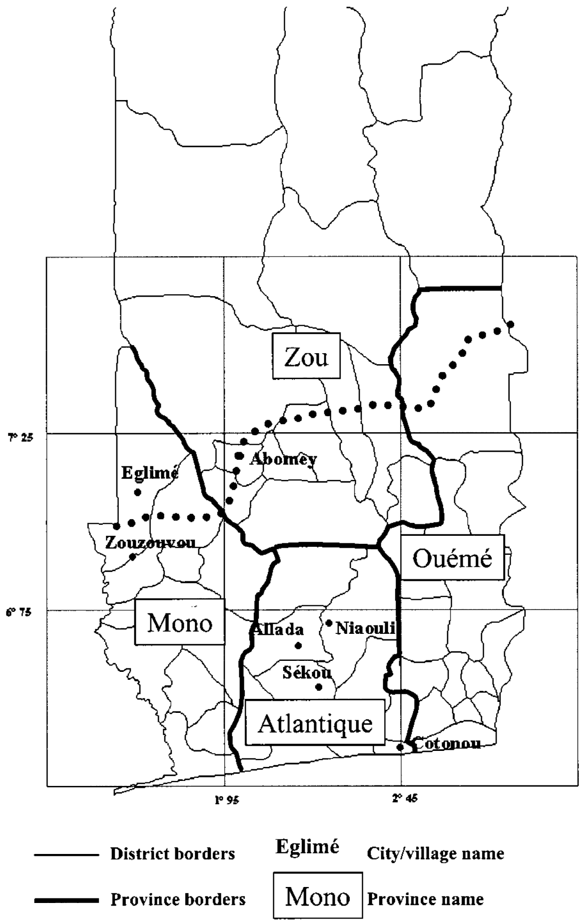

Figure 1. Approximate position of the DS benchmark in southern Benin, indicating the two major soil associations, the Niaouli and Sékou research stations, the research villages (Zouzouvou and Eglimé), and the different provinces. The dashed line represents the approximate border between the regions with mainly Nitisols (south of line) and mainly Luvisols/Cambisols (north of line).

Setting the scene: General characteristics, fertilizer use and N status of the soils in the DS benchmark villages

The DS benchmark area is located in the southern part of Benin Republic (Figure 1). The dominant soils in the southern part of the DS benchmark are deep red Nitisols developed on sedimentary deposits, often referred to as ‘terre de barre’. The northern part comprises mainly shallow and /or stony soils (Luvisols/Cambisols) developed on metamorphic and crystalline parent rocks. Koudokpon et al. (1994) estimated the average maize grain production in the Mono province of Benin at 750 kg ha^{-1} between 1984 and 1987.

In two villages in the benchmark area (Zouzouvou and Eglimé), a survey was conducted on the use of organic and inorganic inputs (Houngnandan, 2000). After the survey, 24 farmers’ fields were randomly selected to implement on-farm trials on the impact of the combined application of organic and inorganic amendments on maize yield. Prior to this, soil was taken from each field to conduct a missing nutrient trial in the greenhouse with maize as a test crop.

Results from the survey indicate that almost all of the interviewed farmers use inorganic inputs on at least one of their fields, depending on the crop and the availability of fertilizer (Table 1). However, the rate at which N-fertilizers are applied is far below the – in itself rather low – recommended rate of 60 kg N ha^{-1} (Table 1). The large number of farmers using fertilizer in the DS benchmark villages may be as a result of the existing credit scheme for cotton-fertilizer (Bosc and Freud, 1995). Organic matter use is lower than fertilizer use, but reasonably high in Zouzouvou (Table 1), caused by the successful introduction of *Mucuna* as a control measure against *Imperata cylindrica* by the 'Recherche Appliquee en Milieu Reeel' project (Houndékon and Gogan, 1996).

As a consequence of the low inputs of inorganic fertilizer, 96% of the selected fields in the DS villages responded to N (shoot biomass of the minus N treatment $<$ 80% of the shoot biomass in the completely fertilized treatment) and 63% to P (shoot biomass of the minus P treatment $<$ 80% of the shoot biomass in the completely fertilized treatment). Responses of maize to cations, S or micronutrients were marginal in potted soils from both villages.

Grain and herbaceous legume growth and contribution to N supply

Annual herbaceous or grain legumes are often advocated as sources of organic matter because of their potential ability to fix N_2 from the atmosphere and because their biomass usually has a relatively high biochemical quality and consequent N release characteristics. Grain legumes, such as cowpea (*Vigna unguiculata*), are traditionally part of the existing cropping systems in the DS benchmark. Recently, farmers in Southern Benin have shown interest in *Mucuna pruriens*, a herbaceous legume, as a suppressor of *Imperata cylindrica* (Versteeg et al., 1998). Annual legumes were observed to produce between 383 and 8700 kg biomass ha^{-1} and to accumulate between 12 and 193 kg N ha^{-1} in the aboveground biomass in the DS benchmark (Table 2). Between 23 and 70% of this N was observed to be derived from N_2 fixation (Table 2).

The observed large variation in biomass production and N accumulation indicates that legumes do not perform equally well in all locations and should not be considered as a panacea to soil fertility regeneration. Sanginga et al. (1996) observed nodule numbers on *Mucuna* to vary between 0 and 135 nodules per quadrant (0.5 $\times$ 0.5 m) in 34 fields in the DS benchmark. Houngnandan et al. (2000) observed an increase in *Mucuna* nodule numbers (from 18 to 39 nodules plant^{-1}) and mass (from 4.1 to 12.3 g plant^{-1}) after rhizobial inoculation in Zouzouvou and Eglimé. These improved nodulation characteristics resulted in a subsequent 25% increase in biomass at 20 weeks after planting. Response to fertilizer P application has been inconsistent and may enhance, not affect, or even depress N accumulation of *Mucuna*, *Lablab purpureus* and soybean biomass, grown on Fashola (DS) soil, and in the case of soybean was observed to depend on the variety (Sanginga et al., 1999). In Sékou in the DS benchmark area, 2 cowpea varieties were shown to respond significantly to TSP addition (Figure 2).

In the DS benchmark, legumes have been shown to significantly enhance grain yields of a subsequent maize crop, compared with yields obtained in a maize-maize or natural fallow-maize cropping sequence. Versteeg et al. (1998) observed that maize yields after *Mucuna* were 33% higher than yields after maize on 15 farmers' fields on the Adja Plateau in Southern Benin. On severely depleted soils yielding only 480 kg maize grains ha^{-1}, yields were increased to 1140 kg ha^{-1} on 19 depleted farmers fields on Adja plateau. Houngnandan (2000) observed increases in maize grain yield from 1650 to 2750 kg ha^{-1} for maize following *Mucuna* compared with maize following maize or natural fallow on 10 farmers' fields in Zouzouvou and Eglimé. In a trial established on 24 farmers' fields in the same villages, Vanlauwe et al. (1999) showed an increase in maize yield relative to the control after applying 90 kg N ha^{-1} as cowpea haulm residues of 49% on the 6 fields with the lowest average yields (poorest fields) and 24% on the 6 fields with the highest average yields (richest fields) (Figure 3).

Although maize following a herbaceous legume can significantly benefit from the previous presence of this legume, the land is kept out of production for at least one growing season. This is hardly acceptable to the farmer community in a region where population pressure on land is very high, as in the Mono province of Benin. In the case of a grain legume, the N harvest index needs to be smaller than the proportion of the legume N fixed from the atmosphere for the legume to contribute N to the system. As accumulation of N in grain legumes is often lower than in herbaceous

Table 1. Proportion of farmers using inorganic fertilizer and organic matter and mean application rates of inorganic N for the research villages in the DS (Zouzouvou and Eglimé). After Houngnandan (2000)

Village	Use of inorganic fertilizer	Use of organic matter	Inorganic N application rate
	% of farmers	% of farmers	kg N ha^{-1}
Zouzouvou	86	57	26
Eglimé	99	1	28
Mean	93	29	27

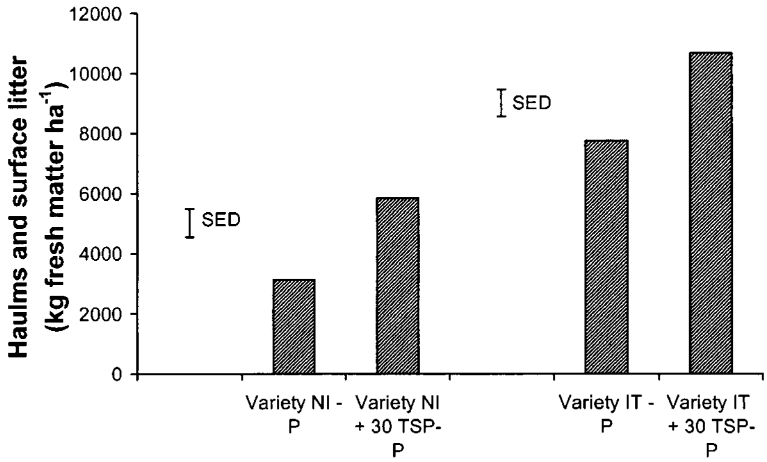

Figure 2. Biomass production of cowpea variety Ni-86-650-3 (medium duration) and IT89KD-288 (long duration) as affected by the addition of 30 kg triple superphospate (TSP) P ha^{-1} during the first cropping season in Sékou in 1998, measured at 12 and 17 weeks after planting, respectively. The error bar indicates the Standard Error of the Difference (SED).

legumes because of their shorter growth cycle and/or less vigorous growth, it is unlikely that maize N nutritional requirements can be completely supplied by a preceding grain legume, although the recent development of 'dual purpose' grain legumes, which produce appreciable amounts of grains and biomass, may improve the proportion of fixed N remaining in the soil at grain harvest. Moreover, maize yields need to double in the next 20 years to at least 1500 kg ha^{-1} from the currently low yields of 750 kg ha^{-1} (Koudokpon et al., 1994) to support the projected demand for cereals, as estimated by Pinstrup-Andersen et al. (1997). The addition of mineral fertilizer is essential to obtain yield increases of this order of magnitude in the absence of abundantly available land. Vissoh et al. (1998) similarly concluded that additions of external inputs are required to achieve sustainability of a *Mucuna*-maize rotation in the Mono province of Benin.

Koudokpon et al. (1994) observed an increase in maize yield from 625 to 1350 kg ha^{-1}, following a short season *Mucuna* fallow and ascribed part of the '*Mucuna*-effect' to the applied inorganic fertilizer (100 kg NPK ha^{-1} and 50 kg urea ha^{-1}). In a multi-locational trial in 24 fields in Zouzouvou and Eglimé, mixing 45 kg N ha^{-1} as cowpea residues with 45 kg N ha^{-1} as urea led to a maize grain yield increase of 115% on the 25% poorest fields, which was similar to the yield increase of the maize treated with 90 kg urea-N ha^{-1} (Figure 3a). On the 25% richest fields, the increase in grain yield in the combined treatment was 58% and significantly lower than the yield increase in the treatments supplied with 90 kg urea-N ha^{-1} (Figure 3b). Assuming that responses to organic matter and fertilizer N are linear, the combination treatment also showed a positive interaction between organic matter and fertilizer N amendments of about 200 kg grain ha^{-1} for the poorest fields, while for the

Table 2. Biomass production and N accumulation for selected annual and perennial species, grown in the DS benchmark of Benin

	Soil type	Period of biomass production	Cropping system	Biomass production	N accumulation	Proportion of N derived from N_2 fixation	Source
				kg ha^{-1}	kg N ha^{-1}	%	
Annual species							
Cowpea NI-86-650-3	Nitisols	8 weeks	Monocrop	383–1593	12–41	23–68	Diels et al., *unpublished*
Cowpea NI-86-650-3	Luvisols	8 weeks	Monocrop	457–2107	14–52	27–70	Diels et al., *unpublished*
Mucuna pruriens	Nitisol	20 weeks	Monocrop	1800–6900	30–193	30–68	Houngnandan et al., 2000
Mucuna pruriens	Lixisol	20 weeks	Monocrop	1500–8700	22–159	29–60	Houngnandan et al., 2000
Mucuna pruriens	Vertisol	20 weeks	Monocrop	3200–8000	65–171	36–62	Houngnandan et al., 2000
Perennial species							
Leucaena leucocephala	Nitisols	1 year (2)[b]	Hedgerow	2373	92	Unknown	Aihou et al., 1999
Senna siamea	Nitisols	1 year (2)	Hedgerow	6027	175	NA[a]	Aihou et al., 1999
Gliricidia sepium	Nitisols	1 year (2)	Hedgerow	1747	65	Unknown	Aihou et al., 1999
Leucaena leucocephala	Cambisol	1 year (2)	Hedgerow	2993	114	Unknown	Aihou et al., 1999
Senna siamea	Cambisol	1 year (2)	Hedgerow	2477	61	NA	Aihou et al., 1999
Gliricidia sepium (Gs)	Cambisol	1 year (2)	Hedgerow	940	34	Unknown	Aihou et al., 1999
Gs+Flemingia macrophylla	Lixisol	1 year (5)	Hedgerow	1651	42	Unknown	Böhringer and Leihner, 1997
Gs+Flemingia macrophylla	Lixisol	1 year (5)	Tree block	869	23	Unknown	Böhringer and Leihner, 1997

[a] 'NA' means 'not applicable'.
[b] The value in paranthesis is the number of prunings.

richest fields, the effect of both inputs was additive. These added benefits are caused by direct interactions between decomposing organic matter and fertilizer-N leading to improved synchrony between supply of and demand for available N or by alleviation of one or more factors limiting plant growth in the combined treatments leading to a better utilization of the applied urea-N relative to the treatment with sole application of urea. In this particular case, alleviation of P and K deficiencies is not relevant, as both nutrients were added as a basal dressing in all treatments. Studies using ^{15}N labeled fertilizer should reveal whether direct interactions between decomposing organic matter and fertilizer-N occur. The added benefits after combining organic matter with fertilizer-N on the poorest fields are not very large, but at the price levels of mid-1999, this extra grain yield paid back almost twice the cost of urea applied. Although it is necessary to confirm the occurrence of a positive interaction between both additions, at least an additive effect was observed, indicating that organic matter can replace part of the relatively expensive N fertilizer without decreasing maize grain yields.

Both grain and herbaceous legumes potentially enhance grain yield of a subsequent maize crop, although in the case of grain legumes, only 'dual purpose' varieties, having a relatively low harvest index, may produce a sufficient amount of haulms to supply the desired quantity of organic matter. Although herbaceous legumes often produce more biomass than grain legumes and possess other beneficial characteristics, such as the ability to reduce weed pressure, adoption of these legumes into existing cropping systems in the zone may prove to be more difficult than introducing grain legumes which already form part of the cropping systems.

The impact of trees on N cycling in agroforestry systems

Trees are an alternative option for the production of organic matter in the DS, as rainfall is no constraint to intercropping trees and food crops. Trees can influence the N cycle in several ways. Firstly, tree prunings have a certain biochemical quality, which influences their N release and incorporation in the soil organic matter pool. Vanlauwe et al. (1997) demonstrated that the biochemical quality of the prunings of *Leucaena leucocephala* and *Senna siamea* and the rainfall regime

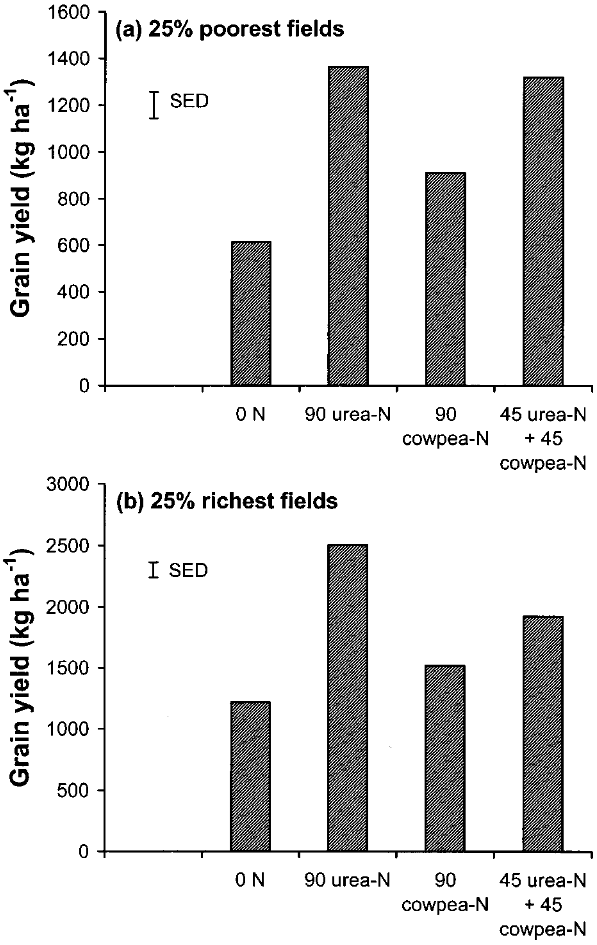

Figure 3. Maize grain (variety DMR) yields in 1998 on the 25% poorest (a) and richest (b) fields as affected by the application of cowpea biomass, urea, or both. In total, 12 farmers' fields in Zouzouvou and Eglimé, two villages in the DS benchmark area were used in the trial. Sitemean yields, or yields averaged over all treatments, were used to classify the fields following their fertility status. Figures in the bar labels are expressed in kg ha^{-1}. The error bars indicate the Standard Errors of the Difference (SED). After Vanlauwe et al. (1999).

were the most important modifiers of the decomposition process in the DS. Secondly, the tree itself may recover part of the nutrients released from the added prunings or nutrients below the reach of more shallow rooted food crops. Vanlauwe et al. (1998a) reported that the fast-growing *Leucaena* trees recovered 25% of the applied residue N in the first two prunings after residue application, while the slowly growing *Dactyladenia* trees only recovered 1%. Moreover, most of the leguminous tree species fix N_2 from the atmosphere.

In alley cropping systems, trees were observed to produce yearly between 940 and 6027 kg biomass ha^{-1} and to accumulate between 34 and 175 kg N ha^{-1} in the aboveground biomass in the DS benchmark (Table 2). Aihou et al. (1999) observed that tree biomass production by *Senna* was higher on a Nitisol with a chemically degraded topsoil than on a non-degraded Cambisol (Table 2). This was attributed to the higher subsoil fertility of the degraded Nitisol (the 60–125 cm layer of the Nitisol had a CEC of 4.6 cmol (+) kg^{-1}, a total N content of 4.5 g kg^{-1}, and contained 280 g clay kg^{-1}, while the 56–98 cm layer of the Cambisol had a CEC of 1.7 cmol (+) kg^{-1}, a total N content of 1.7 g kg^{-1}, and contained 120 g clay kg^{-1}). Obviously, trees can only recover nutrients from the subsoil when those nutrients are present at greater soil depths. Böhringer and Leihner (1997) similarly concluded that the dependence of *Gliricidia sepium* and *Flemingia macrophylla* on soil fertility raises the question of their role in reclaiming degraded sites without external inputs. Moreover, Sanginga et al. (1991) reported intra- and inter-specific variations in growth and P accumulation of *Leuceana* and *Gliricidia* as affected by the soil P status.

Tree–derived biomass has been shown to increase maize grain yield in the absence of inorganic fertilizers. In a cut-and-carry system with prunings of *Senna siamea* near Allada, Leihner et al. (1996) reported that for every ton of applied *Senna* prunings, maize grain yield increased by 72 kg. In a similar cut-and-carry system in Sékou with prunings from *Leucaena leucocephala*, *Azadirachta indica* and *Senna*, applied at 90 kg N ha^{-1}, maize yield was observed to increase from 311 to 663 kg ha^{-1}, on average (Figure 4). Residue quality was observed not to significantly affect grain yield. Using a wider range of residue qualities, a significant linear relationship was observed between the maize total N accumulation and the lignin-to-N ratio of the residues in a pot trial with a wide range of tree-derived organic materials and livestock manure, for a similar soil type sampled in Niaouli (Figure 5). Growing trees together with maize requires proper management of the trees to minimize tree-crop competition. Although Versteeg et al. (1998) reported that maize grain yield in alley cropping without fertilizer addition increased from 1200 to 1450 kg ha^{-1}, the yield decreased to 500 kg ha^{-1} in the absence of proper tree management and timely pruning. Böhringer and Leihner (1997) showed yield increases relative to the no-tree control of 129 and 219 kg grain ha^{-1} in an alley cropping and a tree block cropping system, respectively.

Although agroforesty systems without external inputs can significantly increase maize yield compared with a no-tree control (see above), the observed yield increases in tree-crop intercrop systems are often even lower than in the case of a herbaceous legume-maize rotation due to competition between the food crop and the trees. On the other hand, in cut-and-carry systems, the benefits from the fallow phase for the food crop are limited to the application of tree biomass, rather than to the whole spectrum of processes influencing the soil N status if the fallow species is grown on the same plot of land. Trees could also be used to regenerate sites with a severely degraded topsoil, as in the *Acacia auriculiformis* shock treatment for comatose soils or completely depleted soils producing less than 170 kg maize grains ha^{-1} (Versteeg et al., 1998). Also in the case of agroforestry systems, the addition of mineral fertilizer appears to be essential to obtain yield increases of the order of magnitude needed to sustain the growing demand for cereals without further degrading the soil resource base.

In a cut-and carry system with *Senna* leaves, Leihner et al. (1996) demonstrated that for a large number of fields in the Allada region, the largest response to applied nutrients was observed in the treatment in which the mulch was combined with mineral fertilizer. In a similar cut-and-carry system with residues from *Leucaena*, *Azadirachta* and *Senna* in Sékou, the combined application of organic matter and urea-N was shown to give significantly higher maize yields than the application of only organic matter, applied at the same N rate, and similar yields as applying 90 kg urea-N ha^{-1} (Figure 4) (Vanlauwe et al., 2000). In this trial, added benefits in the order of 500 kg grains ha^{-1} were obtained in the treatments with combined application of organic matter and urea and these benefits were attributed to an improved availability of soil moisture during the grain filling period – which was devoid of precipitation – in the combined treatments, relative to the sole-urea treatments (Vanlauwe et al., 2000). Direct interactions between decomposing organic matter and urea-N were less likely as residue quality did not appear to significantly affect grain yield in the combined treatments. As residue quality affects the decomposition and N mineralization process, direct interactions between decomposing organic matter and urea-N would be influenced by the factors governing the decomposition process. In an alley cropping trial in the DS benchmark, Aihou et al. (1999) showed that alley cropping supplied with a minimal amount of fertilizer could sustain maize yields on a non-degraded site and enhance maize yields on a severely degraded site, especially with *Senna siamea* as hedgerow (Figure 6). Fertilizer applications alone failed to do so on both sites (Figure 6).

Although the adoption rate of trees in the DS is low, mainly caused by socio-economic constraints, they may be indispensable to produce the necessary amounts of biomass to sustain crop yield in a region where animal manure production is minimal and where herbaceous legumes are not producing the necessary quantities of biomass, as on soils with a severely degraded topsoil. Moreover, trees provide firewood, which is in short supply in the more densely populated areas of the DS. The biggest problem to address may be the design of a proper agroforestry system which provides enough tree biomass to sustain soil fertility without complicating the lives of the farmer community.

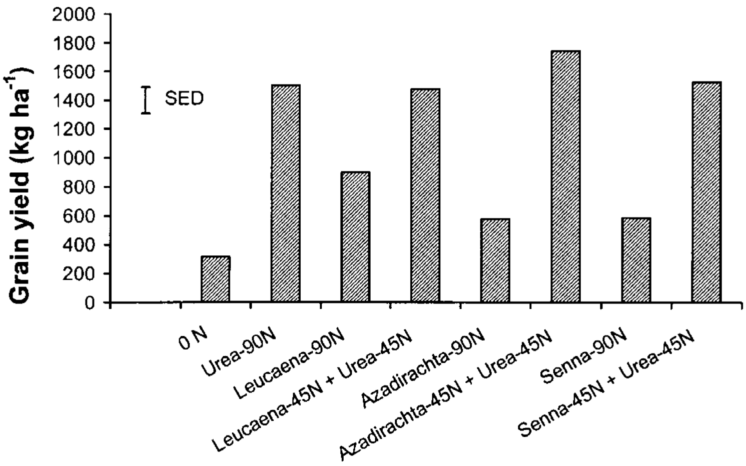

Figure 4. Maize (variety Oba Super II) grain N uptake in Sékou in 1997 as affected by additions of organic N, urea-N, and their combination. The organic matter was harvested from trees near the field and incorporated in ridges. The error bar indicates the Standard Error of the Difference (SED). After Vanlauwe et al. (2000).

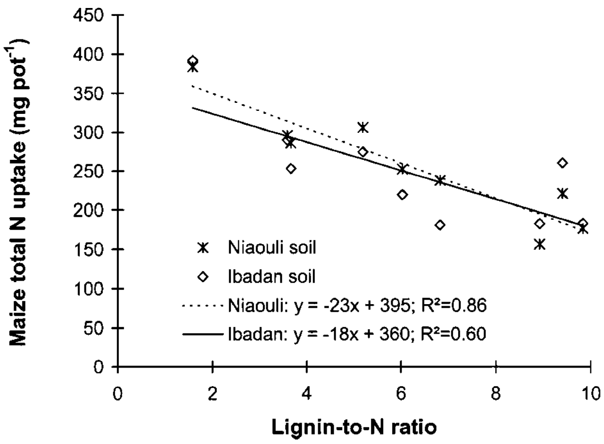

Figure 5. Relationships between the total N uptake of 7-weeks old maize plants and the lignin–to-N ratio of organic materials (*Mucuna pruriens*, *Lablab purpureus*, *Azadirachta indica*, *Leucaena leucocephala*, *Acacia auriculiformis*, *Senna siamea*, poulty manure, cattle manure, goat manure), applied at an equivalent rate of 90 kg N ha^{-1} in a greenhouse pot experiment. Soils from Ibadan (Derived Savanna, south-western Nigeria) and Niaouli (Derived Savanna benchmark in southern Benin) were included.

Conclusions

In regions with a high population density, such as southern Benin, where land is scarce, fertilizers are needed at an adequate level to increase crop yield to levels estimated to be necessary to support the growing demand. Due to the high cost of fertilizers and the physico-chemical nature of the soils in the region, the inorganic inputs need to be supplemented with organic matter. Possible added benefits obtained after combining organic matter with N fertilizer could further improve crop yields.

As organic inputs are often harder to obtain than fertilizers, it is necessary to develop cropping systems in which organic matter is produced on part of the crop land, separated in time or space. Rotations between herbaceous or grain annual legumes and maize or agroforestry systems are two possible examples. Both annual legumes as well as trees are, however, also susceptible to variations in soil fertility status and inorganic amendments and should not be considered as a panacea to arrest resource degradation anywhere and anytime.

Although in annual legume-maize rotations, as well as in agroforesty systems, maize may benefit solely from the additions of organic matter, it was proven in several cases, that mixing a limited amount of fertilizer N with this organic matter may increase

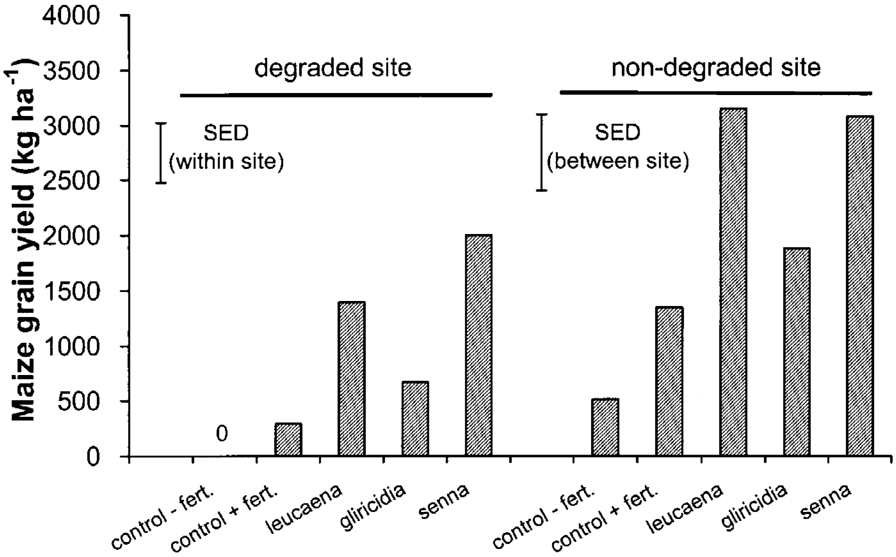

Figure 6. Maize yields (variety DMR) in 1996 in alley cropping trials, established on a degraded and non-degraded site in Niaouli, Bénin Republic. The degraded site had been used for mechanised fertilizer trials, while the non-degraded site was cleared from a natural fallow of minimally 30 years prior to trial establishment. Maize grain yields at trial estalishment in 1990 were 401 and 2181 kg ha^{-1} on the degraded and non-degraded site, respectively. The error bar indicates the Standard Error of the Difference (SED). After Aihou et al. (1999).

maize yields to the desired levels. In certain cases positive interactions between organic matter and fertilizer N inputs were observed. Finally, the rate and extent of adoption of the proposed systems by the farmer community will determine their agronomic and socio-economic robustness.

Acknowledgements

The authors are grateful to ABOS, the Belgian Administration for Development Cooperation, for sponsoring this work as part of the collaborative project between KU Leuven and IITA on 'Balanced Nutrient Management Systems for Maize-based Farming Systems in the Moist Savanna and Humid Forest Zone of West-Africa'. IITA publication IITA/99/CP/16.

References

Aihou K, Vanlauwe B, Sanginga N, Lyasse O, Diels J and Merckx R 1999 Alley cropping in the moist savanna zone of West-Africa: I. Restoration and maintenance of soil fertility on 'terre de barre' soils in Southern Bénin Republic. Agroforest. Syst. 42, 213–227.

Böhringer A and Leihner D E 1997 A comparison of alley cropping and block planting systems in sub-humid Bénin. Agroforest. Syst. 35, 117–130.

Bosc P and Freud E H 1995 Agricultural innovation in the cotton zone of francophone West and Central Africa. *In* Moist Savannas of Africa: Potentials and Constraints for Crop Production. Eds. BT Kang, IO Akobundu, VM Manyong, RJ Carsky, N Sanginga and EA Kueneman. pp 265–306. International Institute of Tropical Agriculture, Ibadan, Nigeria.

Buresh R J, Sanchez P A and Calhoun F 1997 Replenishing Soil Fertility in Africa. Soil Science Society of America Special Publication 51, Soil Science Society of America, Madison, Wisconsin, USA.

EPHTA 1996 Mechanism for Sustainability and Partnership in Agriculture. International Institute of Tropical Agriculture, Ibadan, Nigeria.

Houndekon V A and Gogan A C 1996 Adoption d'une technologie nouvelle de gestion des ressources naturelles. Cas du *Mucuna* dans le Sud-Ouest du Bénin. Recherche Appliquée en Milieu Réel, Institut National des Recherches Agricoles du Bénin, Cotonou, Benin Republic.

Houngnandan P 2000 Efficiency of the use of organic and inorganic nutrient sources in maize based cropping systems in the derived savanna of Benin. PhD thesis, Faculty of Agricultural and Applied Biological Sciences, University of Ghent, Ghent, Belgium.

Houngnandan P, Sanginga N, Woomer P, Vanlauwe B and Van Cleemput O 2000 Symbiotic nitrogen fixation response of mucuna affected by rhizobial inoculation in farmers' fields in the derived savanna of Benin. Biol. Fert. Soils (in press)

Jagtap S S 1995 Environmental characterization of the moist lowland savanna of Africa. *In* Moist Savannas of Africa: Potentials and Constraints for Crop Production. Eds. BT Kang, IO Akobundu, VM Manyong, RJ Carsky, N Sanginga and EA Kueneman. pp 9–30. International Institute of Tropical Agriculture, Ibadan, Nigeria.

Koudokpon V, Brouwers J, Versteeg M N and Budelman A 1994 Priority setting in research for sustainable land use: The case of the Adja Plateau, Benin. Agroforest. Syst. 26, 101–122.

Leihner D E, Doppler W and Bernard M 1996 Agro-ecological on-farm evaluation of selected technologies to improve soil fertility in southern Benin. *In* Adapted Farming in West-Africa. Interim Report 1994–1996. pp 381–409. Special Research Programme 308, University of Hohenheim, Hohenheim, Germany.

Manyong V M, Houndékon A V, Gogan A, Versteeg M N and van der Pol F 1996 Determinants of adoption for a resource management technology: the case of *Mucuna* in Benin Republic. *In* Advances in Agricultural and Biological Environment Engineering. Eds. Z Senwen and W Yunlong. pp 86–90. China Agricultural University Press, Beijing, China.

Pinstrup-Andersen P, Pandya-Lorch R and Rosegrant M W 1997 The World Food Situation: Recent Developments, Emerging Issues and Long-term Prospects. 2020 Vision. Food Policy Report. International Food Policy Research Institute, Washington D C, USA.

Renard G, Neefs A, Becker K and Von Oppen M 1998 Soil Fertility Management in West African Land Use Systems. Proceedings of the Regional Workshop, University of Hohenheim, ICRISAT Sahelian Centre and INRAN, 4–8 March 1997, Niamey, Niger. Margraf Verlag, Weikersheim, Germany.

Rhodes E, Bationo A, Smaling E M A and Visker C 1996 Nutrient stocks and flows in West African soils. *In* Restoring and Maintaining the Productivity of West African Soils: Key to Sustainable Development. Eds. AU Mokwunye, A de Jager and E M A Smaling. pp 22–32. IFDC Miscellaneous fertilizer studies no 14.

Sanchez P A 1976 Properties and Management of Soils in the Tropics. John Wiley and Sons, New York, USA.

Sanchez P A 1994 Tropical soil fertility research: Towards the second paradigm. Volume 1. Inaugural and State of the Art Conferences. Transactions 15th World Congress of Soil Science, 10–16 July 1994, Acapulco, Mexico, pp 65–88.

Sanginga N, Bowen G D and Danso S K A 1991 Intra-specific variation in growth and P accumulation of *Leucaena leucocephala* and *Gliricidia sepium* as influenced by soil phosphate status. Plant Soil 133, 201–208.

Sanginga N, Ibewiro B, Houngnandan P, Vanlauwe B, Okogun J A, Akobundu I O and Versteeg M 1996 Evaluation of symbiotic properties and nitrogen contribution of mucuna to maize grown in the derived savanna of West Africa. Plant Soil 179, 119–129.

Sanginga N, Dashiell K, Okogun J A, Lyasse O and Vanlauwe B 1999 Genotypic variability of promiscuous soybean lines and herbaceous legumes in response to P sources and their residual effects on subsequent maize growth in low P soil. Short Fallow Systems to Arrest Resource Degradation Due to Land-Use Intensification. Annual Report 1998. International Institute of Tropical Agriculture, Ibadan, Nigeria. pp 58–62.

Smaling E M A 1993 An Agro-ecological Framework of Integrated Nutrient Management with Special Reference to Kenya. PhD thesis, Wageningen Agricultural University, Wageningen, The Netherlands.

Spencer D S C, Akobundu I O, Jagtap S S, Kang B T and Mulongoy K 1992 Resource and crop management. *In* Sustainable Food Production in Sub-Saharan Africa. I. IITA's Contributions. pp 25–63. International Institute of Tropical Agriculture, Ibadan, Nigeria.

Swift M J 1985 Tropical Soil Biology and Fertility: Planning for Research. Biology International Special Issue 9, IUBS, Paris.

Tian G, Kang B T, Akobundu I O and Manyong V M 1995 Food production in the moist savanna of West and Central Africa. *In* Moist Savannas of Africa: Potentials and Constraints for Crop Production. Eds. BT Kang, IO Akobundu, VM Manyong, RJ Carsky, N Sanginga and EA Kueneman. pp 107–127. International Institute of Tropical Agriculture, Ibadan, Nigeria.

Vanlauwe B and Sanginga N 1995 Efficiency of the use of nitrogen from prunings and soil organic matter dynamics in *Leucaena leucocephala* alley cropping in Southwestern Nigeria. *In* Integrated Plant Nutrition Systems. Eds. R Dudal and R N Roy. pp 279–292. FAO Fertilizer and Plant Nutrition Bulletin 12, FAO, Rome, Italy.

Vanlauwe B, Sanginga N and Merckx R 1997 Decomposition of four *leucaena* and *senna* prunings in alley cropping systems under sub-humid tropical conditions: The process and its modifiers. Soil Biol. Biochem. 29, 131–137.

Vanlauwe B, Sanginga N and Merckx R 1998a Recovery of *Leucaena* and *Dactyladenia* residue nitrogen-15 in alley cropping systems. Soil Sci. Soc. Am. J. 62, 454–460.

Vanlauwe B, Sanginga N and Merckx R 1998b Soil organic matter dynamics after addition of ^{15}N labeled *Leucaena* and *Dactyladenia* residues in alley cropping systems. Soil Sci. Soc. Am. J. 62, 461–466.

Vanlauwe B, Diels J, Lyasse O, Sanginga N, Aihou K, Houngnandan P, Aman S, Tossah B, Iwuafor E N O, Omueti J, Manyong V M, Deckers S and Merckx R 1999 Balanced Nutrient Management Systems for Maize-based Systems in the Moist Savanna and Humid Forest Zone of West-Africa, Annual Report 1998 (January 1998– December 1998). International Institute of Tropical Agriculture, Ibadan, Nigeria.

Vanlauwe B, Aihou K, Aman S, Iwuafor E N O, Tossah B, Diels J, Sanginga N, Merckx R and Deckers S 2000 Agronomic evaluation of the impact of the combined application of organic matter and fertilizer N on maize yield in the West-African moist savanna. Plant Soil (*submitted*).

Versteeg M N, Amadji F, Eteka A, Gogan A and Koudokpon V 1998 Farmers' adoptability of Mucuna fallowing and agroforestry technologies in the coastal savanna of Bénin. Agric. Syst. 56, 269–287.

Vissoh P, Manyong V M, Carsky R J, Osei-Bonsu, P and Galiba N 1998 Experiences with Mucuna in West-Africa. *In* Cover Crops in West Africa Contributing to Sustainable Agriculture. Eds. D Buckles, A Eteka, O Osiname, M Galiba and G Galiano. pp 1–32. International Development Research Centre, Ottawa, Canada.

Section editor: E S Jensen