Improving soil fertility through the use of organic and inorganic plant nutrient and crop rotation in Niger

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Abstract

Food production can be increased through the integration of organic and inorganic nutrient sources coupled with proper land management. Niger is one of the poorest countries in the Sahelian zone of West Africa where soil fertility and rainfall are the most limiting factors for crop production. The majority of the people in this region depend on subsistence agriculture for their livelihood. The population pressure has decreased the availability of arable land and the use of extended fallow periods to restore soil fertility is not possible.

Research results have shown that yields can be increased up to five times with the improvement of soil fertility using a combination of soil tillage, organic and inorganic fertilizers than under traditional practice. Crop yields have also been shown to increase substantially using rotation of cereals with legume or intercropping. Yields of pearl millet can be doubled following cowpea as compared to continuous pearl millet cultivation. These combinations can improve soil properties such as Organic carbon content, Cation Exchange Capacity (CEC) and pH.

There is however a constraint to the applicability of combining inorganic and organic fertilizers due to the high costs of inorganic fertilizers and the low availability of organic fertilizers at the farm level. But it can be addressed by incorporating grain legume production such as cowpea into the cropping system. The grain, which has high market value, can be sold for buying external inputs such as fertilizer and fodder used for animal feeding. The use of external inputs will result in an increasing biomass at farm level, which increases the crop residue for mulching to mitigate land degradation and increase productivity

Key words: Crop residue, market value, organic and inorganic nutrients, soil fertility, cropping system, millet, cowpea, soil tillage

Introduction

Niger is one of the poorest countries in the Sahelian zone of West Africa where soil fertility and rainfall are the most limiting factors for crop production. The majority of the people in this region depend on subsidence agriculture for their livelihood. The population pressure has decreased the availability of arable land and the use of extended fallow periods to restore soil fertility is not possible. According to the UNDP Human Development Index, Niger is ranked lowest globally in terms of life expectancy, education, and income in the world (UNDP 1999) According to FAO (website), the total food production in the Sahel has grown from 1961 to 1996 but this has been far much less than the population growth that has doubled over the same period thus, causing per capita food production to decline substantially.

Presently, traditional practices used by farmers are no longer productive (unsustainable and destructive to the environment) causing soil depletion and demanding more land (Stoorvogel and Smaling 1990). Farmers do not use external inputs, crop residue is removed from the fields every year and inadequate farming systems such as continuous cropping were used. Then land

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is degraded through erosion causing soil and nutrient loss from the topsoil containing organic matter and more nutrients. Soil loss of 190 t ha^{-1} year^{-1} has been measured on bare plots (Buerkert et al. 1996). There is therefore a need to change these traditional ways by adopting some long-term soil fertility management practices to increase food production.

Results of the last s years from a long-term trial started in 1986 will be presented to show the effect of phosphorus, nitrogen and organic matter management for sustainable land use in western zone of Niger. The effect of cropping systems such as rotation on soil fertility will also be discussed. The results demonstrate that introducing legume as cash crop can solve farmers' capacity to buy fertilizers.

Apart from increasing succeeding cereal yields, rotation system has other benefits effects such as crop-livestock integration in Sudano-Sahelian zone. Increasing the legume component in the cropping system will not only improve the soil conditions for the succeeding cereal crop, but will provide good quality livestock feed, manure production for organic amendments of the soils and also cash provision to ameliorate farmers livelihood and their capacity to buy fertilizers.

Materials and methods

The trial covers an area of over four hectares piece of land so that plots could be representative of a farm level. Four replications were made each with 14 plots. Plot dimensions were 50m × 10m and planted at the recommended density of 10,000 plants ha^{-1} for pure millet and 40,000 plants ha^{-1} for pure cowpea. A plot was included to represent farmer's traditional farming practice. Association plots were planted with 10,000 plantsha^{-1} for millet plus 5,000 plants for cowpea. No difference was made on phosphorus application; each plot received the recommended rate of 13 kg P ha^{-1} except the traditional (control) plot but each plot was divided into two parts with one part receiving crop residue and the other part left untreated. Each subplot was divided again in two parts with application of nitrogen on one sub-sub-plot and no nitrogen on the second. Half of the previous year crop residue produced was applied on the part of the plot treated and nitrogen was applied at 30 kg N ha^{-1} in two times of 15 kg. Among these 14 plots we have 9 main treatments, which included 5 intercrops (1–2–3–4–5) and 4 pure crops (6–7–8–9). An additional control (traditional) was added with local variety to be compared

Table 1. Main treatments of different plots in OPSCAR trial

Plot No	Treatment No	Fertilizer	Animal traction	Hand cultivation	Rotation
1	1	No	No	Yes	No
2	2	Yes	Yes	No	No
3	*3*	*Yes*	*Yes*	*No*	*Yes*
4	*3*	*Yes*	*Yes*	*No*	*Yes*
5	4	Yes	No	Yes	No
6	*5*	*Yes*	*No*	*Yes*	*Yes*
7	*5*	*Yes*	*No*	*Yes*	*Yes*
8	6	Yes	Yes	No	No
9	*7*	*Yes*	*Yes*	*No*	*Yes*
10	*7*	*Yes*	*Yes*	*No*	*Yes*
11	8	Yes	No	Yes	No
12	*9*	*Yes*	*No*	*Yes*	*Yes*
13	*9*	*Yes*	*No*	*Yes*	*Yes*
14	10	No	No	Yes	No

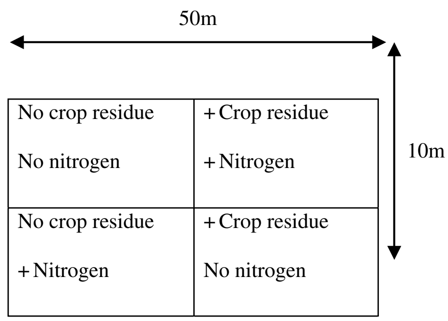

Figure 1. Subdivision of the main plot into four sub-sub-plots.

with the first one where improved variety was used (treatment 10). Treatments (3–5–7–9) were doubled to yield millet and cowpea the same year on 2 rotational plots for each treatment where rotation was used. Table 1 shows the plots and main treatments while Figure 1 shows how plots were subdivided. Data were collected while harvesting, millet panicle, grain and Stover were weighted and yields calculated. MSTAT was used to analyze data and table of ANOVA for interpretations.

Results and discussions

Management of Nitrogen

Nitrogen alone is not significant and it account only for 4% in the total variation, millet grain yield for the control plot was 79 kg ha^{-1} and it was only 107 kg ha^{-1} for a sole addition of 30 kg N ha^{-1} but the yield increased to 210 kg ha^{-1} when crop residue is added and to 1,012 kg ha^{-1} if P is added to the combination

Table 2. Effect of fertilizers, soil tillage, crop residue, cropping system on pearl millet grain yield; Sadore 1998–2003 cropping seasons

Treatments	Pure millet grain yield (kg.ha^{-1})							
	− Rotation				+ Rotation			
	− Crop residue		+ Crop residue		− Crop residue		+ Crop residue	
	−N	+N	−N	+N	−N	+N	−N	+N
Traditional	79	107	142	210				
Phosphorus + HC	445	734	681	1012	709	931	1077	1267
Phosphorus + AT	458	654	628	858	768	965	1016	1199

HC: hand cultivation, planting on flat; AT: Animal traction, planting on ridges.

(Table 2). It is clear enough that the effect of nitrogen is linked to P application and better with a combination of P and organic fertilizer. Christianson and Vlek (1991) used data from long-term experiment from the Sudano-Sahelian Zone to develop response function to N by pearl millet and sorghum and found that the optimum rate is 50 kg N ha^{-1} for sorghum and 30 kg N ha^{-1} for pearl millet. At these N rates the returns were 20 kg grain per kg N for sorghum and 9 kg grain per kg N for pearl millet.

Mughogho et al. (1986) found significant relationships between crop yields and N recovery. N losses averaged 20% in the humid and sub-humid zones with maize and were significantly less than the average loss of 40% found over all treatments in the Sudano-Sahelian zone. Bationo and Vlek (1998) reported that in the Sahelian zone, nitrogen use efficiencies (NUE) were 14% in plots without lime and phosphorus whereas this amount increased to 28% when P and lime were applied. Rotation of cereals with legumes could be a way to increase NUE: from 20% in the continuous cultivation of pearl millet to 28% when pearl millet was rotated with cowpea.

Phosphorus management

In the case studied millet grain yield did not increase with addition of nitrogen (79 to 107 kg ha^{-1}) but when phosphorus was added the yields increased significantly from 445 to 734 kg ha^{-1} (Table 2). The crop biomass also follows the same trend with P application (Table 3). The data in Table 2 indicates that from 1998 to 2003 the average control plot was 79 kg grain ha^{-1}. The sole addition of 30 kg P2O5 ha^{-1} without N fertilizers increased the average yield to 445 kg ha^{-1}. The addition of only 30 kg N ha^{-1} did not increase the yield significantly over the control and the average grain yield obtained was 107 kg ha^{-1}. It is now accepted that the replenishment of soil capital phosphorus is not only a crop production issue, but an environmental issue and P application is essential for the conservation of the natural resource base. The data further suggests that when P is applied the response to N can be substantial and with the application of 30 kg N ha^{-1} a pearl millet grain yield of 734 kg ha^{-1} was obtained as compared to 445 kg ha^{-1} when only P fertilizers were applied. This data clearly indicates that P is the most limiting factor

Table 3. Effect of fertilizers, soil tillage, crop residue, cropping system on pearl millet TDM yield; Sadore 1998–2003 cropping seasons

Treatments	Pure millet TDM yield (kg.ha^{-1})							
	− Rotation				+ Rotation			
	− Crop residue		+ Crop residue		− Crop residue		+ Crop residue	
	−N	+N	−N	+N	−N	+N	−N	+N
Traditional	641	962	987	1331				
Phosphorus + HC	2281	3224	3150	4296	3264	3970	4608	5459
Phosphorus + AT	2138	2932	2903	3927	3443	4452	4615	5565

HC: hand cultivation, planting on flat; AT: Animal traction, planting on ridges.

Table 4. Effect of fertilizers, soil tillage, crop residue, cropping system on cowpea fodder yield; Sadore 1998–2003 cropping seasons

Treatments	Cowpea fodder yield (kg ha^{-1})							
	− Rotation				+ Rotation			
	− Crop residue		+ Crop residue		− Crop residue		+ Crop residue	
	−N	+N	−N	+N	−N	+N	−N	+N
Traditional	293	519	503	530				
Phosphorus + HC					1051	1224	1105	1267
Phosphorus + AT					764	888	914	1091

HC: hand cultivation, planting on flat; AT: Animal traction, planting on ridges.

in those sandy Sahelian soils and there is no significant response to N without correcting first for P deficiency.

Phosphorus is the most limiting factor to crop production in the sandy soils of Sahelian zone. Available P in these soils is very low less than 2 mg P kg^{-1}. Manu et al. (1991) on a fertility study found that the amount of total P in these soils ranged from 25 to 340 mg kg^{-1} with a mean of 109 mg kg^{-1}.The low content of both total and available P parameters may be related to several factors such as parent materials, form in the soil and low level of organic matter. About 80% of the soils in sub-Saharan Africa are short of this critical nutrient element and without the use of phosphorus, other inputs and technologies are not effective.

The soils of the Soudano-Sahelian zone have very low capacity to fix P (Sanchez and Uehara 1980). P sorption maximum was determined using the method of Fox and Kamprath (1970) and the values of maximum P sorbed ranged from 27 mg kg^{-1} to 253 mg kg^{-1} with a mean of 94 mg kg^{-1}. Phosphorus deficiency is a major constraint to crop production and response to nitrogen is substantial only when both moisture and phosphorus are not limiting.

In this long-term soil management trials, crop residue and ridging and rotation of pearl millet with cowpea were also evaluated to determine their effect on Phosphorus Use Efficiency (PUE). The results showed that productivity of the sandy soils can be increased significantly with the adoption of improved crop and cropping systems, whereas the absolute control recorded 79 kg ha^{-1} of pearl millet grain; 1,267 kg ha^{-1} was obtained when phosphorus nitrogen and crop residue were applied and followed leguminous cowpea upon the previous season. Results indicated that for the total dry matter yield PUE increases from 126 with only P application to 228 when P is applied in combination with nitrogen, crop residue and to 318 in a rotation system (Table 6) cowpea fodder production was increased to 1267 kg/ha in the rotation system (Table 4) while the grain production was low and variable with an highest yield of only 213 kg/ha (Table 5). But the high value of cowpea products (Table 6) and its role in soil fertility through rotation play a lot in the promotion of cowpea crop in the promotion of cowpea crop in the system. In these sandy soils, ridge has no significant effect on grain production but a very small effect on biomass. Its effect can be observed early on development of crops and during poor rainfall year at the beginning of the raining season when wind erosion can reduce crop growth.

Table 5. Effect of fertilizers, soil tillage, crop residue, cropping system on cowpea grain yield; Sadore 1998–2003 cropping seasons

Treatments	Cowpea grain yield (kg ha^{-1})							
	− Rotation				+ Rotation			
	− Crop residue		+ Crop residue		− Crop residue		+ Crop residue	
	−N	+N	−N	+N	−N	+N	−N	+N
Traditional	37	39	43	39				
Phosphorus + HC					199	172	150	164
Phosphorus + AT					181	154	196	213

HC: hand cultivation, planting on flat; AT: Animal traction, planting on ridges.

Table 6. Total price of cowpea products compared to fertilizer used price in rotation system; Sadore 1998–2003 cropping seasons

Treatment	Yield/Prices	− Rotation				+ Rotation			
		− Crop residue		+ Crop residue		− Crop residue		+ Crop residue	
		−N	+N	−N	+N	−N	+N	−N	+N
Traditional	Grain yield	37	39	43	39				
	Fodder yield	293	519	503	530				
	Fertilizer used	0	0	0	0				
	Grain price	8325	8775	9675	8775				
	Fodder price	8790	15570	15090	15900				
	Total price	17115	24345	24765	24675				
	Fertilizer price	0	0	0	0				
	Benefits	17115	24345	24765	24675				
Phosphorus + HC	Grain yield					199	172	150	164
	Fodder yield					1051	1224	1105	1267
	Fertilizer used					167	232	167	232
	Grain price					44775	38700	33750	36900
	Fodder price					31530	36720	33150	38010
	Total price					76305	75420	66900	74910
	Fertilizer price					16700	23200	16700	23200
	Benefits					59605	52220	50200	51710
Phosphorus + AT	Grain yield					181	154	196	213
	Fodder yield					764	888	914	1091
	Fertilizer used					167	232	167	232
	Grain price					40725	34650	44100	47925
	Fodder price					22920	26640	27420	32730
	Total price					63645	61290	71520	80655
	Fertilizer price					16700	23200	16700	23200
	Benefits					46945	38090	54820	57455

HC: hand cultivation, planting on flat; AT: Animal traction, planting on ridges; Fertilizer: 100F cfa.kg^{-1}, cowpea grain: 225F cfa.kg^{-1}, cowpea fodder: 30F cfa.kg^{-1}.

Crop residues as organic matter

The PUE for millet TDM increased from 126 to 146 with application of crop residue and to 228 when crop residue was combined with nitrogen (Table 7). In the Sahelian zone a very significant effect between crop residue and mineral fertilizer was reported (Bakayoko et al. 2000). From a long-term experiment started since 1984 Bationo et al. (1993) found that grain yield declined to 160 kg ha^{-1} in unmulched and unfertilized

Table 7. Effect of fertilizers, soil tillage, crop residue, rotation on pearl millet TDM yield and PUE (phosphorus use efficiency); Sadore 1998–2003 cropping seasons

Treatments	Pure millet TDM yield (kg.ha^{-1})															
	− Rotation								+ Rotation							
	− Crop residue				+ Crop residue				− Crop residue				+ Crop residue			
	−N		+N		−N		+N		−N		+N		−N		+N	
	yield	PUE	yield	PUE	yield	PUE	yield	PUE	yield	PUE	yield	PUE	yield	PUE	yield	PUE
Traditional	641		962		987		1331									
Phosphorus + HC	2281	126	3224	174	3150	166	4296	228	3264	202	3970	231	4608	279	5459	318
Phosphorus + AT	2138	115	2932	152	2903	147	3927	200	3443	216	4452	268	4615	279	5565	326

HC: hand cultivation, planting on flat; AT: Animal traction, planting on ridges.

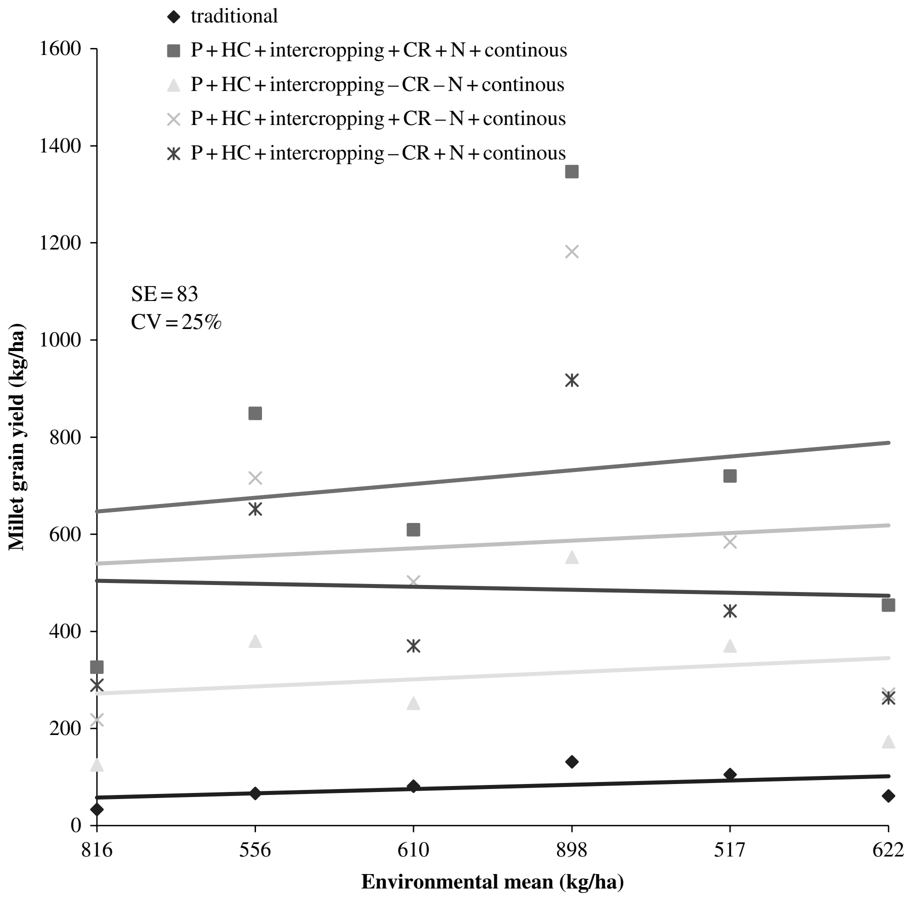

Figure 2. Long term effect of fertilizer, CR and cropping system on pearl millet grain yield, Sadore, 1998–2003.

plots. However, grain yield could be increased to 770 kg ha^{-1} with a mulch of 2 t crop residues per hectare and 1,030 kg ha^{-1} with 13 kg P plus 30 kg N ha^{-1}. The combination of crop residue and mineral fertilizers resulted in grain yield of 1,940 kg ha^{-1}. The application of crop residue can maintain soil organic carbon in the topsoil but continuous cultivation without mulching can reduce it. In the Sudanian zone, many reports have shown the effect of crop residue used as organic amendment (Bationo et al. 1995). Its application result in increasing soil pH, and exchangeable bases and decreased the capacity of the soil to fix phosphorus.

The data in Figures 2 and 3 clearly indicate the advantages of using crop residues both on pearl millet grain and total dry matter.

Soil organic matter is important for sustainable land use management resulting to retention and storage of nutrients, and increasing water holding capacity. Bationo et al. (1995) reported that continuous cultivation in the Sahelian zone has led to drastic reduction in organic matter and a subsequent soil acidification. Bationo and Mokwunye (1991) reported that in the Sudano-Sahelian zone, the effective cation exchange capacity (ECEC) is more related to organic matter than to clay, indicating that a decrease in organic matter will decrease the ECEC and subsequently the nutrient holding capacity of these soils. De Ridder. and van Keulen 1990 found that a difference of 1 g kg^{-1} in organic carbon results in a difference of 4.3 mol kg^{-1}. In many cropping systems few if any agricultural residues are returned to the soil. This leads to decline soil organic matter, which frequently results in lower crop yields or soil productivity.

The soils of the Sudano-Sahelian zone are inherently low in organic carbon. The concentration of organic carbon in their top soil is reported to average 2 mg kg^{-1}. This is due to the low root growth

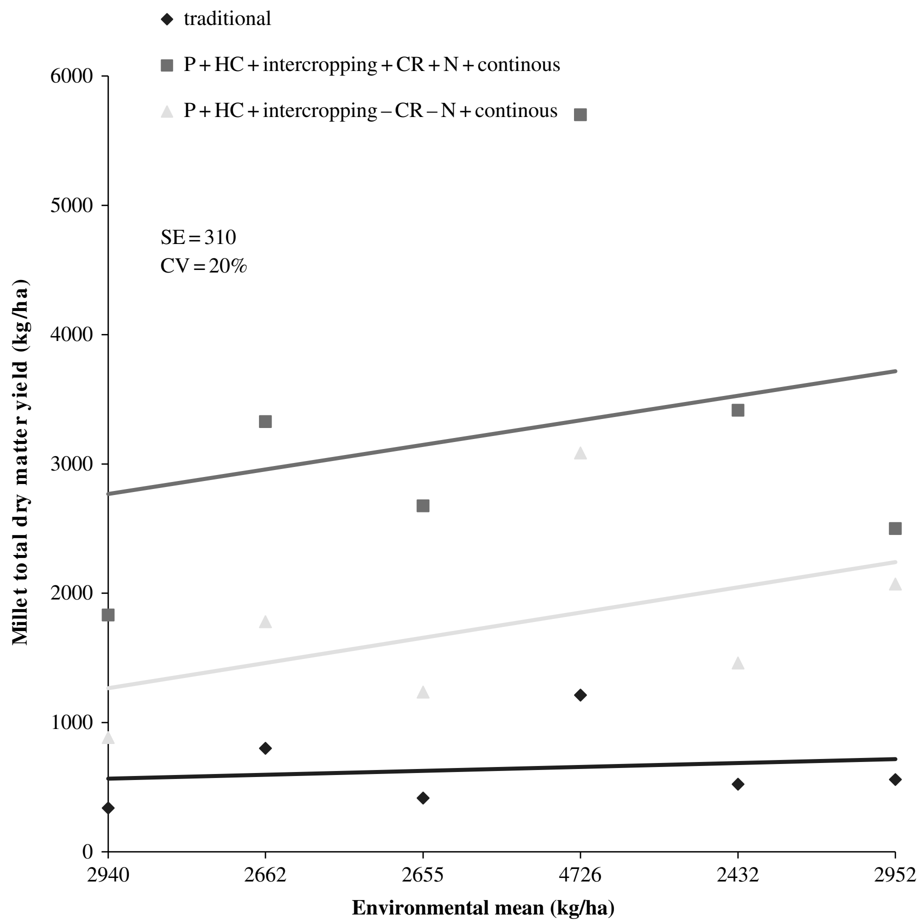

Figure 3. Long term effect of fertilizer, CR and cropping system on pearl millet total dry matter yield, Sadore, 1998–2003.

of crops and natural vegetation but also the rapid turnover rates of organic materials with high soil temperature and microfauna, particularly termites. Manu et al 1991 found in millet producing soils, an average soil Corg content of 7.6 g kg^{-1} with a range from 0.8 to 29.4 g kg^{-1}.

Soil management can have some effects the organic carbon contents. Bationo et al. 1995 found an evidence for rapid decline of organic carbone (Corg) levels with continuous cultivation of crops in the Sudano-Sahelian zone. It was also demonstrated that soil erosion can increase Corg losses from 2% to 6.3%. To prevent these losses, there is a need to practice some soil managements such as crop rotation, application of mineral fertilizers and mulching. Soil tillage will also have a significant effect on annual losses of Corg and more significant if combined to those managements.

Combining N, P and crop residue in production

Whereas treatments, meaning P accounted for 43% of the total variation, nitrogen accounted for 4% in the total variation indicating that P is the most limiting factors at this long-term trial. Crop residue accounted for 8% in the total variation. The sole addition of crop residue without N and P increased yield from 79 to 142 kg grain ha^{-1}. N increased this yield from 142 to 210 kg ha^{-1} and when P was combined with both N and crop residue, the yields increased to 1,012 kg ha^{-1}. So if millet can be rotated with cowpea, high grain production can achieved 1,267 kg ha^{-1} (Table 2).

The data in Table 3 clearly indicate the comparative advantage to combine organic and inorganic plant nutrients in the Sahel soils. A combination of crop residue, P and N achieved more yield as compared to crop residue alone. The biomass can be increased

Table 8. Effect of fertilizers, soil tillage, crop residue, intercropping on pearl millet grain and TDM yield and PUE (phosphorus use efficiency); Sadore 1998–2003 cropping seasons

Treatments	Millet grain and TDM yield (kg.ha^{-1})															
	grain								TDM							
	− Crop residue				+ Crop residue				− Crop residue				+ Crop residue			
	−N		+N		−N		+N		−N		+N		−N		+N	
	yield	PUE	yield	PUE	yield	PUE	yield	PUE	yield	PUE	yield	PUE	yield	PUE	yield	PUE
Traditional	79		107		142		210		641		962		987		1331	
Phosphorus + HC	309	18	489	29	579	34	717	39	1753	86	2142	91	2659	129	3242	147
Phosphorus + AT	455	29	584	37	620	37	779	44	1989	104	2430	113	2632	127	3274	149

HC: hand cultivation, planting on flat; AT: Animal traction, planting on ridges.

up to 4,296 kg ha^{-1} and 5,565 kg ha^{-1} when rotation was used. Combining organic resources and mineral inputs is one of the best ways of the Integrated Soil Fertility Management approach. It's also an issue to the availability of the crop residue for the next year.

Millet-cowpea intercropping

PUE is lower in the intercropping system with a range from 86 to 149 kg TDM kg^{-1} P whereas rotation gives a range from 202 to 326 (Tables 7 and 8). In our experiment trial, continuous intercropping either on

Table 9. Total price of cowpea products compared to fertilizer used price in intercropping system; Sadore 1998–2003 cropping seasons

		− Crop residue		+ Crop residue	
		−N	+N	−N	+N
Traditional	Grain yield	37	39	43	39
	Fodder yield	293	519	503	530
	Fertilizer used	0	0	0	0
	Grain price	8325	8775	9675	8775
	Fodder price	8790	15570	15090	15900
	Total price	17115	24345	24765	24675
	Fertilizer price	0	0	0	0
	Benefits	17115	24345	24765	24675
Phosphorus + HC	Grain yield	69	76	51	54
	Fodder yield	333	496	449	504
	Fertilizer used	167	232	167	232
	Grain price	15525	17100	11475	12150
	Fodder price	9990	14880	13470	15120
	Total price	25515	31980	24945	27270
	Fertilizer price	16700	23200	16700	23200
	Benefits	8815	8780	8245	4070
Phosphorus + AT	Grain yield	43	40	43	48
	Fodder yield	262	252	357	395
	Fertilizer used	167	232	167	232
	Grain price	9675	9000	9675	10800
	Fodder price	7860	7560	10710	11850
	Total price	17535	16560	20385	22650
	Fertilizer price	16700	23200	16700	23200
	Benefits	835	−6640	3685	−550

HC: hand cultivation, planting on flat; AT: Animal traction, planting on ridges. Fertilizer: 100F cfa.kg^{-1}, cowpea grain: 225F cfa.kg^{-1}, cowpea fodder: 30F cfa.kg^{-1}.

flat or ridge plot produce less millet and cowpea than rotation and cowpea production cannot support fertilizer needed. The benefit is higher for traditional with an average of 22,725 F cfa ha^{-1} while only an average of 7,477 F cfa ha^{-1} on flat plot and negative 668 F cfa ha^{-1} on ridge plot can be gained (Table 9). Fussell and Serafini (1985) reported yield advantages from 10–100% in millet-cowpea systems. Farmers seem to prefer intercropping because they believe to its yield stability in both good and poor rainfall years whereas rotation has best production only when rainfall is good Ntare (1989) reported yield advantages of 20–70% depending on the different combinations of pearl millet and cowpea cultivars. Traditional intercropping cover over 75% of the cultivated area in the Sudano-Sahelian zone, but the use and efficiency of fertilizers under these systems is not clear enough. The growth of these crops is rapid under P application and then competition between cereal and legume depend on their planting date; one can significantly reduce the yield of the other.

Crop rotation

The study demonstrates that including a combination of rotation, inorganic and organic nutrient sources have high potential in increasing pearl millet grain yields in the very poor Sahelian soils (Tables 2 and 3) and also millet biomass and cowpea fodder yields (Tables 4 and 5). Farmers can gain only an average benefit of 22,725 F cfa ha^{-1} from cowpea in the traditional way. This benefit can reach an average of 53,434 F cfa.ha^{-1} on flat plot and 49,328 F cfa.ha^{-1} on ridged plot (Table 6). It's clear that more benefits are possible with rotation system compared to the traditional and intercropping systems both on millet and cowpea. Despite the recognized need to apply chemical fertilizers for high yields, the use of fertilizers in West Africa is limited mainly by lack of capital and other socio-economic factors. Cheaper means of improving soil fertility and productivity are therefore necessary.

Nitrogen-15 (^{15}N) has been used to quantify the amounts of nitrogen fixed by cowpea under different soil fertility levels showed that nitrogen derived from the air (NDFA) varies from 65 to 88% and can reach 89 kg N ha^{-1} in the complete treatment where all nutrients were applied. In a comparison of different cropping systems, it have been shown that nitrogen use efficiency increased from 20% in continuous pearl millet cultivation to 28% when pearl millet was rotated with cowpea (Bationo et al. 1998). It is clear that although the above ground biomass of the legume will be used to feed livestock and not returned to the soil, rotation will increase not only the yields of succeeding cereal crop but also its nitrogen use efficiency. The different cropping systems have a significant effect on the soil organic carbon, which levels, was 0.22% in the continuous systems whereas it increased to 0.27% in the rotation systems. As a result of this, soil pH was higher in the rotation systems as compared to the continuous millet systems.

Conclusion

The use of rotation, organic and inorganic nutrients is a good way to conduct research with small-scale farmers. But this research may be developed in a judicious way to be compatible to farmer's needs and possibilities. Its efficiency can for example be increased by reduction of nutrient losses through erosion, increasing biomass production on the farms for domestic use, livestock feeds and for soil mulching in a cycle of sustainable land use. The resource poor farmers have adopted few of the technologies proposed by researchers to address land degradation because of their capacity to invest in onerous soil fertility managements and others socio-economics factors. To be adopted researchers have to test their technologies in a participatory approach with land users. It is also important to combine rainwater and nutrient managements because in the Sudano-Sahelian zone, erratic rainfall, its distribution in space and time and runoff-susceptible land are the main problems that have to be addressed for crop production. Some water conservation and water harvesting techniques have to be combined to organic and inorganic amendments to secure agricultural production and reduce farmer's financial risks of purchasing fertilizers. Ridging is one of these techniques although it is significant only in poor rainfall years. Another important future research opportunity is the selection of genotypes that can be efficient for better utilization of P applied. Farmers seem to prefer their local variety and a comparison of the two traditional plots with improved variety (treatment 1 = 134 kg grain ha^{-1}) and local variety (treatment 10 = 303 kg grain ha^{-1}) confirmed their choice. Under P treatment, the result is the same confirmed by other experiments. But in some years with short rainfall period, the long cycle to maturity causes some problems on the local variety.

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