Integrated soil fertility management, and effective water conservation technology for sustainable dryland agriculture in sub-Saharan Africa

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Integrated soil fertility management, an effective water conservation technology for sustainable dryland agriculture in sub-Saharan Africa

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Abstract

Soil fertility is naturally low in extensive parts of sub-Saharan Africa (SSA) and nutrient mining, through crop nutrient removal without adequate replenishment, leads to soil degradation.

To reverse soil and environmental degradation, it is imperative to develop new and sustainable technologies in cooperation with farmers. IFDC is involved in the development of Integrated Soil Fertility Management (ISFM) strategies that enhance both agricultural productivity and soil fertility through the appropriate and integrated use of locally available organic resources and inorganic fertilizers. IFDC has developed – in close collaboration with its partner institutions and major stakeholders (i.e. farmers, input dealers, traders, rural bankers) a participatory process-oriented approach to promote ISFM strategies in several well-targeted areas in West Africa.

Strategic research is being carried out with partners in West Africa to fill gaps in existing knowledge and in particular, to examine synergies obtained from ISFM strategies and their impact on water- and nutrient-use efficiencies. Concepts of water-limited versus *nutrient-limited growing conditions and results from strategic research efforts in south Togo and Burkina Faso are reported on. The combined use of mineral fertilizers and a mucuna short fallow resulted in significant gains in agricultural productivity in mixed maize-manioc production systems in Togo. The mulching effect of mucuna led to increased grain yield and nutrient (N) use efficiency by maize. This was ascribed to the effectiveness of mucuna mulch in improving water conservation and crop establishment. In Burkina Faso, stone rows and grass strips were shown to be effective means to conserve water, but sorghum productivity and water use efficiency were only improved with application of compost or urea-N. The combined application of urea-N and various organic soil amendments led to increased grain yield and N agronomic efficiency by sorghum, but not water conservation. In SSA, nutrients will be often be more limiting than water and ISFM is, therefore, key to improved agricultural productivity and increased water use efficiency.*

Key words: Water use efficiency, fertilizer use efficiency, land degradation, integrated soil fertility management

Introduction

Food production in sub-Saharan Africa (SSA) has not kept pace with population growth. In order to become self-sufficient in food, the production in SSA has to increase. In areas with high population density, it means that more food has to come from the same land area. However, the extremely poor African soils and the often unfavourable climatic conditions result in low agricultural production and the population can therefore not be supported by merely exploiting the natural resources available, even at low population densities (Breman *et al*., 2001).

Without nutrient inputs, this means that the soil nutrient supplying capacity is gradually being depleted and farmers get into a vicious cycle of *low soil fertility, low productivity, low income, no inputs, low soil fertility*. Fertilizers could be part of a solution to correct environmental degradation and to properly address rising food demands. Average fertilizer use in Africa is very low (about 8 kg ha^{-1}, i.e. only 1/10th of world average). Most soils of the West African Sahel and savannah zones are so poor in fertility that the efficiency of mineral fertilizers, if applied, is very low.

In addition to soil fertility, drought and degradation of soil physical properties are the other two major biophysical constraints to agricultural production in the semi-arid zones. The main constraint to crop production is not the limited annual rainfall but the limited proportion of rainfall used by rangeland vegetation (Sivakumar & Wallace, 1991). In the Sahel, for example, 85-95% of the rainfall is lost through evaporation, runoff and percolation. Nutrients are lacking to enable plants to use water for growth and soils in the semi-arid zone are generally poor in soil organic matter (SOM) and highly susceptible to erosion and crusting. Increasing available plant nutrients leads to a 3-5 times higher production and water use; reducing rainfall loss to only 50% (Penning de Vries & Djitéye, 1991).

Integrated soil fertility management (ISFM) refers to making best use of inherent soil nutrient pools, locally available amendments and mineral fertilizers to increase land productivity while maintaining or enhancing soil fertility in the broadest sense, i.e. nutritional, biological and physical soil properties. ISFM may gradually lead to improved SOM content and an increase in the soil's nutrient capacity. ISFM may also have important synergistic effects related to improved mineral fertilizer use efficiency and water use efficiency.

Crop residue recycling, mulching, application of manure and use of cover crops may increase nutrient availability and use efficiency through reduced runoff and evaporation losses of water, resulting in improved rainwater infiltration and water storage capacity. Breman & Van Reuler (2003) reported examples of increased mineral fertilizer use efficiency as a result of ISFM for a range of agro-ecological growing conditions and production systems in SSA. Crop residues are an important source of animal fodder, building material and fuel and these alternative uses of crop residues compete with their use for soil management purposes. Moreover, soil fertility is often limiting plant growth and therefore, the production of plant material that can be used as organic amendments. Judicious use of mineral fertilizers may raise yields in the short term and ultimately result in enhanced production of crop residues and other organic fertilizer sources that help improve soil fertility.

IFDC-Africa, in cooperation with national and international partners, is currently developing baskets of ISFM options for target regions in West Africa. Locally available organic and mineral amendments that are being used include household waste, compost, livestock manure, cover crops and agro-forestry and also rock phosphate.

Productivity in dryland agriculture is driven by both nutrient and water availability. In a given production situation either water or nutrients will be most limiting. This paper reviews concepts related to nutrient- and water-limited growing conditions and demonstrates benefits from ISFM through three case studies based in Togo and Burkina Faso.

Water- or nutrient-limited growth concept

Intensification of agriculture becomes a necessity when over-population leads to over-exploitation of resources, particularly when migration is unfeasible, sources of income outside agriculture are scarce and the creation of alternative employment is not economically viable. In such cases, external inputs are needed to address the loss of soil nutrients and to increase the potential productivity of the existing natural resources. This implies that a change is needed in production systems, from self-sufficiency to market-oriented strategies.

A critical question is what inputs are needed, when and where. The project Primary Production Sahel (PPS) addressed this question for semi-arid and sub-humid West Africa (Penning de Vries & Djitèye, 1991).

In most of these regions, nutrients appeared to be more limiting than water for plant production. Only 10 to 15% of the rainfall is used by plants growing in natural rangelands and the plants do not find adequate nutrients for growth, even when water is available. Soil improvement in these areas improves the efficiency of water use by a factor of 3 to 5. Nitrogen and phosphorus are the main limiting factors. Fertilizer can increase rangeland production in the southern Sahel from 1.5 to 3.0 t ha^{-1} dry matter to 4 to 12 t ha^{-1}.

The predominance of poor soil over lack of water in limiting rangeland productivity has important consequences for both animal and crop production. Fodder quality is inversely proportional to quantity. Where water is more limiting than nutrients, fodder quality is high. This is the case at the desert border, where crop production is impossible due to low and erratic rainfall. Going south, rangeland productivity increases with increasing rainfall, but fodder quality decreases.

In contrast, applying only 30 kg ha^{-1} of nitrogen, plus phosphorus and potassium, to rainfed millet in the southern Sahel, improved the efficiency of water use by a factor of two to three (Bationo *et al*., 1991). Thus, by increasing effective water availability, fertilization can be considered an alternative to irrigation or water conservation measures.

The relative availability of water and nutrients determines which external input is needed most to increase production and to increase the carrying capacity of the natural resources. Water availability is a function of rainfall, redistribution of rainwater by runoff and run-on, and losses by evaporation and leaching. Nutrient availability depends on soil fertility, soil-enrichment processes (e.g. biological nitrogen fixation and weathering), nutrient inputs (e.g. by wind, water and animals) and nutrient losses through erosion, leaching and export by agriculture. In West Africa, the transition from nutrient- to water-limited production occurs at an annual rainfall of about 300 mm.

In areas where soils are shallow, with low water storage capacity, or where runoff is enhanced either naturally or due to human activities, the transition to nutrient-limited production occurs at higher levels of annual rainfall. In cases of enhanced run-on, the transition to water-limited production occurs at an annual rainfall of less than 300 mm, even in West Africa. But where soils are of greater than average fertility, or when mineral or organic fertilizers are used, the transition to water-limited production occurs at an annual rainfall of more than 300 mm.

Areas with nutrient-limited production can be differentiated based on the degree of deficiency of different nutrients. Nitrogen is the most critical limiting factor in large parts of West Africa, but phosphorus can be equally or more limiting. Agricultural practices may cause potassium to become the limiting factor. The nature of the deficiency depends also on the nature of the crops and/or livestock tended. For example, leguminous crops are usually limited by phosphorus, since they can obtain nitrogen from the air. Cattle may be in trouble on rangeland limited by nitrogen, while goats may still thrive by browsing greenery from shrubs and trees.

Water is not the only factor that limits plant production at levels of rainfall below the threshold for nutrient-limited production. At very low levels of annual rainfall, the vegetation itself may become limiting; the amount of antecedent biomass at the beginning of the rainy season may be too low to allow efficient use of the small amounts of available water. This may also occur at higher rainfall if exploitation of vegetation causes its degradation.

Case studies

Mixed maize-cassava production system in the coastal savannah of Togo

Experimental set-up

In southern Togo, farmers use a mixed maize-cassava production system with occasional legumes (groundnut, cowpea) and tree crops (oil and coconut palms, mango trees). The annual weather is tropical with a bi-modal rainfall pattern, i.e. about 300 to 500 mm between March and July (first rainy season) and about 150 mm between September and November (second rainy season). Farmers can, in principle, grow two maize crops per year, but risks of total crop failure are high in the second season due to the erratic nature of rainfall distribution. From 1999-2002, a trial was initiated in the village of Djaka Kopé (6º28'N, 1º38'E) to compare maize mono-cropping (one maize crop in the main wet season) with a maize-mucuna relay intercropping system (maize in the main wet season and a mucuna cover crop in the second wet season). The objectives of the field trials were (1) to determine the response of maize to fertilizer applied with and without a mucuna short fallow (MSF) and (2) to examine the effectiveness of MSF in conserving soil water and improving mineral fertilizer use efficiency in the succeeding maize crop. Prior to the experiments reported, farmers used the fields for maize or maize-cassava mixed cropping in Djaka Kopé for at least 10 years.

With the maize-mucuna relay intercropping system, farmers sow mucuna in between maize plants of about 6 weeks old. After maize harvest, the mucuna covers the soil during the short rainy season, smothering weeds and leaving a thick mulch at the end of its life cycle (6-7 months, accumulating on average about 6 t ha^{-1} of above-ground dry matter at maturity).

After hand clearing, mucuna shoots (leaves+stems) and maize crop residues were incorporated by hand hoeing during the land preparation. As the incorporation of mucuna shoot and maize stover is very labour demanding, it was not completely incorporated and a part was left on the soil surface as mulch. Maize is sown at 0.8 m x 0.4 m distance, at 2 plants $hill^{-1}$ and mucuna at 0.8 m x 0.8 m distance and 1 plant $hill^{-1}$. Soils in Djaka Kopé are rhodic ferralsols (FAO, 1988), locally known as *terre de barre*. Soil texture is predominantly sandy, with a clay content of approximately 9 % in the surface and 37 % in the subsoil (Tossah, 2000). The experimental set-up was a randomised complete block design with four replicates and 9 treatments for both the maize mono-cropping system and the maize-mucuna relay system.

Plot size was 6 m x 6 m. Factors were urea-N application at 0, 50 and 100 kg N ha^{-1} applied in two equal splits at 15 days after sowing (DAS) and 45 DAS and P-application (as triple super phosphate, TSP) at 0, 20 and 40 kg P ha^{-1}, applied at 15 DAS.

All plots received a yearly basal application of 100 kg K ha^{-1} as potassium sulphate (42% K, 19% S) to avoid that K or S would limit crop growth, applied in two equal splits at 15 DAS and 45 DAS. Rhodic ferralsols in Djaka Kopé are known to have very low K supplying capacity (Van Reuler & Tamelokpo, 1997).

Results and discussion

Maize grain yield without MSF nor N or P fertilizer steadily increased from a low 0.4 t ha^{-1} in 1999 to 2.8 t ha^{-1} in 2001 (Table 1), apparently profiting from residual effects of K application and incorporation of crop residues. With MSF, corresponding yields were 0.6 t ha^{-1} in 1999 and 3.9 t ha^{-1} in 2001, illustrating a strong beneficial effect of MSF on yield ($P < 0.001$), especially for the 0 and 50 kg N ha^{-1} treatments.

Significant additional yield increases were, therefore, obtained as a result of N fertilizer and MSF interaction ($P < 0.001$). Yields in 2002 without MSF were relatively low because of poor crop establishment. In the MSF treatments, moisture was better conserved as a result of the mulching effect of the mucuna residues.

In the current experimental set-up, this effect was seen once in four years. Farmers are, however, aware of the beneficial effect of mucuna.

Simulation modelling techniques may be employed to investigate the frequency of a significantly better crop establishment because of a mucuna mulch over a period of say about 20 to 30 years. Average soil water content during the period of maize growth was significantly higher after MSF (Table 2). Mulching has been shown to induce lower soil temperature, greater soil water retention (De Vleeschauwer *et al.*, 1978; Buerkert *et al.*, 2000), increased root density and enhanced lateral growth and abundance of roots (Lal, 1979; Maurya & Lal, 1981), which may all result in improved water and nutrient use efficiency. Indeed, the relationship between grain yield and nutrient uptake is shifted by MSF (Figure 1).

Data plotted to illustrate the relationship between grain yield and nutrient uptake revealed that most of the point showing the association between grain yield and N uptakes after two successive MSF are distributed above and those without MSF below the fitting line, showing the beneficial effect of MSF on nutrient use efficiency.

The most likely explanation for this better N use is that MSF provides other non-nutritional benefits.

These non-nutritional benefits from cover crops have been ascribed to improvement of soil structure through physical soil protection (from surface mulched residues), suppression of diseases and release of growth-promoting substances (Baldock *et al.*, 1981; MacRae & Mehuys, 1985; Osunlaja, 1990), resulting in a better conservation and use of N and water.

Sorghum-based production system in the Soudan savanna of Burkina Faso

Experimental-setup

Two trials were conducted at the Saria Agricultural Research Station (12°16'N, 02°09'W) in Burkina Faso in the northern part of the Soudan savanna agro-ecological zone (Fontes & Guinko, 1995). Average annual rainfall over the last 30 years was about 800 mm. Rainfall is mono-modal, lasting from May to October. Soils at the station are predominantly ferric Lixisols (FAO-UNESCO, 1994) with an average slope of 1.5% and a hardpan at a depth of 0.7 m.

The textural class according to USDA system is sandy loam in the 0-30 cm layer (63% sand, 24% silt, 13% clay). Average bulk density is 1.7 at 0-15 cm layer. Soils have very low organic C content (3.8 g kg^{-1}), N (0.4 g kg^{-1}), exchangeable K (0.05 me 100 g^{-1}), CEC (1.83 me 100 g^{-1}) and available Olsen P (13 mg kg^{-1}) (Sedogo, 1993).

The objective of the first experiment was to investigate the effectiveness of the combined application of fertilizer N (60 kg urea-N ha^{-1}) and various organic amendments including 10 t ha^{-1} of sorghum stover, 10 t ha^{-1} of cattle/goat manure, 10 t ha^{-1} of aerobic compost and 10 t ha^{-1} of anaerobic compost, on soil carbon, residual soil water content and sorghum performance.

Prior to the experiments, the field for the first trials was left to 10 years weedy fallow. The experiment is being conducted since 1980. The experimental design is a 5^2 factorial in six replicates, consisting of 60 plots (5.2 * 4 m).

The factors investigated were amendment and mineral fertilizer (urea). Amendments were applied once yearly just after ploughing. Urea was applied in two equal splits and all plots received a yearly basal application of 13 kg P ha^{-1} as SSP and 25 K ha^{-1} as potassium sulphate to avoid K and P deficiency. Nitrogen agronomic efficiency was calculated as kg additional grain yield produced per kg fertilizer N applied.

The objective of the second experiment was to assess the combined effectiveness of soil water conservation (SWC) measures and the application of organic and inorganic sources on soil water content and sorghum performance. The experiment was conducted from 2001 to 2002, combining soil and water conservation (SWC) measures (stone rows and *Adropogon gayanus* grass strips) and organic/mineral nitrogen source on sorghum production (*Sorghum bicolor* L. Moench).

The design was a randomised Fischer block with nine treatments and two replicates, including stone rows (without fertilizer application, with urea N, with compost), grass strips (without fertilizer application, with urea N, with compost), compost without SWC measures, urea without SWC measures and the control without inputs and SWC measures.

Each plot (100 m long and 25 m wide) was isolated from the surrounding area by a 0.6 m high earth bund. In each plot, subplots of 10 m by 2 m were delimited in the preceding 1999 rainy season using stone rows or grass strips to investigate sorghum yield and soil water variation.

Each stone row consisted of two rows of stones (about 0.25 m high) placed in a furrow and the grass strip comprised three rows of grass of 0.3 m wide.

In all plots, a 110-day sorghum variety (Sariasso14) was sown across the slope in rows by hand at the rate of 31 250 seedlings per hectare (0.8 m x 0.4 m) after two ox-drawn ploughs. Manure, compost and urea were

Table 1 Maize grain yield (t ha^{-1}) in Djaka Kopé during four years with and without mucuna short fallow (MSF) and N application (0, 50 and 100 kg ha^{-1}) and P application (0, 20 and 40 kg ha^{-1}). Data from 1999 (Yr 1) to 2002 (Yr 4)

	Without MSF												**With MSF**											
	Yr1			Yr2			Yr3			Yr4			Yr1			Yr2			Yr3			Yr4		
	P0	P20	P40	P0	P20	P40	P0	P20	P40	P0	P20	P40	P0	P20	P40	P0	P20	P40	P 0	P 20	P40	P 0	P20	P40
N0	0.4	0.7	0.5	1.3	1.7	1.4	2.8	2.8	2.5	1.0	2.2	2.6	0.6	0.5	0.6	2.3	2.2	2.1	3.9	4.0	3.6	3.3	3.5	4.1
N50	1.2	1.6	1.3	2.2	2.7	2.2	3.3	3.8	3.6	1.2	2.8	3.2	1.5	1.9	1.7	2.9	2.8	2.8	4.3	5.2	4.7	3.8	4.6	4.4
N100	1.5	2.1	1.7	2.5	2.9	2.7	4.1	4.7	4.2	1.1	2.6	3.3	1.6	2.2	2.0	2.9	2.9	2.9	4.3	4.9	4.8	3.6	3.8	4.1
LSD$_{(0.05)}$	0.6																							
CV (%)	18.0																							

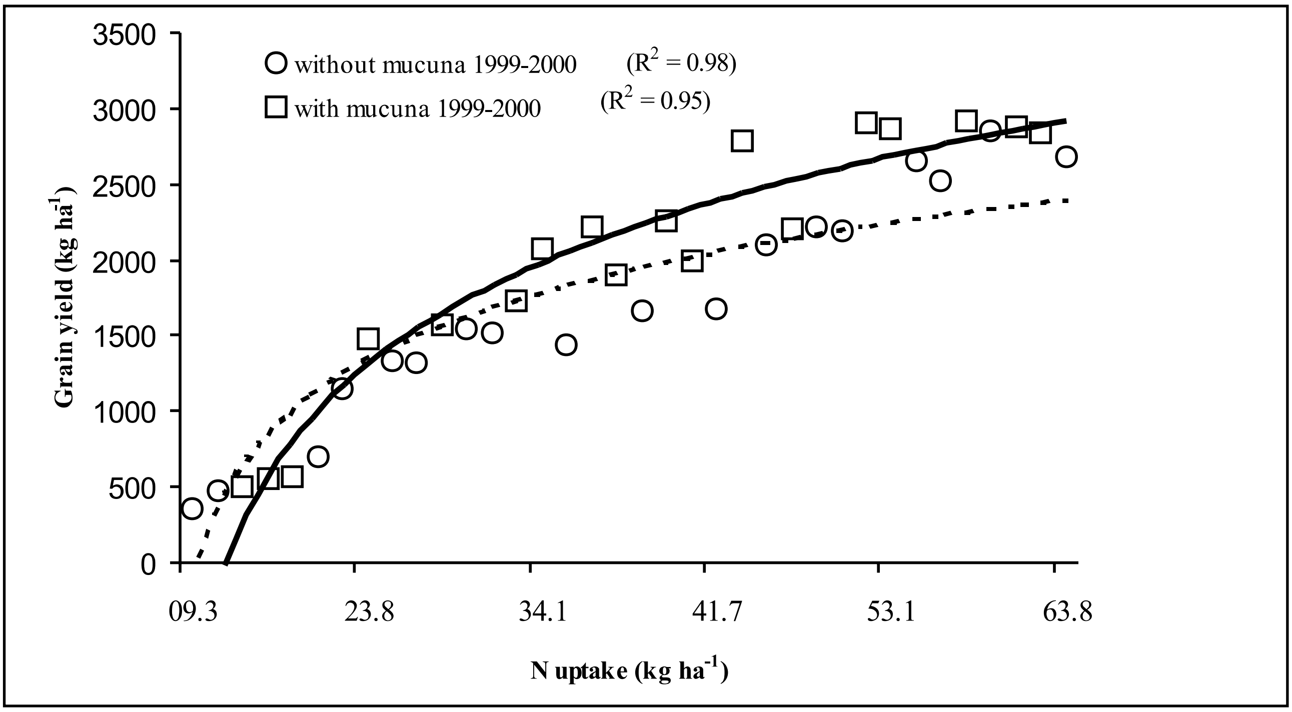

Figure 1 ***Effect of mucuna short fallow on N uptake-yield building relationship by maize (1999-2000)***

Table 2 ***Gravimetric soil water content (%) as affected by various soil organic amendments in Saria (Burkina Faso, 10 t ha^{-1}) and Djaka Kopé (Togo, 6 t ha^{-1})***

Site		**Saria**				**Djaka Kopé**	
Depth (cm)	Control	Straw	Manure	AC	Ana C	Control	Mucuna
0-15 cm a)	4.64	4.29	5.02	4.94	4.24	4.76	6.89
15-40 cm b)	7.13	7.83	6.3	7.22	6.24		
CV (%)	36.0 a	26.0 b				35.0	
$LSD_{0.05}$						1.8	
Probability		ns a)	ns b)			P < 0.05	

ns not significant; a and b at 0-15 cm and 15-45 cm, respectively; AC aerobic compost, Ana C anaerobic compost

Table 3 ***Soil carbon content (0-10 cm depth) as affected by 8-year application of 10 t ha^{-1} of various organic amendments in Saria (Burkina Faso)***

Amendment	**Total organic C (%)**		**Total N content (%)**	
	without N	**with N**	**without N**	**with N**
Fallow	0.42	–	0.034	–
No amendment	0.39	0.35	0.024	0.024
Straw	0.46	0.48	0.030	0.031
Manure	0.44	0.42	0.030	0.033
Aerobic compost	0.46	0.44	0.032	0.032
Anaerobic compost	0.51	0.46	0.035	0.033

Sedogo *et al.* (1989)

applied each year at a rate of 50 kg N ha^{-1}, corresponding to the Burkina Faso recommended manure/compost rate of about 5 to 7 t ha^{-1}. Urea was applied in two equal splits at 21 days and 56 days after planting during hand hoeing. All plots received a yearly basal application of 20 kg ha^{-1} P (TSP) to avoid P deficiency.

Results and discussion of experiment 1

Results indicated a yield response and maintaining soil organic carbon (SOC) when high manure and compost rate (10 t ha^{-1}) are applied (Table 3, Figure 2). Application of mineral fertilizer led to substantial yield increases. Grain yields after straw application were the lowest while those

Table 4 ***Chemical composition of organic soil amendments (OSA) used in the experiment B in Saria (Burkina Faso)***

	1981[a]			**1988** [b]		
OSA	**C total (%)**	**N total**	**C/N**	**C total (%)**	**N total**	**C/N**
Straw	39.4	1.47	93	42.5	0.60	71
Manure	21.7	0.42	15	22.3	1.27	18
Aerobic compost1)	32.5	0.76	43	17.0	0.88	19
Anaerobic compost2)	42.2	0.52	81	30.6	0.98	31

[a] Sedogo, 1981; [b] Bonzi, 1989; [1] 100% sorghum stover; [2] 75% sorghum stover + 25% cow manure

observed after manure application were the highest. Nitrogen agronomic efficiency was the highest in manured plots (13.3 kg kg^{-1}), followed by plots with aerobic (13.0 kg kg^{-1}) and anaerobic (4.5 kg kg^{-1}) compost. The results reflect the impact of the quality of organic amendments (Table 4) on crop yield and SOC. The higher grain yields and nitrogen agronomic efficiency observed on manured plots as compared to other organic amendments may be attributed to higher nutrient (macro- and micro-nutrient as well) supply/release from the biologically-active pools of manure (Buresh *et al*., 1997; Giller *et al.,* 1997). Amendments with low C/N ratio, lignin and polyphenol contents decomposed rapidly, having a high direct nutrient effect and those with a high C/N ratio, lignin and polyphenol contents decomposed and released nutrients slowly, contributing little to direct nutrient supply (De Ridder & Van Keulen, 1990).

Values of SOC in the soil demonstrate that the addition of the amendments at 10 t ha^{-1} for 8 years led to small increases in soil C and N contents (Table 3). The increase of SOC observed in anaerobic composted plots was more pronounced than in other plots. The carbon content in the stover and anaerobic compost was relatively higher as compared to other organic amendments, showing the close relationship between the quality of amendments and the evolution of organic C in the soil. Pichot *et al.* (1981) found that annual applications of 60 t ha^{-1} of cattle manure increased soil C from 2.5 to 6.6 g kg^{-1} after 18 years at Saria, Burkina Faso.

At Kabete in Kenya, addition of 10 t ha^{-1} of cattle manure combined with return of all crop residues failed to prevent a decline in the SOM contents in an Alfisol cropped annually to maize and beans (Smaling *et al.,* 1997). A test of different soil fertility management practices in an 18 yr-old experiment including addition of (i) mineral fertilizers, (ii) cattle manure, (iii) retention of maize stover and (iv) crop rotations, revealed that all management strategies resulted in a net decline of soil organic C after 18 yr of maize-bean rotation, except the treatment receiving fertilizer, manure and stover, where the least soil C was lost (Kapkiyai *et al.,* 1999).

In this experiment, soil water content was not affected neither by the soil organic content nor the type of organic amendments (Table 2). This suggests that when aiming at improving water retention capacity of sandy soils in the

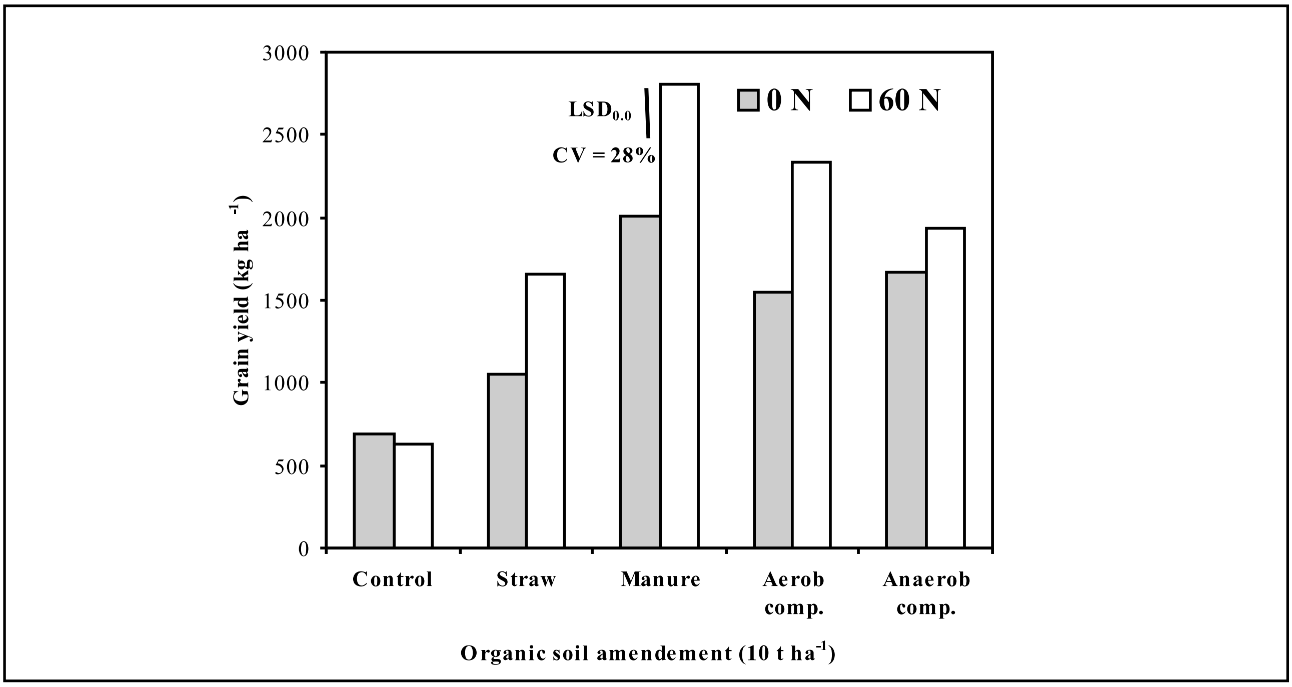

Figure 2 ***Sorghum grain yield (kg ha^{-1}) as affected by organic amendments and fertilizer N rates at Saria, Burkino Faso, 2002***

semi-arid zone of Burkina Faso, organic soil amendment may not be an effective measure. The results are in accordance with the studies of Cisse & Vachaud (1987) who showed that on the sandy soils in semi-arid West Africa, water storage capacity was not modified by long-term manure application.

Results and discussion of experiment 2

During the two years of the study reported here, all treatments reduced runoff compared to control plots (Table 5). Runoff in treatments with stone rows was generally less than in treatments with grass strips when compared in pairs (T_{SR}/T_{GS}; T_{SRC}/T_{GSC}; T_{SRU}/T_{GSU}). There were significant differences in soil water content between treatments (Table 5). Soil water content in the rooting zone was higher in plots with soil management technologies than in the control plots. Barriers formed by stone lines or grass strips delay the onset of runoff, accumulating more water that infiltrates in these plots than in the control plots. Plots with stone rows were wetter than those with grass strips. Treatments with organic amendments or mineral fertilizer were wetter than control plots but less dry than treatments with stone rows or grass strips alone. This indicates that stone rows and grass strips play a major role in collecting water and increasing infiltration. Plots with fertilizer were wetter than plots with organic inputs. Apparently, water consumption in the plots with organic input was greater than in the plots without. The higher water consumption in the plots with organic input can be ascribed to the probably higher root density and the vigorous lateral root growth (Hafner *et al.*, 1993). In this study, soil water retention seems not to be affected by organic inputs as usually reported. These results seem to be supported by a long-term crop residues management experiment on a sandy soil in Niger where the addition of crop residues had no effect on soil water use or water-holding capacity (Bationo *et al.*, 1993).

The treatment effect on sorghum grain and straw yields was statistically significant for the three years (Table 6). However, the crop production on plots with only SWC measures without nutrient was not significantly different from that of the control plots without SWC measures. Furthermore, water use efficiency (WUE) between treatments when compared (Table 6) showed only slight differences of WUE between composted or fertilized plots without SWC measures and those where these were combined. This suggests that water was not a limiting factor in these years. Highest grain yield and water use efficiency were observed in organic fertilized plots, followed by urea-fertilized plots. Similar results were observed for straw yield. Combining urea with stone rows or grass strips increased grain yield by 95% and 40 % compared to stone rows and grass strips, respectively. This indicates that under the average annual rainfall in this semi-arid region (even when well distributed in time), implementing SWC measures alone without addition of nutrients will not produce higher yields (Zougmoré *et al.*, 2000).

Conclusions

In the coastal savannah of Togo, mucuna mulching contributed greatly to grain yield increase and improved nutrient use efficiency. These were ascribed, among others, to a better water conservation in the soil. Under water-limited growing conditions, such as the coastal savannah of Togo, mucuna-technology is crucial when aiming at sustainable and market-oriented maize production. Mulching may not be practical and even conflicting where (for instance in the semi-arid zone) crop residues are needed for animal feeding. In the semi-arid zone of Burkina Faso, composting and water conservation technologies such as grass strips and stone rows were equally effective in reducing runoff. Plots with stone rows were significantly wetter than those with grass strips. This indicates that stone rows could play a key role in collecting and conserving rainwater in Burkina Faso. Though the plots with soil and water conservation (SWC) measures were wetter than the plots without, crop production on both plots (with or without SWC)

Table 5 Volumetric soil water content in the root zone (%) for years 2001 and 2002 as affected by organic amendments and soil and water conservation measures at Saria, Burkina Faso

Amendments and SWC measures	Date of measurement		Runoff (%)	
	27/08/2001	15/07/2002	2001	2002
T_o	10.1 d	10.1 cd	0	0
T_{SR}	12.8 b	11.4 b	71	71
T_{GS}	12.1 c	10.3 c	65	70
T_{SRC}	10.9 d	08.6 f	74	94
T_{SRM}/T_U	10.4 d	10.3 c	51	53
T_{GSC}	13.4 b	09.3 e	22	57
T_{GSM}/T_C	11.6 c	09.8 d	63	84
T_{SRU}	14.4 a	12.4 a	46	49
T_{GSU}	10.5 d	10.0 cd	32	87
Probabilty	< 0.001	< 0.001		

Zougmoré *et al.*, 2000

Table 6 Sorghum performance and water use efficiency as affected by soil and water conservation measures and organic soil amendments and fertilizer N, Saria, Burkina Faso, in 2001 and 2002

Amendments and	**Grain yield (kg ha^{-1})**		**Water use efficiency (kg mm^{-1})**	
SWC measures	**2001**	**2002**	**2001**	**2002**
T_o	1099 ab	1164 d	5.9 ab	4.3 d
T_{SR}	1226 ab	1308 cd	6.4 ab	5.0 cd
T_{GS}	896 b	983 d	4.5 b	3.6 d
T_{SRC}	2535 a	2766 a	11.5 a	10.1 a
T_{SRM}/T_U	2106 ab	1403 c	8.6 ab	5.3 cd
T_{GSC}	2338 ab	2536 b	10.6 a	9.7 b
T_{GSM}/T_C	2278 ab	2385 b	10.2 a	8.8 b
T_{SRU}	1796 ab	1511 c	8.7 ab	6.2 c
T_{GSU}	1537 ab	1411 c	7.6 ab	5.2 c
Probabilty	< 0.05	< 0.05	< 0.05	< 0.05

Zougmoré *et al.* (2000)

T_o control, T_{SR} stone rows (SR), T_{SRC} SR + compost, T_{GS} grass strips (GS), T_{GSC} GS + compost, T_{SRM}/T_U SR + manure, T_{GSM}/T_C GS + manure, T_{SRU} SR + fertilizer N, T_{GSU} GS + fertilizer N

were nearly the same. This suggests that, under the average annual rainfall in Burkina Faso, improved water conservation alone without addition of nutrients may not result in higher yield. Nutrients will often be more limiting than water as soil fertility is very poor. Yield was significantly influenced by the quality of soil amendments, though the soil water content was not. Stone rows and grass strips conserved soil water but did not increase crop performance significantly. The results provide evidence of appreciable improvement of nutrient and water use efficiency when both SWC measures and nutrient amendments are integrated. The synergetic effect deriving from improved water and nutrient use through integrated soil fertility management may increase crop productivity, depending on judicious management of the most limiting production factor.

The contrasting effects of organic soil amendments on water conservation and crop performance obtained in both agro-ecological zones revealed that water and nutrient conservation research and recommendations need to be context specific, including agro-ecology, ecotope, soil type and socio-economics. The diversity and dynamics of farmer reality in dryland areas will require a farmer-participatory learning and action research approach in order to ensure fine-tuning of promising integrated water and nutrient management options.

References

Baldock, J.O., Higgs, R.L., Paulson, W.H., Jackobs, J.A. & Shrader, W.D., 1981. Legume and mineral N effects on crop yields in several crop sequences in the Upper Mississippi Valley. *Agronomy J.* 73, 885-890.

Bationo, A. & Mokwunye A.U., 1991. Role of manures and crop residue in alleviating soil fertility constraints to crop production. With special reference to the Sahelian and Sudanian zones of West Africa. *Fertilizer Research* 29, 117-125.

Bationo, A., Christianson, C.B. & Klaij M.C., 1993. The effect of crop residues and fertilizer use on pearl millet yields in Niger. *Fertilizer Research* 34, 251-258.

Bonzi, M., 1989. Etude des techniques de compostage et évaluation de la qualité des composts: Effets des matières organiques sur les cultures et la fertilité des sols. Mémoire d'Ingénieur du développement Rural, IDR Université de Ouagadougou, Burkina Faso, 61 pp.

Breman, H., Rob Groot, J.J. & Van Keulen, H., 2001. Resource limitation in Sahelian agriculture. *Global Environmental Change* 11, 59-68.

Breman, H. & Van Reuler, H., 2003. Integrated soil fertility management to trigger agricultural intensification and to stop environmental degradation in Africa. ASA paper, International Fertilizer Development Center (IFDC).

Buerkert, A., Bationo, A. & Dossa, K., 2000. Mechanism of residue mulch-induced cereals growth increases in West Africa. *Soil Sci. Soc. Am. J.* 64 (1), 346-358.

Buresh, R.J., Sanchez, P.A. & Calhoun, F., 1997. Replenishing soil fertility in Africa. *Proceedings of an international symposium*, held at the 88th Annual Meetings of the American Society of agronomy and the Soil Science Society of America, Special Publication number 51, Madison, Wisconsin, USA.

Cisse, L. & Vachaud, G., 1987. Effet d'un amendement organique sur l'infiltration, les coefficients de transferts hydriques, et l'évaporation d'un sol sableux dégradé du Nord-Sénégal. *Hydrol. Continent* 2, 15-28.

De Ridder, N. & Van Keulen, H., 1990. Some aspects of the role of organic matter in sustainable intensified arable farming systems in the West-African semi-arid tropics (SAT). *Fertilizer Research* 26, 299-310.

De Vleeschauwer, D., Lal, R. & De Boodt, M., 1978. The comparative effects of surface applications of organic mulch versus chemical soil conditioners on physical and chemical properties of the soil and on plant growth. *Catena* 5, 337-349.

FAO, 1988. Soil map of the World, Rome.

FAO-UNESCO, 1994. Soil map of the World. ISRIC, Wageningen.

Fontes, J. & Guinko, S., 1995. Carte de la végétation et de l'occupation du sol du Burkina Faso. Note explicative. Ministère de la coopération française, Toulouse.

Giller, K.E., Cadisch, G., Ehaliotis, C., Adams, E., Sakala, W. & Mafongoya, P., 1997. Building soil nitrogen capital in Africa. In Replenishing Soil Fertility in Africa. Eds. R. Buresh, P.A. Sanchez and F. Calhoun. *Soil Sci. Soc. Am. and Am. Soc. Agronomy*. SSSA Special Publication Number 51.

Hafner, H., George, E., Bationo, A., Martin, P. & Marschner, H., 1993. Effect of crop residues on root growth and nutrient acquisition of pearl millet in an acid sandy soil in Niger. *Plant and Soil* 150, 117-127.

Kapkiyai, J.J., Karanja, N.K., Qureshi, J.N., Smithson, P.C. & Woomer, P.L., 1999. Soil organic matter and nutrient dynamics in a Kenya nitisol under long-term fertilizer and organic input management. *Soil Biology and Biochemestry* 31, 1773-1782.

Lal, R., 1979. Influence of with- and between-row mulching on soil temperature, soil moisture, root development and yield of maize (*Zea mays* L.) in a tropical soil. *Field Crop Research* 1, 127-139.

Macrae, R.J. & Mehuys, G.R., 1985. The effect of green manuring on the physical properties of temperate soils. *Adv. Soil Science* 3, 71-94.

Maurya, P.R. & Lal, R., 1981. Effect of different mulch materials on soil properties and the root growth and yield of maize (*Zea mays* L.) and cowpea (*Vigna unguiculata*). *Field Crop Research* 4, 33-45.

Osunlaja, S.O., 1990. Effect of organic soil amendments on the incidence of stalk rot of maize. *Plant and Soil* 127, 237-241.

Penning De Vries, F.W.T. & Djiteye., M.A., 1991. La productivité des pâturages sahéliens. Une étude des sols, des végétations et de l'exploitation de cette ressource naturelle. Agric. Res. Rep. 918, PUDOC, Wageningen. 523 pp.

Pichot, J., Sedogo, M.P., Poulain, J.P. & Arrivets, J., 1981. Evolution de la fertilité d'un sol ferrugineux tropical sous l'influence de fumures minérales et organiques. *Agronomie Tropicale* 36, 122-133.

Sedogo, P.M., 1981. Contribution à l'étude de la valorization des résidus culturaux en sol ferrugineux et sous climat tropical semi-aride. Matière organique du sol, nutrition azotée des cultures. Thèse Docteur Ingénieur, INPL Nancy, 135pp.

Sedogo, P.M., Lompo, F. & Hien V., 1989. Etude du role spécifique de la matière organique dans l'évolution des sols sous culture. Communication présentée à la 7 ème conférence internationale de l'IFOAM, 2-5 Janvier 1989, Ouagadougou, 30pp.

Sedogo, P.M., 1993. Evolution des sols ferrugineux lessivés sous culture : incidence des modes de gestion sur la fertilité. Thèse de doctorat, Université Nationale de Côte d'ivoire (Abidjan) et la Faculté des Science et Technique du Burkina Faso (Ouagadougou).

Sivakumar, M.V.K. & Wallace, J.S., 1991. Soil water balance in the Sudano-Sahelian zone: Need, relevance and objectives of the workshop. In Soil water balance in the Sudano-Sahelian Zone. Eds. M.V.K. Siwakumar, J.S. Wallace, C. Renard and C. Giroux. *Proc. Int. Workshop Niamey* 3-10. IAHS Press Institute of Hydrology Wallingford, UK.

Smaling, E.M.A., Nandwa, S.M. & Janssen, B.H., 1997. Soil fertility in Africa is at stake. In Replenishing Soil Fertility in Africa. Eds. R. Buresh, P.A. Sanchez and F. Calhoun. *Soil Sci. Soc. Am. and Am. Soc. Agronomy* 47-61. SSSA Special Publication Number 51.

Tossah, B.K., 2000. Influence of soil properties and organic inputs on phosphorus cycling in herbaceous legume-based cropping systems in the West African derived savanna. Ph.D. Thesis nr. 428. K.U. Leuven (Belgium). 104 pp.

Van Reuler, H. & Tamelokpo, A.F., 1997. A farmer-oriented approach to soil fertility management including the creation of a revolving fund – a case-study from southern Togo. *IBSRAM Proc*. No. 10. Abengourou, Côte d'Ivoire.

Zougmoré, R., Guillobez, S., Kambou, N.F. & Son, G., 2000. Runoff and sorghum performance as affected by the spacing of stones lines in the semi-arid Sahelian zone. *Soil and Tillage Research* 56, 175-183.