4.6

Soil fertility management and cowpea production in the semiarid tropics

Bationo, A.[1], B.R. Ntare[2], S.A. Tarawali[3], and R. Tabo[2]

Abstract

Cowpea (*Vigna unguiculata* [L.] Walp.) is an important grain legume in the semiarid zone of West Africa as it is a major source of dietary protein for the people. It is usually grown as an intercrop with the major cereals, namely millet and sorghum. Despite its importance, its yields are very low due to several constraints including poor soil, insect pests, and drought. The soils in semiarid West Africa are inherently low in nitrogen and phosphorus. Soil, water, and nutrient management practices are inadequate to sustain food production and to meet the food requirements of the fast growing population. Research results show that proper management of organic amendments such as crop residues and manure, which are essential complements to mineral phosphorus fertilizers, can increase yields of cowpea and associated cereals more than three fold. Direct application of indigenous phosphate rocks can be an economical alternative to the use of imported, more expensive soluble phosphorus fertilizers for cowpea production in the region. The agronomic effectiveness of indigenous phosphate rock is about 50% compared to the imported single superphosphate. Furthermore, when the unreactive phosphate rocks are partially acidulated at 50%, their agronomic effectiveness can increase to more than 70%. Studies on cereal–cowpea rotation revealed that yields of cereals succeeding cowpea could, in some cases, double compared to continuous cereal cultivation. With efficient soil fertility management, cowpea can fix up to 88 kg N/ha and this results in an increase of nitrogen use efficiency on the succeeding cereal crop from 20% in the continuous cereal monoculture to 28% when cereals are in rotation with cowpea. Furthermore, the use of soil nitrogen increased from 39 kg N/ha in the continuous cereal monoculture to 62 kg N/ha in the rotation systems. Future research needs to focus on understanding the factors affecting phosphorus uptake from different sources of natural rock phosphate. There is also a need to quantify the below-ground nitrogen fixed by different cowpea cultivars. The increase of cowpea productivity in the cropping systems in this region will improve the nutrition of people, increase the feed quantity and quality for livestock, and contribute to soil fertility maintenance. This should contribute to reduction in poverty and environmental degradation.

Introduction

Cowpea (*Vigna unguiculata* [L.] Walp.) is an important grain legume in the West African Semiarid Tropics (WASAT), where it occupies 6 million hectares. Cowpea is an important component of the predominantly cereal/legume production systems in the region. The

---

1. Tropical Soil Biology and Fertility (TSBF) c/o UNESCO, PO Box 30592, Nairobi, Kenya.
2. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), BP 320, Bamako, Mali.
3. International Livestock Research Institute/International Institute of Tropical Agriculture (ILRI/IITA), PMB 5320, Ibadan, Nigeria.

most important cereals are sorghum and pearl millet and cowpea is often intercropped with these cereals (Steiner 1984).

Cowpea grain contains about 22% protein and constitutes a major source of protein for resource-poor rural and urban people. It is estimated that cowpea supplies about 40% of the daily protein requirements to most of the people in Nigeria (Muleba et al. 1997). The crop residues from cowpea constitute an important source of livestock feed especially in the dry savannas of WASAT.

The principal reasons for farmers to intercrop are flexibility, profit maximization, risk minimization, soil conservation and maintenance, weed control, and nutritional advantages (Norman 1984; Swinton et al. 1984; Shetty et al. 1995; Fussell and Serafini 1985). In mixed cropping systems, cowpea yields are very low due to low soil fertility, low planting densities, and pests and diseases (Ntare 1989, Reddy et al. 1992). Cowpea grain yield varies between 50 kg/ha and 300 kg/ha in farmers' fields in marked contrast to over 2000 kg/ha obtainable on research stations and by large-scale commercial enterprises in pure cropping. In the mixed farming systems of the WASAT, increasing legume component in the farming systems is important in order to increase the availability of fodder as livestock feed while increasing soil fertility.

Rotation of cereals with legumes has been extensively studied in recent years. Use of rotational systems involving legumes is gaining importance throughout the region because of economic and sustainability considerations. The beneficial effect of legumes on succeeding crops is normally exclusively attributed to the increased soil N fertility as a result of N_2 fixation. The amount of N_2 fixed by leguminous crops can be quite high, although it has been demonstrated that legumes can also deplete soil nitrogen (Rupela and Saxena 1987, Blumenthal et al. 1982).

Most of the data reported on the quantity of N fixed by legume crops in the WASAT concerned the aboveground part of the legume and very little is known about the nitrogen fixed by the roots. Where much of the legume biomass is returned to the soil as green manure, a positive N balance is to be expected. However, this may not be true for cowpea, where the bulk of above biomass is removed from the system. Nevertheless, there are many other positive effects of grain legumes such as the improvement of soil biological and physical properties and the ability of some legumes to solubilize occluded phosphorus and highly insoluble Calcium-bounded phosphorus by roots exudates (Arihara and Ohwaki 1989). Other advantages of crop rotation include soil conservation (Stoop and Staveren 1981), organic matter restoration (Spurgeon and Grimson 1965), and pest and disease control (Curl 1963). While considerable information is available on fertilizer requirements for sole cropping of various crops, it is limited for intercropping and rotations.

This paper will review the cowpea production environment, the effect of soil fertility improvement, and will conclude with new research opportunities.

Cowpea production environment

Cowpea is predominantly grown in the WASAT. This zone is characterized by a growing period of 60–150 days. The rainfall is low, variable, and undependable. One striking feature of the soils is their inherent low fertility expressed in low levels of organic carbon (generally less than 0.3%), total and available phosphorus and nitrogen, and effective cation exchange capacity (ECEC) (Table 1). About 98% of the soil nitrogen is stabilized in organic matter. Thus, the total nitrogen in the soil and the amount of nitrogen released

Table 1. Means and ranges of selected physical and chemical properties of West African semiarid soils from 30 representative sites.

Parameter	Range	Mean
pH-H_2O (2 : 1 water : soil)	3.95–7.6	6.17
pH-KCl (2 : 1 water : soil)	3.41–7.0	5.05
Clay (%)	0.7–13	3.9
Sand (%)	71–99	88
Organic matter (%)	0.14–5.07	1.4
Total nitrogen (mg/kg)	31–226	446
Exchangeable bases (cmol/kg)		
Ca	0.15–16.45	2.16
Mg	0.02–2.16	0.59
K	0.03–1.13	0.20
Na	0.01–0.09	0.04
Exchangeable Al (cmol/kg)	0.02–5.6	0.24
Effective cation exchange capacity (cmol/kg)	0.54–19.2	3.43
Base saturation (%)	36–99	88
Al saturation (%)	0–46	3
Total phosphorus	25–941	136
Available phosphorus	1–83	8
Maximum P sorbed	27–406	109

Source: Bationo et al. (2000).

for plant nutrients uptake will depend on the organic matter level of the soil. Total and available P levels are very low and P deficiency is the most limiting soil fertility factor for cowpea production. Apart from low P stocks, the low-activity nature of these soils results in a relatively low capacity to fix added phosphorus (Bationo et al. 1995). Phosphorus sorption maxima of the WASAT soil ranged from 27 to 405 mg P/kg with a mean of 109 mg P/kg. Low quantities of P need to be added to the soil to maintain 0.2 ppm P in the soil solution. At present most cultivated land in the region lose more N, P, and K than gained and continuous cultivation has led to nutrient mining and loss of topsoil by wind and/or water erosion (Table 2). Under these conditions, productivity levels of both cereals and legumes are too low to sustain food production and to meet food requirements of the fast growing human populations.

Although organic amendments such as crop residue, manure, or compost are essential in the sustainability of the cropping systems, they cannot prevent nutrient mining. The addition of organic amendments corresponds in most cases to a recycling process, which cannot compensate for nutrient exported through crop products. As a result, the use of external inputs such as inorganic plant nutrients or local sources of P such as phosphate rock are essential requirements for soil productivity.

Effect of soil fertility improvement on cowpea production

Research results in the region have shown the importance of the improvement of soil fertility for crop production (Mokwunye and Vlek 1986; Pieri 1989; Van Reuler and Jansen 1989; Van der Heide 1989; Bationo and Mokwunye 1991; Sedogo 1993). In the Sahelian zone, soil fertility appears to be more limiting to crop and fodder production than rainfall and the use of fertilizer will increase water-use efficiency (Penning de

Table 2. Annual nutrient losses for some West African countries.

Country	Area ('000 ha)	Losses for the region (10^3 tonnes)		
		N	P_2O_5	K_2O
Benin	2972	41388	10366	32499
Burkina Faso	6691	95391	27754	78764
Ghana	4505	137140	32313	90474
Mali	8015	61707	17888	66725
Niger	985	176120	55331	146617
Nigeria	2813	1107605	316687	946157

Source: Adapted from Stoorvogel and Smaling (1990).

Vries and Djiteye 1991, Breman and de Wit 1983). The use of mineral fertilizers can significantly increase water-use efficiency.

Significant cowpea responses to nitrogen applied as urea have been obtained in different agroecological zones of the WASAT (Table 3). These significant responses indicate that the predominantly sandy soils of the WASAT may be deficient in molybdenum required for efficient symbiotic fixation (Hafner et al. 1992). For example, on the sandy acid soil at Bengou in the Sudanian zone, significant molybdenum response was obtained at different levels of soil fertility management for cowpea (Fig. 1).

Legumes such as cowpea have a high P requirement. P is reported to stimulate root and plant growth, initiate nodule formation, as well as influence the efficiency of the rhizobium-legume symbiosis. It is also involved in reactions with energy transfer, more specifically ATP in nitrogenase activity (Israel 1987). Research conducted at Ikenne in the humid zone and Kamboinse in the Sudanian zone of West Africa indicated a strong differential response to P by cowpea cultivars (Fig. 2). The local Kamboinse variety is a fodder type and the application of P resulted in higher fodder yield but lower grain production. As reported by several scientists such as Dwivedi et al. (1975); Khan and Zende (1977); Stukenholtz et al. (1966); Takkar et al. (1976); and Youngdhal et al. (1977), the application of P resulted in significant decrease of zinc concentration in the cowpea grain which can affect the nutritional quality (Buerkert et al. 1998).

Despite the importance of P in these soils, the use of commercial P fertilizers in the WASAT is limited due to the high cost of imported fertilizers. Several countries in the region, however, are known to have natural phosphate deposits. Direct application of indigenous phosphate rocks (PR) can be an alternative to the use of more expensive water-soluble phosphorus fertilizers. This practice would also promote savings in scarce foreign exchange. The effectiveness of PR depends on its chemical and mineralogical composition, soil factors, and the crops to be grown (Khasawneh and Doll 1978; Lehr and McClellan 1972; Chien and Hammond 1978). The relative agronomic effectiveness of Tahoua PR and Kodjari PR in different agroecological zones of the WASAT has been evaluated (Table 4). The data indicate that Tahoua PR outperformed Kodjari PR in agronomic effectiveness at two of the three sites. These results are in agreement with the chemical composition of the two rocks where the molar PO_4/CO_4 ratio is 25 for Kodjari PR and 4.9 for Tahoua PR. The agronomic cowpea is not better than that of the cereal pearl millet crop. This is in contradiction to other reports where legumes have highest strategy to solubilize PR than cereals by rhizosphere acidulation (Aguilar and Van Diest 1981; Kirk and Nye 1986; Hedley et al. 1982) and exudation of organic acids (Ohwaki and Hirata 1992).

Table 3. Effect of nitrogen on cowpea yield at three sites in 1988.

	Cowpea fodder		
N rates (kg N/ha)	Sadore	Bengou	Tara
0	4069	2213	2974
15	4474	2510	2963
30	4288	2548	3025
45	4264	3008	3500
S.E. (D.F.27)	218.3	153.7	161.3
CV (%)	15	17	15

Source: Bationo and Ntare (2000).

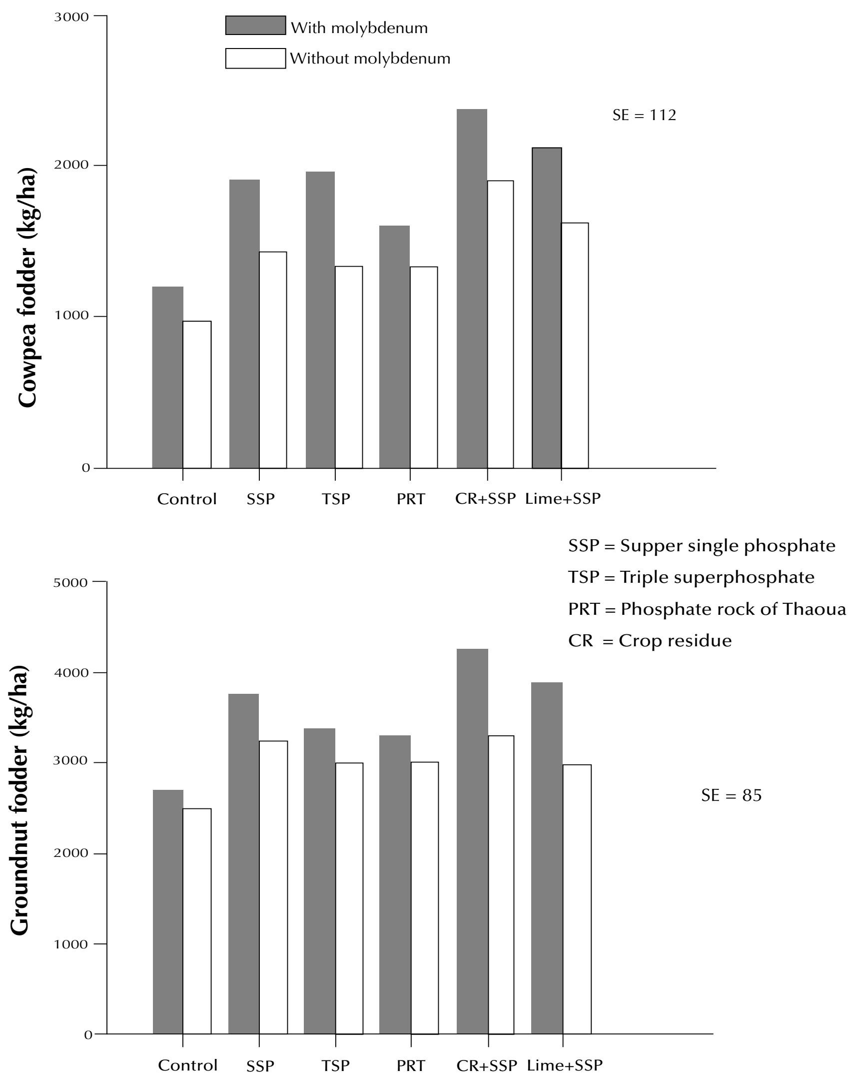

Figure 1. Effects of different phosphorus sources, crop residue, lime, and molybdenum on cowpea and groundnut fodder yield, Tara, Niger, 1993.
Source: Bationo, (unpublished data).

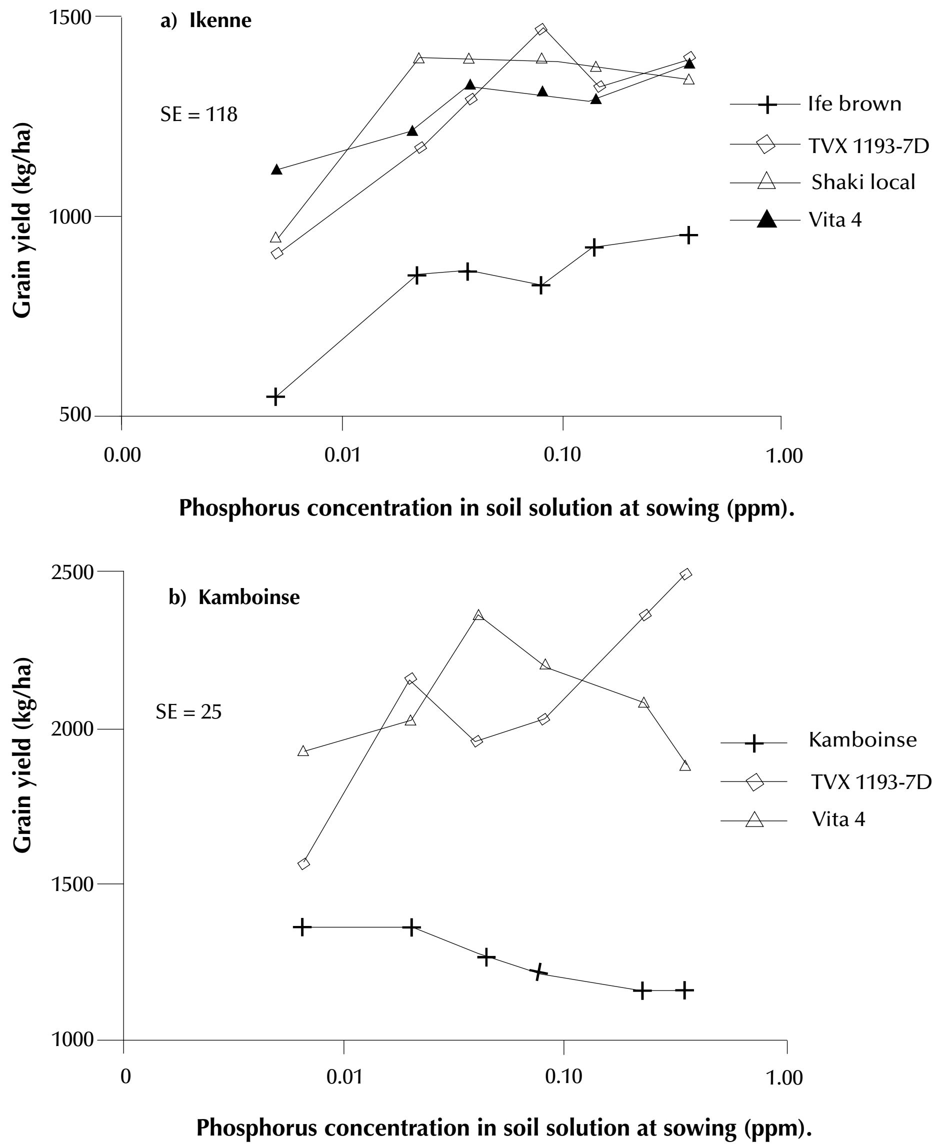

Figure 2. Relationship between grain yield and phosphorus concentration in soil solution at sowing in sandy loam Paleustatif Oxic Paleustalf at (a) Ikenne and (b) Kamboinse.

Table 4. Relative agronomic effectiveness for pearl millet and cowpea as compared to single superphosphate (SSP) (%) of Tahoua phosphate rock (TPR) and Kodjari phosphate rock (KPR) in three agroecological zones of Niger.

	Sadoré		Goberi		Gaya	
	TPR	KPR	TPR	KPR	TPR	KPR
Cowpea fodder (kg/ha)	43	28	73	51	42	42
Cowpea total dry matter (kg/ha)	56	40	72	51	52	55

Source: Mahamane et al. (1997).

The response of cowpea grain and stover yield to different sources of P fertilizers is presented in Figure 3. The application of P fertilizers can triple cowpea stover production. The relative agronomic effectiveness of Phosphate rock annual application (PRA) indigenous to Niger varied from 42 to 54% as compared to the water soluble single superphosphate (SSP) (Table 5). The acidulation of PR at 50% (PAPR 50) with sulfuric acid can increase the relative agronomic effectiveness to 96% for cowpea stover production. For fodder production, triple superphosphate (TSP) relative agronomic effectiveness varied from 77 to 91% indicating that sulfur is needed for cowpea growth.

Research at ICRISAT-Niger has focussed on the placement of small quantities of P fertilizers at planting in order to develop optimum farmer-affordable P application recommendation for increased crop yield. For cowpea stover production, phosphorus-use efficiency increased from 44 with the addition of Kodjari PR to 93 kg/kg phosphorus plus 4 kg P/ha as 15-15-15, respectively, (Table 6).

Long-term experiments are a practical means of addressing the difficult issues associated with quantitative assessment of sustainability in agriculture. In summarizing the results of long-term soil fertility management in Africa, Pieri (1986) concluded that soil fertility in intensive arable farming in the WASAT can only be maintained through efficient cycling of organic materials in combination with mineral fertilizers and with rotation with leguminous N_2-fixing species. Results from a long-term experiment at Sadore in Niger indicated that the application of small quantities of fertilizers and crop residues resulted in an increase of cowpea fodder yield from 1700 to 5300 kg/ha (Fig. 4). In on-farm trials, pocket applications of small quantities of manure (3 t/ha) plus 4 kg/ha of P at seedling time increased cowpea yield from 180 kg/ha in the control plot to 400 kg/ha (Fig. 5).

Effect of cowpea production on soil fertility improvement

Despite the recognized need to apply chemical fertilizers for high yields, the use of mineral fertilizers in West Africa is limited by lack of capital, inefficient distribution systems, poor enabling policies, and other socioeconomic factors. Cheaper means of improving soil fertility and productivity is therefore necessary. Cereal–legume rotation effects on cereal yields have been reported for the WASAT (Bagayoko et al. 1996; 2000; Bationo et al. 1998; Klaij and Ntare 1995; Nicou 1977; Stoop and Staveren 1981; Bationo and Ntare 2000). In all these studies, the yield of cereal after cowpea was significantly higher than in continuous cereal cultivation. Cowpea yield also significantly responded to crop rotation, indicating that factors other than N alone contributed to the yield increases in the cereal–legume rotations.

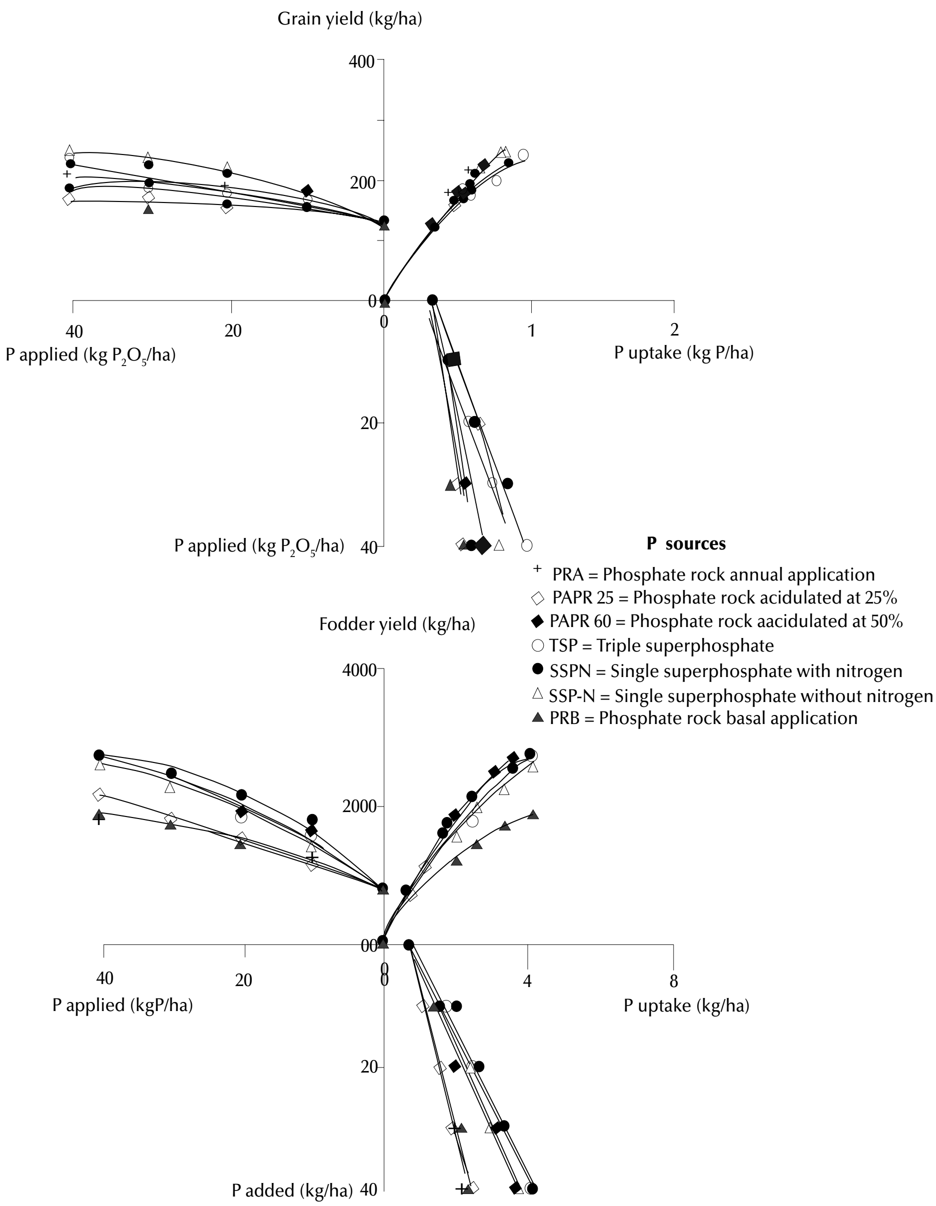

Figure 3. Relationship between cowpea grain and fodder yield with P applied, and between phosphorus applied and phosphorus uptake, Sadoré, Niger, 1983.

Source: Bationo (unpublished data).

Table 5. Relative agronomic effectiveness of different sources of phosphorus on cowpea.

P sources	1993 Grain %	1993 Fodder %	1994 Grain %	1994 Fodder %
Phosphate rock annual application (PRA)	70	54	49	42
Partially acidulated phosphate rock at 25% (PAPR 25)	45	58	61	75
Partially acidulated phosphate rock at 50% (PAPR 50)	72	92	88	96
Triple superphosphate (TSP)	68	91	65	77
Single superphosphate (SSP) Phosphate rock based application	74	87	86	91

Table 6. Effect of different sources of phosphorus and their placement on cowpea yield and Phosphorus-use efficiency (PUE), Karabedji, (1998 rainy season).**

P sources and method of application	Grain Yield (kg/ha)	Grain PUE (kg/ha)	Fodder Yield (kg/ha) P applied	Fodder PUE (kg/ha) P applied
Control	505		1213	
SSP broadcast	1073	44	2120	70
SSP broadcast+SSP HP	1544	61	3139	113
SSP HP	1050	136	2021	452
15-15-15 broadcast	1165	51	2381	90
15-15-15 broadcast+15-15-15 HP	2383	110	3637	142
15-15-15 HP	1197	173	2562	337
PRT broadcast	986	37	2220	77
PRT broadcast+SSP HP	1165	68	3127	113
PRT broadcast+15-15-15 HP	1724	72	3163	115
PRK broadcast	920	32	1791	44
PRK broadcast+SSP HP	1268	45	2588	81
PRK broadcast+15-15-15 HP	1440	55	2792	93
S.E.	164		313	

*SSP Single superphosphate; 15-15-15 compound fertilizer containing 15% N, 15% P_2O_5, 15% K_2O; Tahoua phosphate rock (TPR), Kodjari phosphate rock (KPR).
HP signifies hill placement of fertilizer.
**For broadcast, 13 kg P/ha was applied.
** For HP, 4 kg P/ha as hill placement.
Source: Bationo (unpublished data).

Bationo and Ntare (2000) studied nitrogen dynamics in different cropping systems. In order to determine N availability, the soil was incubated and mineral nitrogen determined at 7, 21, and 35 days (Keeney 1982). Crop rotation significantly affected mineral nitrogen release (Fig. 6). The fallow millet rotation supplied more nitrogen than the cowpea–millet rotation, but the latter was more productive for millet production.

Isotopic dilution method with ^{15}N was used to determine the nitrogen fixed by cowpea using pearl millet as a non-fixing crop. Nitrogen derived from the atmosphere by cowpea varied from 65 to 89% and the total nitrogen fixed by cowpea depended on the level of soil fertility improvement (Table 7). The quantity of nitrogen fixed by

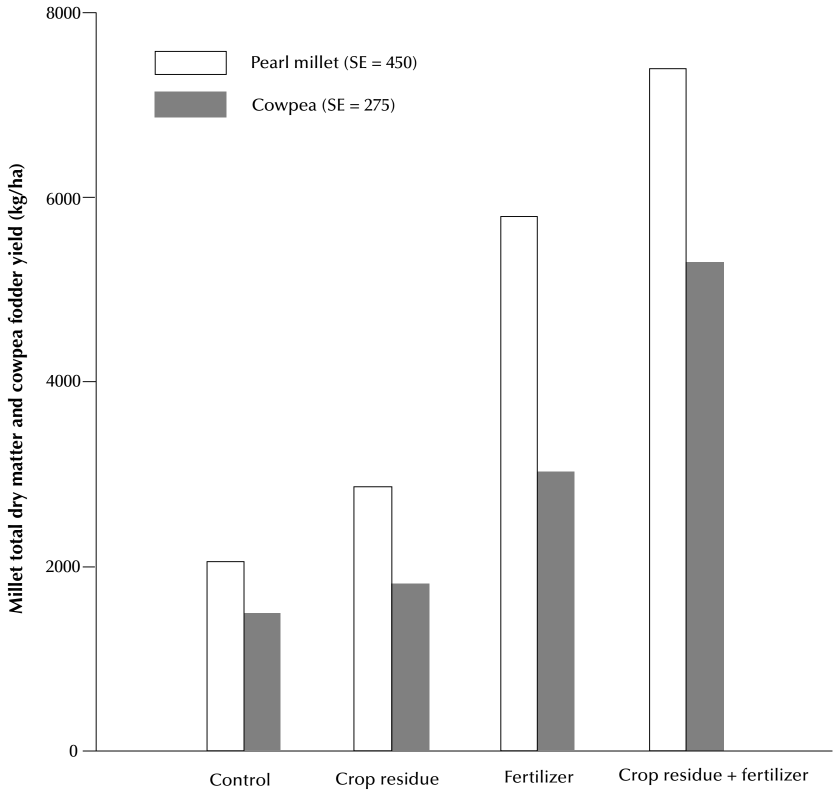

Figure 4. Long-term crop residue management at Sadoré, Niger, 1996.
Source: Bationo et al. (2000).

(2 t/ha of crop residue was applied as mulch in crop residue treatment and 4 t/ha of crop residue was applied as mulch in the crop residue plus fertilizer treatment; fertilizer was applied at 30 kg N/ha and 13 kg P/ha).

cowpea varied from 26 kg/ha in the control plot to 87 kg/ha in the treatment where the soils were amended with mineral and agronomic plant nutrients.

In order to determine ^{15}N recovery from different cropping systems, labeled nitrogen fertilizers were applied to microplots where pearl millet was grown continuously (M–M) in rotation with cowpea (C–M), in rotation with groundnut (G–M), intercropped with cowpea (C/M–C/M), and intercropped with groundnut (G/M–G/M). Nitrogen-use efficiency increased from 20% in continuous pearl millet cultivation to 28% when pearl millet was rotated with cowpea (Bationo, unpublished data). Nitrogen derived from the soil was better used in rotation systems than with continuous millet cultivation.

In another trial on interaction between phosphorus fertilizers and different cropping systems, the application of P had a significant effect on yield of cowpea and pearl millet and rotation performed better than continuous cultivation of both crops (Fig. 7). A higher level of organic carbon was also found in the rotation systems compared to the continuous cropping systems, probably due in part to fallen cowpea leaves (Fig. 8).

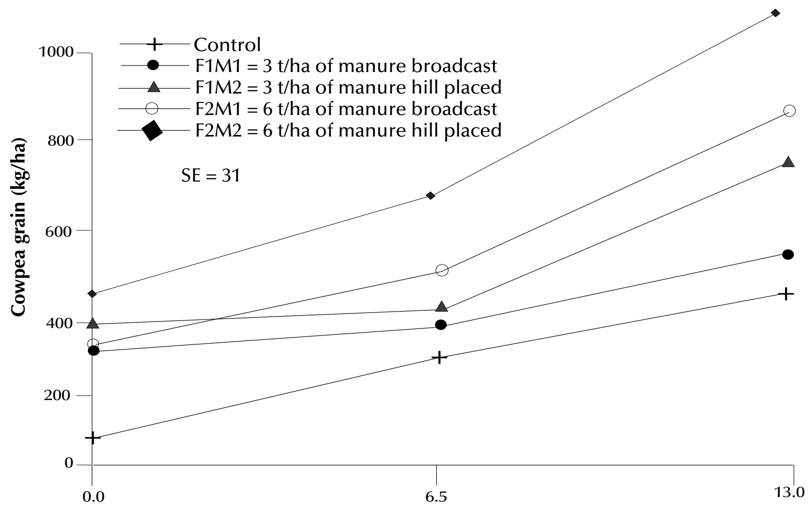

Figure 5. Effects of fertilizer and manure placement on cowpea grain yield, Karabedji, 1999. Source: Bationo (unpublished data).

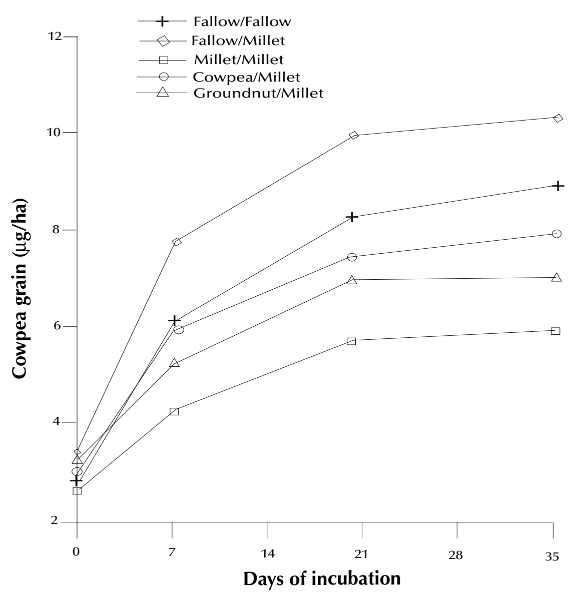

Figure 6. Relationship between cumulative mineral nitrogen and time of incubation of soils from different crop rotations pooled over three sites.
Source: Bationo and Ntare (2000).

Table 7. Nitrogen derived from the air (Ndfa) and total N fixed by cowpea stover using ^{15}N dilution technique, Sadoré, Niger, (1991 rainy season).

Treatment	Yield (t/ha)	N (%)	N yield (kg/ha)	NdFF (%)	Ndfa (%)	N fixed (kg/ha)
Control	1.75	2.18	38	2.43	65	26
Molybdenum	3.08	2.28	71	1.37	80	58
Carbofuran	2.58	2.19	57	2.04	71	41
Manure	2.42	2.44	60	0.79	89	53
Phosphorus	3.58	2.01	65	1.56	78	51
Complete	3.75	2.66	100	0.80	89	89
SE	±0.47	±0.09	±10.39	±0.18	±2.56	±9.06
CV (%)	28	6	27	20	6	29

Source: Bationo (unpublished data).

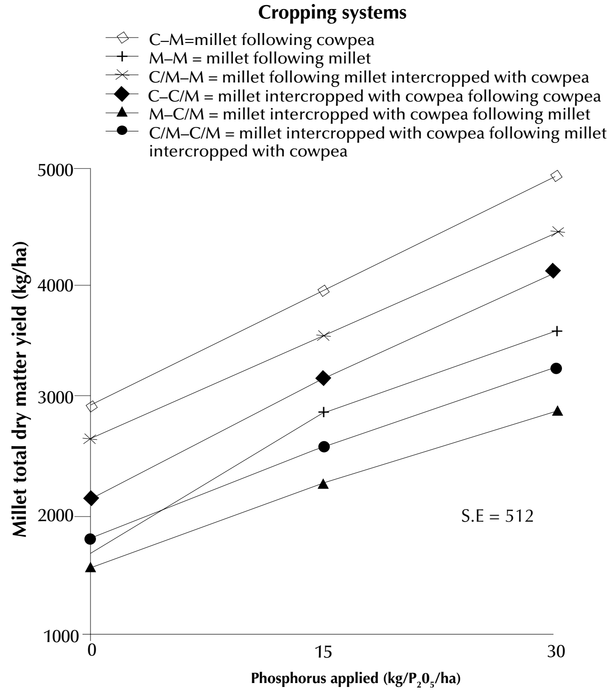

Figure 7. Effects of phosphorus and nitrogen on different cropping systems over four years, Sadoré, Niger.
Source: Bationo (unpublished data).

The application of phosphorus, nitrogen, crop residue, ridging, and rotation of pearl millet with cowpea was evaluated to determine phosphorus-use efficiency. The results showed that soil productivity of the sandy Sahelian soils can be significantly increased with the adoption of improved crop and soil management technologies. Whereas the absolute control recorded 33 kg/ha of grain yield, 1829 kg was obtained when phosphorus, nitrogen, and crop residue were applied to plots that were ridged and in rotation

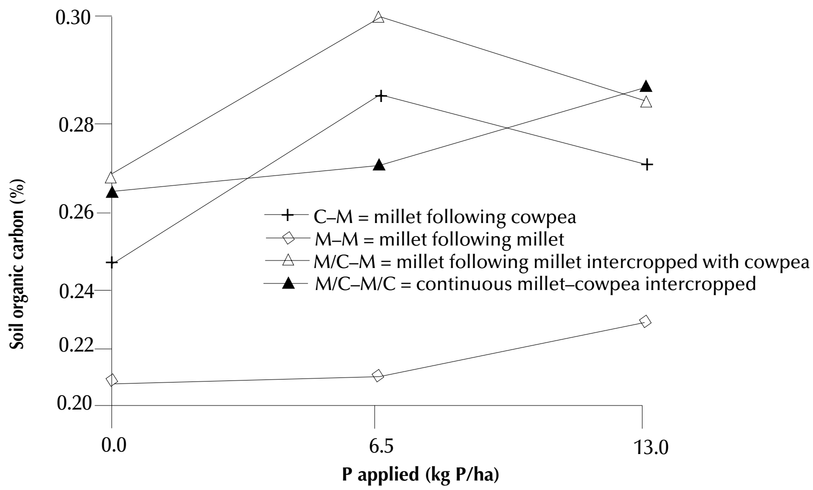

Figure 8. Effects of phosphorus and cropping system on soil organic carbon, after four years of cultivation, Sadoré, Niger, 1995.
Source: Bationo (unpublished data).

with cowpea. The plots without rotation yielded 1146 kg/ha. Results indicated that for grain yield, phosphorus-use efficiency increased from 46 kg/kg P with only phosphorus application, to 133 kg/kg phosphorus when phosphorus was combined with nitrogen and crop residue application and the crop was planted on ridges (Table 8).

Conclusion and research opportunities

In the traditional cropping systems, cowpea is grown between cereals at very low density, as the farmers' primary goal is to produce cereal for family subsistence, cowpea being an additional benefit. This means that farmers need to be assured of sufficient cereal harvest to feed their families before integrating more cowpea in the cropping systems. Cowpea grain yield in the mixed systems is very low, varying between 50 and 300 kg/ha in marked contrast to over 2000 kg/ha on-station and by large-scale commercial enterprises in sole cropping. In addition to the low planting densities, pests and disease control, the inherent low fertility of the soil in the WASAT (particularly phosphorus) is one of the major constraints to cowpea production. Thus, soil fertility replenishment should be an integral part of any program aimed at reversing the downward trend in cowpea production and the conservation of the environment.

Phosphorus is the most limiting plant nutrient for cowpea production in the WASAT and there is ample evidence that indicates marked differences between cowpea genotypes for phosphorus uptake. Understanding the factors affecting phosphorus uptake such as the ability of plants to (i) solubilize soil P through acidification of the rhizosphere and the release of chelating agents and phosphate enzymes, (ii) explore a large soil volume, and (iii) absorb phosphorus from low phosphorus solution would help increase cowpea production and yield in the semiarid tropics.

The available and total phosphorus values are very low in the region. With these extreme low values of total phosphorus, selecting cultivars adapted to low phosphorus condition

Table 8. Effect of mineral fertilizers, crop residue (CR), ridging, and crop rotation on pearl millet and phosphorus-use efficiency (PUE) wastes, Sadoré, Niger (1998 rainy season).

	Without CR, without N				Without CR, without N				Without CR, without N				Without CR, without N			
	TDM		Grain		TDM		Grain		TDM		Grain		TDM		Grain	
Treatment	Yield kg/ha	PUE kg/ha P	Yield kg/ha	PUE kg/ha P	Yield kg/ha	PUE kg/ha P	Yield kg/ha	PUE kg/ha P	Yield kg/ha	PUE kg/ha P	Yield kg/ha	PUE kg/ha P	Yield kg/ha	PUE kg/ha	Yield Pkg/ha	PUE kg/ha P
Control	889		33		2037		58		995		61		1471		98	
13 kg P/ha	2704	140	633	46	4339	177	1030	75	4404	185	726	51	240	4594	1212	86
13 kg P/ha + ridge	2675	137	448	32	4057	155	946	68	3685	210	785	56	4530	235	1146	81
13 kg P/ha + rotation	5306	340	1255	94	6294	327	1441	106	5392	338	1475	109	6124	358	1675	121
13 kg/ P/ha + ridge + rotation	5223	333	1391	104	5818	291	1581	117	6249	404	1702	126	7551	468	1829	133
SE	407		407		407		407		407		407		407		407	

CR: Crop residue; N: Nitrogen; TDM: total dry matter; PUE: phosphorus-use efficiency (kg grain/kg P); yield: g/ha).
Source: Bationo (unpublished data).

would not be feasible as one cannot mine what is not there. Direct application of indigenous PR can be an economic alternative to the use of more expensive imported water-soluble P fertilizers. The effectiveness of mycorrhizal in utilizing soil P has been well documented (Silberbush and Barber 1983; Lee and Wani 1991; Daft 1991). An important future research opportunity is the selection of cowpea genotypes that can efficiently associate with vesicular-arbuscular mycorrhizal (VAM) for better utilization of P from applied PR.

Cereal–cowpea rotations have led to increased cereal yields at many locations in the WASAT. Factors such as mineral nitrogen (VAM) for P nutrition improvement and plant parasitic nematodes have been identified as mechanisms accelerating the enhanced yield of cereals in rotation with cowpea. Most of the research quantified the aboveground N fixed by different cowpea cultivars, but very little is known about the below-ground N fixed by cowpea. In the WASAT, most of the aboveground cowpea biomass is used for animal feed and not as green manure. Further research should focus more on on-farm quantification of the below-ground N fixed by cowpea in order to identify the best cultivar for soil N buildup.

The identification and alleviation of technical and socioeconomic constraints in order to increase cowpea in the present cropping systems needs attention in future. As a cash crop, farmers will increase their purchasing power to acquire external inputs such as fertilizers. The enhancement of cowpea in the present cropping systems will not only improve the soil conditions for the succeeding cereal crop, but will provide good quality livestock feed, and the manure produced will be of better quality for soil fertility improvement.

References

Aguilar, A.S. and A. Van Diest. 1981. Rock-phosphate mobilization included by the alkaline uptake pattern of legumes utilizing symbiotically fixed nitrogen. Plant and Soil 61: 27–42.

Arihara, J. and Y. Ohwaki. 1989. Estimation of available phosphorus in vertisol and alfisol in view of root effects on rhizosphere soil *in* XI Colloquium on plant nutrition-physiology and applications, 30 July to 4 August 1989. Wageningen, The Netherlands.

Bagayoko, M., S.C. Mason, S. Traore, and K.M. Eskridge. 1996. Pearl millet/cowpea cropping systems yield and soil nutrient levels. African Crop Science Journal 4: 453–462.

Bagayoko, M., A. Buerkert, G. Lung, A. Bationo, and V. Romheld. 2000. Cereal/legume rotation effects on cereal growth in Sudano–Sahelian West Africa: soil mineral nitrogen, mycorrhizae, and nematodes. Plant and Soil 218: 103–116.

Bationo, A. and A.U. Mokwunye. 1991. Alleviating soil fertility constraints to increased crop production in West Africa. The experience in the Sahel. Fertilizer Research 29: 95–115.

Bationo, A., A. Buerkert, M.P. Sedogo, B.C. Christianson, and A.U. Mokwunye. 1995. A critical review of crop residue use as soil amendment in the West African semi-arid tropics. Pages 305–322 *in* Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa, edited by J.M. Powell, S. Fernandez Rivera, T.O. Williams, and C. Renard. Proceedings International Conference, ILCA, Addis Ababa, Ethiopia.

Bationo, A., F. Lompo, and S. Koala. 1998. Research on nutrient flows and balances in West Africa: State-of-the-art. Pages 19–36 *in* Nutrient balances as indicators of production and sustainability in sub-Saharan African agriculture, edited by E.M.A. Smaling. Agriculture, Ecosystems and Environment 71: 1, 2, and 3.

Bationo, A. and B.R. Ntare. 2000. Rotation and nitrogen fertilizer effects on pearl millet, cowpea, and groundnut yield and soil chemical properties in a sandy soil in the semi arid tropics, West Africa. Journal of Agricultural Science, (Cambridge) 134: 277–284.

Bationo, A., S.P. Wani, C.L. Bielders, P.L.G. Vlek, and U. Mokwunye. 2000. Crop residue and fertilizer management to improve soil organic carbon content, soil quality, and productivity in the desert margins of West Africa. Pages 117–145 *in* Global climate change and tropical ecosystems, edited by R. Lal, J.M. Kimble, and B.A. Stewart. Advances in Soil Science. CRC Press, Washington DC, USA.

Blumenthal, M.J, V.P. Quach, and P.G.E. Searle. 1982. Effect of soybean population density on soybean yield, nitrogen accumulation, and residual nitrogen. Australian Journal of Experimental Agriculture 28: 99–106

Breman, H. and C.T. de Wit. 1983. Rangeland productivity and exploitation in the Sahel. Science 221: 1341–1347.

Buerkert, A., C. Haate, M. Ruckwied, and H. Marschner. 1998. Phosphorus application affects the nutritional quality of millet grain in the Sahel. Field Crops Research 57: 223–235.

Chien, S.H. and L.L. Hammond. 1978. A simple chemical method for evaluating the agronomic potential of granulated phosphate rock. Soil Science Society of America Journal 42: 615–617.

Curl, E.A. 1963. Control of plant diseases by rotation. Botanical Review 29: 413–479.

Daft, M.J. 1991. Influences of genotypes, rock phosphate, and plant densities on mycorrhizal development and the growth responses of five different crops. Agriculture, Ecosystems and Environment 35: 151–169.

Dwivedi, R.S., N.S. Randwawa, and R.L. Bansal. 1975. Phosphorus-zinc interaction. I. Sites of immobilization of zinc in maize at high levels of phosphorus. Plant and Soil 43: 639–648.

Fussell, L.K. and P.G. Serafini. 1985. Associations de cultures dans les zones tropicales semi-arides d'Afrique de l'Ouest: strategies de recherché anterieures et futures. (In Fr.) Pages 254–278 *in* Technologies appropriees pour les paysans des zones semi-arides de l'Afrique de l'Ouest, edited by H.W. Ohm and J.G. Nagy. Purdue University, West Lafayette, Indiana, USA.

Hafner, H., B.J. Ndunguru, A. Bationo, and H. Marshner. 1992. Effect of nitrogen, phosphorus, and molybdenum applications on growth and symbiotic N_2 fixation of groundnut in an acid sandy soil in Niger. Fertilizer Research 156: 164–176.

Hedley, M.J., P.H. Nye, and R.E. White. 1982. Plant-induced changes in the rhizosphere of rape (*Brassica napus* var. Emerad) seedlings. II. Origin of the pH change. New Phytologist 91: 31–44.

Israel, D.N. 1987. Investigation of the role of phosphorus in symbiotic nitrogen fixation. Plant Physiology 84: 835–840.

Khan, A.A. and G.K. Zende. 1977. The site for Zn-P interactions in plants. Plant and Soil 46: 259–262.

Keeney, D.R. 1982. Nitrogen availability indices. Pages 711–730 *in* Methods of soils analysis, edited by A.L. Paye et al. American Society of Agronomy, Madison, Wisconsin, USA.

Khasawneh, F.E. and E.C. Doll. 1978. The use of phosphate rock for direct application to soils. Advanced Agronomy 30: 155–206.

Kirk, G.J.D. and P.H. Nye. 1986. A simple model for predicting the rate of dissolution of sparingly soluble calcium phosphate in soil. I. The basic model. Journal of Soil Science 37: 529–540.

Klaij, M.C. and B.R. Ntare. 1995. Rotation and tillage effects on yield of pearl millet (*Pennisetum glaucum*) and cowpea (*Vigna unguiculata*), and aspects of crop water balance and soil fertility in semi-arid tropical environment. Journal of Agriculture Science (Cambridge) 124: 39–44.

Lee, K.K. and S.P. Wani. 1991. Possibilities for manipulating mycorrhizal associations in crops. Pages 107–166 *in* Phosphorus nutrition of grain legumes in the semi-arid tropics, edited by C. Johansen, K.K. Lee, and K.L. Sahrawat. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Patancheru, AP 502324, India.

Lehr, J.R. and G.H. McClellan. 1972. A revised laboratory reactivity scale for evaluating phosphate rocks for direct application. Bulletin 43, Tennessee Valley Authority, Muscle Shoals, Alabama, USA.

Mahamane, I., A. Bationo, F. Seyni, and Z. Hamidou. 1997. Acquis récents des recherches sur les phosphates naturels du Niger. Pages 73–78 *in* Soil fertility management in West African land use systems, edited by G. Renard, A. Neef, K. Becker, and M. von Oppen. Margraf Verlag, Weikersheim, Germany.

Mokwunye, A.U., and P.L.G. Vlek (editors). 1986. Management of nitrogen and phosphorus fertilizers in sub-Saharan Africa. Martinus Nijhoff, Dordrecht, The Netherlands.

Muleba, N., C. Dabire, J.B. Suh, I. Drabo, and J.T. Ouedraogo. 1997. Technologies for cowpea production based on genetic and environmental manipulations in the semi-arid tropics. Pages 195–206 *in* Technology options for sustainable agriculture in sub-Saharan Africa, edited by T. Bezuneh, A.M. Emechebe, J. Sedgo, and M. Ouedraogo. Publication of the Semi-Arid Food Grain Research and Development Agency (SAFGRAD) of the Scientific, Technical and Research Commission of OAU, Ouagadougou, Burkina Faso.

Nicou, R.N. 1977. Le travail du sol dans les terres exondées du Sénégal. Motivations constraintes. ISRA–CNRA, Bombay, India. 51 pp.

Norman, D.W. 1974. Rationalizing mixed cropping under indigenous conditions: the example of northern Nigeria. Journal of Development Studies 11: 3–21.

Ntare, B.R. 1989. Intercropping morphologically different cowpea with pearl millet in a short season environment in the Sahel. Experimental Agriculture 26: 41–47.

Ohwaki, Y. and H. Hirata. 1992. Differences in carboxylic acid exudation among P-starved leguminous crops in relation to carboxylic acid contents in plant tissues and phospholipid levels in roots. Soil Science and Plant Nutrition 38: 235–243.

Penning de Vries, F.W.T. and M.A. Djitèye. 1991. La productivité des pâturages sahéliens: une étude des sols, de la végétation et de l'exploitation de cette resource naturelle. Center for Agricultural Publishing and Documentation (Pudoc-DLO), Wageningen, The Netherlands.

Pieri, C. 1986. Fertilization des cultures vivrières et fertilité des sols en agriculture paysanne subsaharienne. Agronomie Tropicale 41: 1–20.

Pieri, C. 1989. Fertilité des terres de savanes : Bilan de trente ans de recherches et de développement, Centre de coopération internationale en recherche agronomique pour le développement (CIRAD) et le Ministère de la Coopération, Paris, France. 443 pp.

Reddy, K.C., P. Visser, and P. Buekner. 1992. Pearl millet and cowpea yields in sole and intercrop system, and their after-effects on soil and crop productivity. Field Crops Research 28: 315–326.

Rupela, O.P. and M.C. Saxena. 1987. Nodulation and nitrogen fixation in chickpea. Pages 191–206 *in* The Chickpea Farnham Royal UK, edited by M.C. Saxena and K.B. Singh. Commonwealth Agricultural Bureaux International and International Center for Agricultural Research in the Dry Areas.

Sedogo, M.P. 1993. Evolution des sols ferrugineux lessivés sous culture: influence des modes de gestion sur la fertilité: Thèse de Doctorat Es-Sciences, Abidjan, Université Nationale de Côte d'Ivoire.

Shetty, S.V.R., B.R. Ntare, A. Bationo, and C. Renard. 1995. Millet and cowpea in mixed farming of the Sahel. A review of strategies for increased productivity and sustainability. Pages 293–304 *in* Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa, edited by J.M. Powell, S. Fernandez Rivera, T.O. Williams, and C. Renard. Proceedings International Conference, ILCA, Addis Ababa, Ethiopia.

Silberbush, M. and S.A. Barber. 1983. Sensitivity of simulated phosphorus uptake to parameters used by a mechanistic-mathematical model. Plant and Soil 74: 93–100.

Spurgeon, W.I., and P.H. Grimson. 1965. Influence of cropping systems on soil properties and crop production. Mississippi Agricultural and Forestry Experiment Station Bulletin No. 710.

Steiner, K.G. 1984. Intercropping in tropical smallholder agriculture with special reference to West Africa. Stein, West Germany. 304 pp.

Stoop W.A. and J.P.V. Staveren. 1981. Effects of cowpea in cereal rotations on subsequent crop yields under semi-arid conditions in Upper Volta. Pages 653–657 *in* Biological nitrogen fixation technology for tropical agriculture, edited by P.C. Graham and S.C. Harris. Centro International de Agricultura Tropical (CIAT), Cali, Colombia.

Stoorvogel, J.J. and E.M.A. Smaling. 1990. Assessment of soil nutrient depletion in sub-Saharan Africa 1983–2000. Report 28, The Winand Staring Centre for Integrated Land, Soil and Water Research (SC-DLO), Wageningen, The Netherlands.

Stukenholtz, D.D., R.J. Olsen, G. Gogan, and R.A. Olsen. 1966. On the mechanism of phosphorus-zinc interaction in corn nutrition. Soil Science Society of America Proceedings 30: 759–763.

Swinton, S.M., G. Numa, and L.A. Samba. 1984. Les cultures associées en milieu paysan dans deux regions du Niger: Filingue et Madarounfa. Pages 183–194 *in* Proceedings of the Regional Workshop on Intercropping in the Sahelian and Sahelo-Sudanian zones of West Africa, 7–10 November 1984, Institute du Sahel, Niamey, Niger.

Takkar, P.N., M.S. Mann, R.L. Bansal, N.S. Randwawa, and H. Singh. 1976. Yield and uptake response of corn to zinc as influenced by phosphorus fertilization. Agronomy Journal 68: 942–946.

Van der Heide, J. (editor). 1989. Nutrient management for food crop production in tropical farming systems. Institute for Soil Fertility Research (IB-DLO), Haren, The Netherlands.

Van Reuler, H. and B.H. Jansen. 1989. Nutritional constraints in secondary vegetation and upland rice in southwest Ivory Coast. Pages 371–382 *in* Mineral nutrients in tropical forest and savanna ecosystems, edited by J.H. Proctor. Special Publication 9 of The British Ecological Society, Blackwell Scientific Publications, Oxford, England.

Youngdhal, L.J., L.V. Svec, W.C. Liebhardt, and M.R. Tel. 1977. Changes in the zinc-65 distribution in corn root tissue with phosphorus variable. Crop Science 17: 66–69.