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Response of cowpea and soybean to P and K on *terre de barre* soils in southern Bénin

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Abstract

Good growth of grain legumes helps food security and protection of the environment but this may require nutrient inputs. A participatory technology development activity explored from 1998 to 2000 the responses of cowpea (*Vigna unguiculata*) and soybean (*Glycine max* (L.) Merr.) to inorganic soil amendments (P and K) on *terre de barre* soils with different levels of degradation in southern Bénin. Adingnigon, on the Abomey plateau, represents a level of severe degradation, while Hayakpa, on the Allada plateau, is still relatively non-degraded. Treatments included: (i) an unamended control, (ii) P fertilizer only, applied in 1998 or 1999, and (iii) P plus K applied in 1999. At Hayakpa, yields without fertilizer were generally moderate to high; responses to P were statistically significant and K application had a significant effect on soybean yield in 2000. At Adingnigon, P application had a large relative effect (30–200%) but a small absolute effect (less than 100 kg/ha) on cowpea and soybean yield. Subsequent K application increased grain yields further (approximately 100 kg/ha) but still not up to the cowpea yield potential. When 13 Mg/ha of organic amendment (chicken manure or cotton seed) were applied to severely degraded plots at Adingnigon with prior grain yields below 200 kg/ha, cowpea yields of more than 500 kg/ha were achieved, approaching their biological potential for the zone. It is clear from this study that (i) P and K inputs are needed for grain legumes even on relatively non-degraded *terre de barre* soils and (ii) inorganic fertilizer alone will not revive highly degraded soils on the *terre de barre* plateaus of southern Bénin.

Keywords: Organic amendments; Cowpea; Soybean; Soil degradation; Farmer-managed trials

1. Introduction

A major landscape feature of southern Bénin is a series of low-lying plateaus with red soils called *terre de barre*. This soil type occupies approximately 5320 km^2 in southern Bénin (INRAB, 1997) and a similar area in southern Togo and southwest Nigeria. The *terre de barre* plateaus support the highest rural population densities in southern Bénin, in many places more than 240 inhabitants per square kilometer (INRAB, 1997; Floquet and Mongbo, 1998). The human population on the *terre de barre* plateaus in southern Bénin is estimated to be 1 462 000 (INRAB, 1997). Soils in Bénin vary from highly degraded to non-degraded depending on their settlement pattern over the last 300 years.

The Abomey plateau is the seat of the former Dahomey kingdom, whose strength resulted in a stable settlement pattern for 300 years (Floquet and Mongbo, 1998). This stability resulted in a long-term process of land-use intensification and nutrient mining. Soil fertility in the area became increasingly poor, eliminating the possibility of maize and even cassava cropping, except in compound farms of restricted size (Floquet and Mongbo, 1998). At some

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point in time, the area became a food deficit zone, importing grain. Floquet and Mongbo (1998) estimated that grain stores are empty in the area for more than 7 months in the year, compared with less than 4 months in other zones. Thus, the plateau of Abomey is one of the most highly degraded areas of southern Bénin. In contrast to this, the Allada plateau has areas of relatively recent cropping on soils that are relatively fertile. The village of Hayakpa was chosen to represent this condition. There, grain stores are empty for only 1.4 months in the year (Floquet and Mongbo, 1998).

Severe soil degradation has been commonly observed in southern Bénin (see references to ‘comatose’ soils by Versteeg et al., 1998) and it has been reversed by using Mucuna (*Mucuna pruriens* var. *utilis*) fallow or Acacia (*Acacia auriculiformis*) woodlots (Versteeg and Koudokpon, 1993). Results of participatory research to restore soil fertility at Adingnigon on the Abomey plateau had shown that mucuna planted fallow was not acceptable to farmers because it took land out of crop production without offering an economic product. On the other hand, Acacia woodlots were acceptable because of the fuel and construction wood produced while regenerating the soil. The premise of the present study is that grain legumes can be promoted for soil fertility maintenance because they are a source of food and/or cash. Although their benefit to the soil is moderate, they can be expected to provide some soil improvement whereas continuous cropping of cereals would not do so. In the moist savanna of Nigeria, moderate nitrogen fertilizer replacement values of approximately 30 kg/ha have been estimated for soybean (Carsky et al., 1997; Sanginga et al., 2001) and cowpea (Carsky et al., 2001).

The overall objective of the research was to identify (with farmers) the inputs that would allow farmers to obtain a good growth of grain legumes, assuming that this will improve the soil N supply for maize cropping. Fertilizer is rarely used in these villages and it was hypothesized that phosphorus (P) would be the most important limiting nutrient for grain legumes on the *terre de barre* soils. This was based on the commonly observed need of legumes for adequate soil P (Giller and Wilson, 1991) and the fact that soil P in the area is approximately 5 μg/g (Carsky and Eteka, 2000). This is well below the critical level published by Aune and Lal (1995). Potassium (K) deficiency symptoms have been observed elsewhere on the *terre de barre* plateaus in southern Bénin—on *Pueraria phaseoloides* near Avrankou (2°39′E; 6°36′N) and on *M. pruriens* var. *utilis* near Sekou (2°16′E; 6°37′N). Thus, it was expected that K could also be a limiting nutrient for grain legumes. Finally, in cases where fields did not respond to fertilizer alone, we hypothesized that organic matter would be needed if productivity were to be increased.

2. Materials and methods

2.1. Initiation of trials in 1998

The research sites are at Adingnigon, southwest of Bohicon at approximately 07°08′N, 02°02′E and 150 m above sea level and Hayapka (2°08′E; 6°33′N) near Allada (Fig. 1). The soils are called nitosols (FAO) or *sols ferrallitiques moyennement désaturés appauvris* (Raunet, 1977). These soils can be characterized as slightly acid in the surface layer and acid in the subsoil (Fig. 2).

Farmers who had been collaborating with a previous soil management project were invited to a meeting and volunteered to take part in the trials. These farmers made small plots of 200 m^2 available for the research.

TSP was applied at a rate of 150 kg/ha to 150 m^2 of the 200 m^2 plot, leaving 50 m^2 for the control plot. The TSP (17.6% P) was broadcast uniformly after soil samples were taken at 20 points from the entire plot to 15 cm depth. Plant-available P using the Bray-1 extractant and exchangeable bases using ammonium acetate solution were determined. Groundnut, soybean, and cowpea were grown in the first season of 1998 in both villages, resulting in low numbers of replications for each crop.

In the second season at Adingnigon, cowpea line IT93KZ-4-5-6-1-5 was grown after groundnut and soybean and local soybean variety from the major market in Cotonou (Dantokpa) was grown after cowpea. The research team took over the planting of soybean, a new crop in the village. At podding of soybean, six plants were dug up with a garden fork (approximately 30 cm-long tines). Nodule fresh weight, nodule number, and root dry weight were determined. Cowpea variety IT84D-449 provided by the IITA-Bénin research farm was planted at Hayakpa. The research team protected cowpea with insecticide,

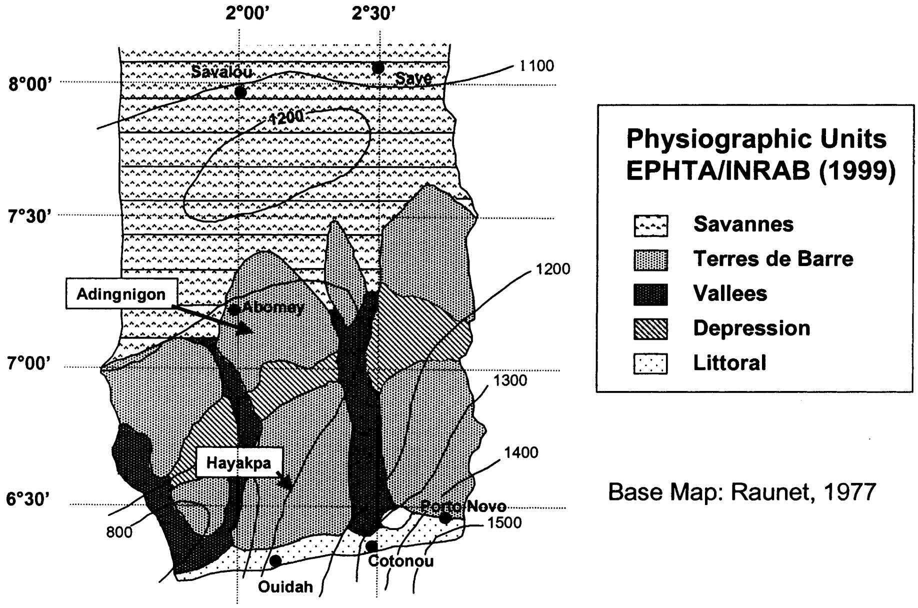

Fig. 1. Location of Adingnigon and Hayakpa on the Abomey and Allada *terre de barre* plateaus of southern Bénin.

once at flowering, once at the time of pod formation, and once before pod maturity. The cowpea variety used at Adingnigon was IT93KZ-4-5-6-1-5 with putative resistance to the *Striga gesnerioides* strain found on the Abomey plateau after being screened at Kano and Zakpota (on the Abomey plateau) for many years.

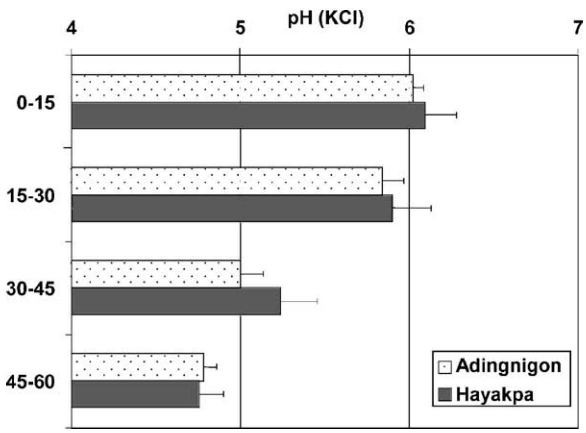

Fig. 2. Soil pH (KCl) as a function of depth at highly degraded Adingnigon and non-degraded Hayakpa. Standard errors of the means are given in error bars.

2.2. Modifications of trials in 1999 and 2000

In 1999, Muriate of potash at a rate of 100 kg/ha was applied to half of the plot to which P had been applied in 1998 (Fig. 3) in a band of 5 cm from the crop row, after 3–4 weeks of planting. All farmers grew cowpea at both villages in the first season. Cowpea variety IT84D-449 was grown at Hayakpa and IT93KZ-4-5-6-1-5 at Adingnigon.

In the second season, soybean variety TGx1485-1D was grown at Adingnigon with a fresh application of K. This dose was applied to one half of the plot to which K had been applied in the first season (see Fig. 3). At Hayakpa, application of K was not repeated in the second season because no response was observed in the first season. Hayakpa farmers insisted on growing cowpea again and IT84D-449 was used.

In 2000, on 15 of the most highly degraded fields at Adingnigon, 13.3 t/ha of chicken manure/bedding or spoiled cotton seed were applied to the surface of former P plus K plots. The chicken manure had an average total N concentration of 2.3% and total P content of 1.3%. The average nutrient concentration of the cotton seed was 2.9% N and 0.6% P. Cowpea variety IT93KZ-4-5-6-1-5 was planted. Yield loss from

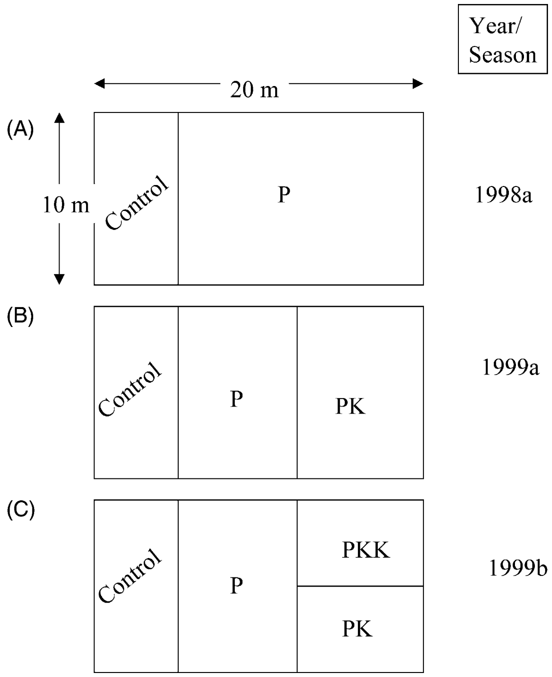

Fig. 3. Plot plan showing farmers' plot of 10 m length and 20 m width divided for application of P in 1998, K in the first season of 1999 (PK), and K in the second season of 1999 (PKK).

birds was estimated in these trials. It had been observed in previous seasons that increased yield from fertilizer was offset somewhat by additional bird and rat damage. Damage was estimated by counting damaged pods and multiplying this number by the average weight of undamaged pods.

Soybean variety TGx1485-1D was planted at Hayakpa where rainfall was late to establish and poorly distributed. Rodents damaged seedlings and replanting was done where necessary.

2.3. Data analysis

In 1998, paired *t*-tests were used to estimate P fertilizer effects on grain yield and roots and nodules of soybean. In subsequent seasons, ANOVA was used to estimate effects on grain yield of the fertilizer treatments separately for the villages, crops, and years. Standard errors of the difference between means were calculated. In 2000, the organic amendments were applied to three plots that received the previous K application (cotton seed followed PK in eight repetitions and PKK in seven repetitions; and chicken manure followed PK in seven repetitions and PKK in eight repetitions). Therefore, these treatments were combined as 'organic amendment after P and K' for the ANOVA. Comparison of soil pH by depth increment was done for the two villages using five fields per village in which soils were sampled to 60 cm depth. A two-sample *t*-test was done after testing for equality of variances of the two samples. Comparison of concentrations of exchangeable bases and Bray-P was done using the Kruskal–Wallis rank sum test.

3. Results

3.1. P response in first year—1998

In the first season of 1998, farmers planted soybean at a very low density and early growth was very poor due to drought. Cowpea was not protected from insect attack and yield loss was very high. Also there was insufficient seed of cowpea resistant to *S. gesnerioides*. This was supplemented by a photoperiod-sensitive variety that did not produce seed during the first season. The effects of the nontreatment factors (insect, weed, and animal damage) were important and responses to applied P were not significant.

In the second season at Adingnigon, response to P application was 95% for cowpea and 147% for soybean (Table 1) and the effect was significant. However, even though responses were relatively important, the average yield with P applied was only 193 kg/ha for soybean and 117 kg/ha for cowpea. The low yield of soybean was partly due to late planting and some shattering of grain at maturity. The responses to P application of soybean root dry matter ($P < 0.0065$), nodule number per plant ($P < 0.0001$) and nodule

Table 1
Effect of P applied in the first season of 1998 on grain legume yield (kg/ha) at Adingnigon and Hayakpa in the second season of 1998

Village	Crop	Number of fields	Soil amendment		Prob > *t*
			None	P	
Adingnigon	Soybean	13	78	193	0.0195
Adingnigon	Cowpea	10	60	117	0.0078
Hayakpa	Cowpea	22	360	497	0.0175

Table 2
Effect of P application in the first season of 1998 on soybean root and nodule growth at podding in the second season at Adingnigon ($n = 24$)

Parameter	Soil amendment		Prob > t
	None	P	
Number of fresh nodules per plant	10.4	21.4	0.0001
Nodule fresh weight (g) per plant	0.42	0.80	0.0002
Root dry matter (g) per plant	0.52	0.81	0.0065

Table 3
Effect of P and K application on cowpea grain dry matter yield in the first season of 1999[a]

Village	Number of fields	Soil amendment			SED	Prob > F
		None	P	PK		
Adingnigon	46	93	122	239	13.1	0.0001
Hayakpa	42	1028	1126	1128	28.5	0.0006

[a] P applied in first season of 1998 on some fields and in first season of 1999 on others.

fresh weight ($P < 0.0002$) were significant (Table 2). At Hayakpa, the mean yield of cowpea on unamended plots was 360 kg/ha and response to P (an additional 137 kg/ha) was statistically significant (Table 1).

3.2. Residual P effect and K response in the second year—1999

At Adingnigon, the response of cowpea to K applied in the first season was significant and the grain dry-matter yield was twice as high as with P application alone (Table 3). This confirmed the hypothesis that K was limiting the response to P. However, in spite of a good variety and adequate protection from insects, cowpea yields were still low, the mean being less than 250 kg/ha. In Hayakpa, the mean cowpea grain yield was more than 1000 kg/ha without fertilizer applied. The response to P alone was significant but represented an increase less than 10%.

Adingnigon farmers' plots were classified into severely degraded (less than 200 kg/ha) and highly degraded (200–500 kg/ha) using the cowpea grain yield results with P and K applied. Severely degraded and highly degraded fields were distinguishable by their lower concentrations of exchangeable bases (Table 4).

In the second season, the response of soybean to residual P at Adingnigon was significant and there was an additional significant increase from K application (Table 5). There was no grain yield increase from a fresh K application in the second season. However, there were five fields where no grain was produced except after a fresh application of K (Table 5). At Hayakpa, second season cowpea yields were low because of high disease and insect pressure on cowpea grown after cowpea according to the wishes of the farmers. Still the effect of P and K combined was significant (Table 5).

3.3. Residual P and K effect and response to organic additions in the third year—2000

At Adingnigon, the grain yield with P application alone was not significantly different from the control, but the effect of P plus K application was significant (Table 6). The effect of two K applications was not significantly higher than after one application at both sites. On the 15 highly degraded fields that received organic matter (in addition to residual P and K) the

Table 4
Classification of fields at Adingnigon by their yield of cowpea grain in 1999 with P and K applied and associated soil properties (0–15 cm depth)[a]

Field grouping	N	Yield (1999a)	K (cmol/kg)	Ca (cmol/kg)	Mg (cmol/kg)	Bray-1 P (mg/kg)
Adingnigon						
<200 kg/ha	14	119 a (11.1)	0.16 a (0.026)	1.66 a (0.193)	0.91 a (0.103)	3.5 a (0.35)
>200 kg/ha	12	318 b (23.5)	0.20 a (0.036)	2.72 ab (0.330)	1.50 b (0.197)	5.4 ab (1.15)
Hayapka	21	1128 c (47.9)	0.26 b (0.024)	3.70 b (0.198)	1.67 b (0.073)	5.7 b (0.44)
Prob > K–W[b]		0.0001	0.0002	0.0001	0.0003	0.0006

[a] Similar data for a non-degraded site (Hayakpa) is included for comparison. Values in parentheses are standard errors of means. Means followed by the same letter are not different using the Kruskal–Wallis rank sum test at 0.05 rejection level.
[b] Prob > K–W signifies probability of a greater value of the Kruskal–Wallis statistic.

Table 5
Effect of P and K application on grain dry matter yield of soybean at Adingnigon and cowpea at Hayakpa in the second season of 1999[a]

Village	Number of fields	Soil Amendment				SED	Prob > *F*
		None	P	K (99a)	K (99b)		
Adingnigon	44	135	225	293	293	22.0	0.0001
Adingnigon	5	0	2.2	0	44	10.6	0.0047
Hayakpa	37	179	198	227	–	23.1	0.0123

[a] P applied in first season of 1998 on some fields and in first season of 1999 on others. K (99a) refers to K applied in the first season of 1999 while K (99b) refers to a second K fertilizer application in the second season of 1999.

Table 6
Effect of residual P and K application on grain dry matter yield of cowpea at Adingnigon and soybean at Hayakpa in the first season of 2000[a]

Village	Number of fields	Soil amendment				SED	Prob > *F*
		None	P	PK	PK + OM		
Adingnigon	15	111	96	–	539	43.8	0.0001
Adingnigon	35	123	163	288	–	40.3	0.0001
Hayakpa	29	459	669	799	–	54.0	0.0001

[a] P applied in first season of 1998 on some fields and in first season of 1999 on others. K refers to mean of one K application in the first season of 1999 and two K applications in 1999 at Adingnigon.

average yield of cowpea grain dry matter was more than 500 kg/ha. A comparison of the same 15 fields with the same cowpea variety in the first seasons of 1999 and 2000 (Fig. 4) shows the substantial increase of cowpea grain yield from the organic additions. At Hayakpa, the response of cowpea to P application was significant and the response to K application was also significant (Table 6).

4. Discussion

4.1. P fertilizer effect

The initial hypothesis of this study was that P would be the major nutrient limiting the attainment of cowpea and soybean yield potential. The response to P was significant in most cases. Exceptions to this were

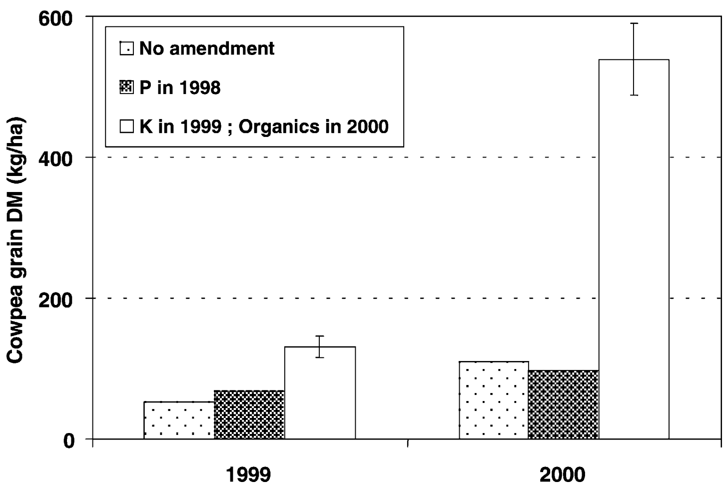

Fig. 4. Effect of application of P, K, and organic amendments to 15 highly degraded farmers' fields on first season cowpea grain yield at Adingnigon in 1999 and 2000. Least significant differences (0.05) are given for each year in error bars.

(i) when cowpea after cowpea suffered from serious disease and insect pressure at Hayakpa in the second season of 1999, (ii) on highly degraded soils at Adingnigon in the first season of 2000, and (iii) on all other fields at Adingnigon in the first season of 2000. The effect of applied P was relatively small and depended on native soil fertility. For example, the absolute increase in cowpea yield from P application was greater at Hayakpa than at Adingnigon. For the 1998b and 1999a seasons combined, the totals are 86 kg grain/ha at Adingnigon and 225 kg/ha at Hayakpa. It can be hypothesized that P fertilizer could be a long-term investment that would pay-off over several seasons in the absence of other limiting factors. However, it is not appropriate to use the dataset to estimate the long-term effect of P because there were other limiting nutrients at Adingnigon.

Despite significant responses to P, returns on investment were negative in the year of application. Summing the responses over all seasons and eliminating severely degraded fields gave positive returns to P, especially whenever soybean was grown because there was no insecticide investment. Cumulative grain yield increase over four seasons from one initial P application was 216 kg/ha at Adingnigon and 464 kg/ha at Hayakpa.

4.2. Response to K fertilizer

It was further hypothesized that K deficiency was limiting response to P at Adingnigon. Response to K was significant in all cases at Adingnigon and in soybean at Hayakpa in 2000. Exceptions were the first season of 1999 at Hayakpa, when yield was already 1.1 t/ha with P alone and the second season when cowpea grown immediately after cowpea suffered from intense disease and insect pressure.

The data suggest an important residual effect of applied K. Two applications during 1999 and only one application in the first season of 1999 did not differ in their effect on soybean grain yield in the second season of 1999. Furthermore, the effect of K applied in 1999 on cowpea yield in 2000 was still significant. Leaching of K in southern Bénin may be limited by the fact that monthly rainfall never exceeds monthly potential evapotranspiration by more than about 10%. Poss et al. (1997) estimated rates of K leaching on similar *terre de barre* soils of southern Togo at 4.5 kg K/ha per year in unamended soil and 7.5 kg/ha per year for soil receiving 137 kg K/ha per year. However, on five fields soybean yields were nil except with a second K application. This suggests that on these very poor fields, the K applied in the first season may have been lost to leaching in that season.

The return on the investment in the first application of K fertilizer was substantial because it was amortized over two seasons. Cumulative grain yield increase over three seasons from one initial K application was 310 kg/ha at Adingnigon and 161 kg/ha at Hayakpa.

Aïhou et al. (1999) sampled degraded and non-degraded fields on *terre de barre* soils at the Niaouli research station in southern Bénin. They found that total N (0.3 vs. 0.9 g/kg) and exchangeable bases (0.7 vs. 3.7 cmol(+)/kg) were drastically reduced on the degraded field compared to the non-degraded field. In contrast, soil pH levels were similar (5.3 vs. 5.6) as was observed when Adingnigon was compared with Hayakpa (Fig. 2). Soil compaction is not important and rainfall infiltration rates are rapid on degraded *terre de barre* sites, including the highly degraded site at Adingnigon. Therefore, soil degradation in the case of the *terre de barre* soils of southern Bénin and Togo appears to be a relatively simple process of nutrient mining and depletion of organic matter. The result is low macro- and micro-nutrient availability and poor soil moisture retention. Low nutrient availability can be seen in the low biomass of fallow vegetation and the type of vegetation. For example, *Imperata cylindrica* is a dominant grass at Adingnigon, while *Andropogon gayanus* and *Chromolaena odorata* are still important at Hayakpa.

4.3. The need for organic amendments

The low yields at Adingnigon in spite of good pest control, a variety resistant to *S. gesnerioides*, and P and K fertilizer clearly indicated that there were other problems including other limiting nutrients, limited access to water, limited rooting depth, etc. The soil characteristics of the severely degraded fields at Adingnigon (Table 4) suggest that exchangeable bases are limiting a response to P and K. Exchangeable Ca and Mg were lower in the severely degraded plots than in the less degraded plots at Adingnigon and all plots at Hayakpa. This led to a decision to apply organic materials to the 15 most degraded fields.

The substantial increase of cowpea yield with the application of organic matter was probably due to several effects including improved moisture availability, supply of nutrients not included in the P and K fertilizers, and biological activity (De Ridder and van Keulen, 1990). Organic additions have been shown to improve water capture and retention (Lal et al., 1980) and the *terre de barre* soils are drought-prone. The organic additions also supplied N to the legume crops, which could be a limiting factor for the grain legumes if biological activity is low. The N applied in chicken manure or cotton seed was more than 300 kg/ha. Other nutrients supplied would be exchangeable bases or even trace elements. Rebafka et al. (1993) demonstrated that applications of crop residues on poor soils in Niger resulted in increased molybdenum concentration in the plant, increased N fixation, and increased yield of groundnuts.

One may wonder if the organic additions alone may have been sufficient to achieve cowpea yield increases observed without P and K fertilizer. The organic amendments may have provided enough P and K to satisfy the crop requirement. The amount of P applied was 80 kg/ha as cottonseed and 173 kg/ha as chicken manure. Rates of decomposition were not measured, but cotton seed was still visible at the end of the season, suggesting that decomposition was slow and P release may have been inadequate. The concentration of the exchangeable bases and even trace elements should be determined for the organic amendments. If the major benefit of the organic amendments is the supply of trace elements, then much smaller quantities of organic amendments will be sufficient.

Farmers will have difficulty in applying the levels of organic matter that were used in this trial. Although, it can be hypothesized that the effect will last several seasons, the transport cost for the amounts used in this study will be prohibitive except for high-value crops. Farmers will need to grow their own organic amendments in situ, which will require either a high input of land, a high input of nutrients, or a long time period. One promising technology in southern Bénin is the *A. auriculiformis* woodlot, which improves the soil while producing an economic product (fuel or construction wood) over a period of about 5 years (Versteeg et al., 1998).

5. Conclusion

Responses of cowpea and soybean to P and K were generally significant at a relatively non-degraded site (Hayakpa) and a severely degraded site (Adingnigon). Residual effects of P and K fertilizer were significant. The cumulative yield increase appear to justify the application of P at both sites and K at Adingnigon. Cumulative increases due to P addition were 216 kg/ha at Adingnigon and 464 kg/ha at Hayakpa over four growing seasons. In spite of significant increases with fertilizer application, grain legume yields were low at Adingnigon. Only a large organic amendment was able to achieve mean yields greater than 500 kg/ha. Degradation of the *terre de barre* soils appears to be a rather simple process of nutrient mining and soil organic-matter depletion. Future research will focus on determining the residual effect of the inorganic and organic amendments and determining the response to smaller rates of organic amendment. Other sources of organic matter will be sought and tested, especially the litter of *A. auriculiformis*.

Acknowledgements

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