International Scholars Journals

African Journal of Soil Science ISSN 2375-088X Vol. 7 (2), pp. 001-006, February, 2019. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Author(s) retain the copyright of this article.

Full Length Research Paper

Yield and nitrogen accumulation in five cassava varieties and their subsequent effects on soil chemical properties in the forest/savanna transitional agro-ecological zone of Ghana

S. Adjei-Nsiah

University of Ghana Agricultural Research Centre, Kade, Institute of Agricultural Research, University of Ghana, Legon, P. O. Box 38, Legon, Ghana. E-mail: y_nsiah@yahoo.co.uk. Tel: +233208206662, +233245395251.

Accepted 17 December, 2018

We evaluated five varieties of cassava for yield, N accumulation and their effect on soil chemical properties. Soil phosphorus content increased drastically after 14 months of crop growth while soil organic carbon, N and exchangeable K contents reduced during the same period. Fresh root yield ranged from 17 t ha^{-1} to 35.9 t ha^{-1}, while total dry matter production also ranged from about 18 t ha^{-1} to about 25 t ha^{-1}. Total N accumulation in the total plant biomass varied from about 228 kg N ha^{-1} to about 288 kg N ha^{-1}. The amount of total N uptake exported from the soil through crop harvest ranged from about 59 kg N ha^{-1} to about 123 kg N ha^{-1} while the total N uptake recycled into the soil through the return of crop residue ranged from 127 kg N ha^{-1} to about 189 kg N ha^{-1}. The study suggests that cassava varieties with high root dry matter yield have the potential of exporting large quantities of nutrients from the soil while varieties with high leaf litter deposition is likely to recycle substantial amount of the plant nutrient uptake.

Key words: Biomass, leaf litter, nutrients, root dry matter, soil chemical properties.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz.) is the most important staple crop in Ghana in terms of area under cultivation and production output (ISSER, 2005). Besides being a major staple crop in Ghana, cassava serves as a source of income for farmers and processors.

In spite of its role in the national economy, cassava production has not been promoted to any appreciable extent with the belief that cassava degrades soil. This perception which is based on the ability of cassava to grow on depleted soils where other crops would fail (Howeler, 2001) is however, contrary to perception by farmers in some parts of Ghana (Adjei-Nsiah et al., 2004) and elsewhere in Africa, (Saidou et al., 2004; Fermont, 2009), that cassava improves soil productivity. The perception that cassava degrades soils may be correct if the crop extracts large amount of nutrients and/or causes severe erosion if it has slow initial growth rate thus resulting in soil degradation as a result of heavy rains (Puthacharoen et al., 1998). In the forest/savannah transitional agro-ecological zone of Ghana, Adjei-Nsiah et al. (2007) reported that yields of maize grown after cassava were higher than those grown after nitrogen-fixing legumes such as cowpea (*Vigna unguiculata*), pigeonpea (*Cajanus cajan*) or mucuna, due possibly to large amount of nitrogen returned into the soil after cassava harvest through incorporation of leaf litters and green leafy biomass into the soil. Although farmers in the forest/savannah transitional zone assume that cassava varieties preceding maize crop usually provide sub-stantial amount of nutrients to the maize crop through litter falls and leafy biomass incorporated into the soil, the relative contributions of nutrients by different cassava varieties is not fully known.

We evaluated different cassava varieties developed by the National Agricultural Research System (NARS) in Ghana in both farmer-managed and researcher-managed experiments on farmers' field. In the researcher-managed experiment, dry matter production, nitrogen accumulation and the effects of cropping on soil chemical properties were evaluated.

The objectives of the study were to assess (1) the yield of elite cassava varieties developed by the NARS and the local varieties being cultivated by farmers; (2) the residual effect of cropping of the various cassava varieties on soil chemical properties and (3) the total N accumulated in the plant biomass of the various cassava varieties and recycled through leaf litters and other crop residues for uptake by subsequent crop.

MATERIALS AND METHODS

The study was conducted in three communities namely Asuoano (7°41´ N, 2°05´ W), Beposo (7°42´ N, 2°05´ W) and Droboso (7°43´ 2°05´ W) near Wenchi in the Brong-Ahafo Region of Ghana. Wenchi is located in the forest/savannah transitional agro-ecological zone of Ghana. The study site is characterised by a bimodal rainfall pattern with a 30-year average of 1271 mm. The major growing season is from April to July and the minor growing season is from September to November followed by a dry season from December to March. The annual rainfall amounts during the study period were 1396 mm (2003) and 1350 mm (2004). The soils which developed on Voltaian sandstone (coarse-grained type) are mainly Lixisols (Asiamah et al., 2000). The topography is gently flat to undulating and soils are well drained, friable, porous and sandy loams.

Researcher-managed experiment

The experimental plot had been under continuous maize cropping for three years (1999 - 2001) and had been abandoned for one year (2002) due to poor soil fertility and high infestation of spear grass (*Imperata cylindrica*). The initial land preparation consisted of harrowing after first and second ploughing. Composite soil samples were taken from 0 - 20 cm and 20 - 40 cm soil depth before the cassava was planted.

The trial consisted of six treatments replicated four times in four blocks. The treatments consisted of five cassava varieties namely Abasafitaa, Tekbankye and Afisiafi (which are improved varieties) developed by the NARS, Bensre and Tuakentemma (which are local varieties usually cultivated by farmers in the study area). To assess the effects of the cassava cropping on soil fertility a fallowed plot which was under spear grass was included as a control.

Plot size was 10 x 8 m. There were 3 m alleys between plots and replicates. Distance between rows was 100 cm and distance within rows was 50 cm. The cassava was planted during the last week of May 2003.

Six months after planting, 5 litter traps each measuring 50 by 50 cm and raised about 30 cm from the ground were placed under the cassava canopies to trap fallen leaf litters. The litters were collected every four weeks, oven dried at 70°C for 2 days for dry matter determination.

In September 2004 which was approximately 64 weeks after planting the cassava, an area of 12 m^2 (2 rows of 6 m) of the cassava plot was harvested. The plants were separated into roots, stems and foliage and weighed. Sub- samples of all harvested components were taken and oven dried at 70°C for 2 days for dry matter determination.

Sub-samples of plant parts of all cassava varieties were analysed for nitrogen (N). These plant parts were then grouped into two categories: (1) plant parts that would normally be removed from the field in the harvested products; and (2) plant parts that would remain in the field and be incorporated into the soil. The amounts of DM and N that would either be removed from the field or reincorporated into the soil were also calculated.

After harvesting the cassava in September 2004, soil samples were collected from 0 - 20 cm and 20 - 40 cm depth layers of the soil and analysed for soil chemical properties.

Farmer-managed experiments

Selection of farmers was based on interest and preparedness to spend one day in a week on the experimental field. The experiments were conducted on collective plots in each of the communities.

Land preparation on farmers' fields consisted of ploughing by tractor followed by harrowing using hoe. On the farmer-managed plots, one other additional variety namely Gblemo duade was included by the farmers in addition to the five varieties used in the researcher- managed experiments because this variety is high yielding but has high water content. Planting, field management and harvesting decisions were made by farmers. All participating farmers in each of the communities met with the researcher and decided when to plant, weed and harvest. The idea of having the experiments on collective plots was moved by the farmers. There were no replications within each experiment. Instead, each community represented a replicate.

Litter traps measuring 50 by 50 cm and raised 30 cm above the ground were placed under the canopies of the cassava to trap falling leaf litter. The litters were weighed together with the farmers every four weeks to determine the amount of litter produced by each of the varieties. The yield of the different cassava varieties was assessed with the farmers through ranking and scoring as well as by harvesting and weighing the roots.

Plant and soil analysis

Percent nitrogen in various plant parts of all the cassava varieties was determined by kjeldahl digestion and calorimetric analysis of NH_4-N in the digest.

Soil pH was determined in water suspension at 1: 1 ratio; organic C by Walkley-Black procedure; total N by kjeidahl method; available P by Bray-1 method and exchangeable bases (K, Ca and Mg) by 1 M NH_4 OAC method (ASA - SSSA, 1982).

Statistical analysis

Data were subjected to analysis of variance (ANOVA) using the general linear model (GLM) procedure (SAS, 1996). Data on soil chemical properties, cassava yield and DM and N contents of component parts of cassava varieties were analysed using randomized complete block design.

RESULTS AND DISCUSSION

The organic carbon at the start of the experiment were 8.0 and 5.4 g kg^{-1} for the (0 - 20) and (20 - 40) cm depth respectively in 2003 (Table 1) compared to an average of 6.7 and 4.7 g kg^{-1} for the (0 - 20) and (20 - 40) cm depth respectively in 2004 (Table 2). The reduction in organic carbon (-16% in the uppermost layer and -13% for the lower layer) could be attributed to mineralization of organic matter to supply nutrients for plant uptake (Ayanaba et al, 1976). Observations by Ayanaba et al. (1976) and Zingore et al. (2005) that organic matter content of tropical soils decline rapidly confirms the observed

Table 1. Initial soil chemical and physical characteristics of the 0 - 20 cm and 20 - 40 cm layers of the soil before planting the cassava in 2003.

Soil layer (cm)	pH	OC	Total N	P-Bray	Avail. K	Ca	Mg	Sand	Silt	Clay
	(1:1 H_2O)	(g kg^{-1})		(mgkg^{-1})	(me 100 g^{-1})			%		
Researcher-managed experiment										
0 - 20	6.0	8.0	0.96	4.6	0.21	2.6	1.9	73	12	15
20 - 40	6.0	5.4	0.60	2.5	0.20	2.1	1.5	72	12	16
Farmer-managed experiment										
0-20	5.6	7.4	0.80	6.1	0.22	2.0	1.9	76	7	17
20-40	5.8	4.3	0.70	3.3	0.12	1.4	1.5	72	6	22

Table 2. Effect of preceding cassava variety on chemical characteristics of 0 - 20 cm and 20 - 40 cm soil layers in September, 2004.

Soil chemical properties	Abasafitaa	Tekbankye	Afisiafi	Bensre	Boakentemma	Bush fallow	Mean	SED	Significance
0 - 20 cm									
pH (1:1 H_2O)	6.2	6.2	6.3	6.2	6.2	6.2	6.2	0.06	NS
Organic C (g kg^{-1})	6.8	6.3	5.2	7.1	7.5	7.3	6.7	0.86	NS
Total N (g kg^{-1})	0.6	0.60	0.60	0.57	0.60	0.57	0.59	0.04	NS
P-Bray (mg kg^{-1})	11	7.7	8.3	9.5	8.4	8.6	8.9	1.8	NS
Avail. K (me 100 g^{-1})	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.016	NS
Ca (me 100 g^{-1})	2.7	2.5	2.4	2.8	2.4	2.8	2.6	0.16	NS
Mg (me 100g^{-1})	2.3	2.2	2.3	1.9	2.0	2.5	2.2	0.18	NS
20 - 40 cm									
pH (1:1 H_2O)	6.2	6.2	6.2	6.1	6.1	6.2	6.2	0.06	NS
Organic C (g kg^{-1})	5.3	4.2	4.6	4.6	4.8	4.6	4.7	0.28	0.05
Total N (g kg^{-1})	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.05	NS
P-Bray (mg kg^{-1})	7.2	4.9	4.9	4.8	5.0	4.8	5.3	1.21	NS
Avail. K (me 100 g^{-1})	0.08	0.07	0.07	0.07	0.06	0.07	0.07	0.010	NS
Ca (me 100 g^{-1})	2.0	2.1	2.0	2.2	2.0	2.3	2.1	0.13	NS
Mg (me 100 g^{-1})	1.7	1.8	1.8	1.7	1.7	2.1	1.8	0.23	NS

SED = Standard error of difference.

Table 3. Root yield and N removal by five cassava varieties grown at Wenchi expressed in both kg ha^{-1} and kg t^{-1} harvested product.

Variety	Root yield (t ha^{-1})		N		
	Fresh	Dry	Kg ha^{-1}	Kg t^{-1}DM produced	
	Researcher-managed experiment				Farmer-managed experiment
Abasafitaa	35.9	11.4	101.4	9.1	28.0
Tekbankye	26.5	10.4	96.0	9.1	22.8
Afisiafi	30.5	9.4	87.1	9.1	23.0
Bensre	31.2	14.6	122.9	8.4	30.7
Boakentemma	17.4	6.4	59.3	9.1	21.0
SED	4.9	0.25	19.4	0.92	40.4
Significance	0.05	0.01	NS	NS	7.2

SED = Standard error of difference.

reduction in the organic carbon content of the soil.

Total soil N was significantly reduced from an initial amount of 0.96 g kg-1 in 2003 (Table 1) to an average of about 0.60 g kg-1 in 2004 (Table 4) in the uppermost soil layer and from 0.6 g kg^{-1} to an average of 0.40 g kg^{-1} in the 20 - 40 cm depth. The rapid decline in the soil N content in this study, confirms CIAT (1982) report that cassava depletes a large amount of N for root yield formation. Soil available P was generally increased from 4.6 (Table 1) to an average of 8.9 mg kg^{-1}(Table 2). Although mycorrhizal associations were not studied in this experiment, studies have shown that cassava roots form an association with mycorrhiza which allows for an increased surface area through which diffusion of P into the roots could take place (Howeler, 2001; Howeler and Sieverding, 1983). Exchangeable K was generally significantly reduced (-60%) in the uppermost layer of the soil after fourteen months of crop growth (Tables 1 and 2). Howeler and Cadavid (1983) reported of similar significant reduction in soil exchangeable K after 12 months of crop growth and attributed it to plant uptake as well as to leaching and soil erosion. While Ca content was not affected by cassava cultivation, Mg content was increased from 1.9 to 2.1 me 100 g^{-1} after fourteen months of cropp-ing (Tables 1 and 2). The observed general increase in the Mg status of the soil could be attributed to release of Mg^{2+} from the cassava leave litter that was deposited on the soil surface (Pellet and El-Sharkawy, 1997). Cassava varieties however did not have any significant effect on any of the soil chemical properties.

On the researcher-managed plots, statistically significant ($P < 0.05$) differences in fresh cassava root yield were found between different cassava varieties (Table 3). Fresh root yield ranged from 17.4 t ha^{-1} with 'Boakentemma' to 35.9 t ha^{-1} with 'Abasafitaa'. Root dry matter yield also ranged from 6.4 t ha^{-1} with 'Boakentemma' to 14.6 t ha^{-1} with 'Bensre' with statistically significant ($P < 0.01$) differences between the varieties. On the farmer-managed plots, yields were generally low, with no statistically significant differences among the different varieties. The differences in fresh root yield in the farmer-managed and the researcher-managed fields could be attributed to differences in management practices.

The fresh root yields of all the cassava varieties studied in both the researcher and the farmer managed experiments were generally high compared with the current national average of 12 t ha^{-1} (ISSER, 2005). The yields reported in both the researcher and farmer managed experiment in this study are also comparable to those reported in Ghana under experimental conditions which range between 16 and 32 t ha^{-1} (MOFA, 2004) and elsewhere in other parts of the world (Puttthacharoen et al., 1998; Howeler and Cadavid, 1983). The amount of total dry matter (dry matter of various plant parts of cassava removed in the crop harvest plus those returned to the soil) produced by the various cassava varieties ranged from 17.9 t ha^{-1} with 'Boakentemma' to 24.9 t ha^{-1} with Bensre (Table 4). Except for the variety Boakentemma, in which the largest contribution was made by the stem, the plant part that made the largest contribution to the total dry matter was the root while the leaf made the smallest contribution to the total dry matter. The percent dry matter removed from the field as storage roots by the various cassava varieties varied from 35.7% with Boakentemma to 58.7% with Bensre. In Thailand, Putthachareon (1998) reported that with total dry matter production of about 33.5 t ha^{-1} in four crops of cassava, the percentage DM that was removed from the field was 45%. In Columbia, Howeler (1985) estimated that percentage dry matter removed from the soil was about 60% when total dry matter production was about 23 t ha^{-1}.

The total amount of N accumulated by the different cassava varieties (made up of total N in plant parts of harvested crop removed from the field and total N in plant parts of harvested crop returned to the field) within the fourteen months of crop growth ranged between 228.4 kg ha^{-1} with 'Abasafitaa' and 287.6 kg ha^{-1} with 'Bensre' (Table 4). The amounts of N removed from the system through crop harvest were 59.3, 87.3, 96, 101.4 and 122.9 kg ha^{-1} for Boakentemma, Afisiafi, Tekbankye, Abasafitaa and Bensre respectively.

Table 4. Dry matter (t ha^{-1}) and N content (kg ha^{-1}) of various plant parts of five cassava varieties removed in the crop harvest and those returned to the soil.

Cassava variety	Roots		Leaves		Litters		Stems		Total	
	DM	N	DM	N	DM	N	DM	N	DM	N
Plant parts of harvested crop removed from the field										
Abasafitaa	11.4	101.4							11.4	101.4
Tekbankye	10.4	96.0							10.4	96.0
Afisiafi	9.4	87.2							9.4	87.2
Bensre	14.6	122.9							14.6	122.9
Boakentemma	6.4	59.3							6.4	59.3
SED	2.0	19.4							2.0	19.4
Significance	0.05	NS							0.05	NS
Plant parts of the harvested crop returned to the field										
Abasafitaa			0.93	21.6	4.8	71.9	2.8	33.5	8.5	127.0
Tekbankye			0.83	29.5	5.0	80.6	5.3	68.4	11.1	178.4
Afisiafi			0.92	26.7	4.6	69.1	4.0	47.6	9.5	143.3
Bensre			0.75	32.2	3.9	65.5	5.6	67.0	10.3	164.7
Boakentemma			1.06	41.2	3.9	63.8	6.6	84.5	11.6	189.5
SED			0.13	4.2	0.31	7.04	1.02	15.6	1.3	41.0
Significance			NS	0.01	0.01	NS	0.05	0.05	NS	NS

SED = Standard error of difference.

These values are higher than those reported by Putthachareon et al. (1998) but lower than that reported by Howeler and Cadavid (1983). Howeler (2002) reported that the amount of nutrients removed in the root harvest, is highly dependent on crop growth rate and yield, which, in turn depends on climate, soil fertility and variety.

The amount of N that were recycled through the return of crop residues into the soil were 127.0, 143.3, 164.7, 178.4 and 189.5 kg N ha^{-1} for Abasafitaa, Afisiafi, Bensre, Tekbankye and Boakentemma respectively. These repre-sents 56, 62, 57, 65 and 76% of the total N accumulated by Abasafitaa, Afisiafi, Bensre, Tekbankye and Boakentemma respectively. Thus incorporation of the stems, leaves and leaf litter into the soil would greatly diminish total nutrient export and thus the requirement for fertilization.

Table 4 shows that on average, the largest contribution to the total biomass nitrogen returned to the soil was made by the leaf litter. While there were significant differences among the different cassava varieties with respect to leaf litter production with Tekbankye and Abasafitaa having the highest litter production and the Boakentemma, the least, the amount of N returned into the soil through litter production did not differ very much. The amount of leaf litter reported in this experiment (3.9 to 5.0 t ha^{-1}) is however, comparable to that reported by Carsky and Toukourou (2003) in Benin who collected a total of between 3.4 and 4.1 during 12 months of growth. Our estimate is however higher than that reported by Pellet and El-Shakawy (1997) who reported of values of up to 3 t ha^{-1} for four varieties grown for 10 months. The higher cumulative total of leaf litter reported in this study was partly due to the fact that in our study, measurement was done over a long period of crop growth. Leaf deposition offers a mulch soil-cover and may reduce soil erosion and also contribute to the recycling of substantial amount of nutrients removed from the soil. Pellet and El-Shakawy (1997) reported that leaf litter constituted about 32% of total Ca, 19% of total Mg and 16% of total N uptake in the total cassava biomass. In the present study, leaf litter constituted between 23 and 32% of total N uptake in the total cassava biomass. Our N values were higher, possibly because of differences in methods of litter collection. It is probable that our monthly litter collection reduced losses of nutrients compared with collection of nutrients from the soil surface at the time of harvesting cassava roots.

Although, less than 50% of the total N uptake is lost from the soil through crop harvest, it is estimated that about two thirds of the total amount of K uptake accumulates in the roots and would thus be removed through crop harvest (Howeler and Cadavid, 1983). Thus in this study where root dry matter yield ranged between 6.4 and 14.6 t ha^{-1}, large amount of K could be removed through crop harvest and would thus have to be replaced through fertilization especially as in the case of these soils that contained 0.21 me 100 g^{-1}.

Conclusion

The study suggests that cassava mobilizes and extracts large amounts of N and even larger amount of K (whereas the soil is already suffering from K-limitation) from the soil but recycle substantial amount of the N into the soil through leaf litter deposition. Reduction in the nutrient content of the soil cannot exclude the possibility of losses through erosion and leaching. The study also shows that cassava varietal choice seems unimportant from soil fertility enhancement point of view but from a nutritional point of view since all the cassava varieties studied mobilize similar amount of N. However, as some varieties remove more N through better crop harvest, some varieties recycle more of its total N uptake for subsequent crops (if it is not leached).

ACKNOWLEDGEMENTS

The author gratefully acknowledges the financial contribution made by the Interdisciplinary Research and Education Fund (INREF) of the Wageningen University and Research Centre, the Netherlands and the Netherlands Ministry of International Co-operation (DGIS).

REFERENCES

Adjei-Nsiah S, Leeuwis C, Giller KE, Sakyi -Dawson O, Cobbina J, Kuyper TW, Abekoe MK, Van Der Werf W (2004). Land tenure and differential soil fertility management practices among native and migrant farmers in Wenchi, Ghana: implication for interdisciplinary action research. NJAS-Wageningen J. Life Sci. 52: 331-348.

Adjei-Nsiah S, Kuyper TW, Leeuwis C, Abekoe MK, Giller KE (2007). Evaluating sustainable cropping sequences with cassava and four other legume crops: Effects on soil fertility and maize yields in the forest savannah transitional agro-ecological zone of Ghana. Field Crops Res. 103: 87-97.

Agronomy Society of America-Soil Science Society of America (1982). Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties-Agronomy Monograph no. 9, 2nd ed., ASA-SSA, Madison, USA.

Asiamah RD, Adjei -Gyapong T, Yeboah E, Fening JO, Ampontuah EO, Gaise E (2000). Report on Soil Characterization and Evaluation at four Primary Cassava Multiplication Sites (Mampong, Wenchi, Asuansi and Kpeve) in Ghana. Technical Report No. 200. Soil Research Institute, Kumasi.

Ayanaba AJ, Tuckwell SB, Jenkinson DS (1976). The effects of clearing and cropping on the organic reserves and biomass of tropical forest soils. Soil Biol. Biochemist. 176(8): 519-525.

Carsky RJ, Toukourou MA, (2003). Cassava leaf litter estimation in on-farm trials. Expl. Agric. 40: 315-326.

Centro International Agricultura Tropicale (CIAT) (1982). Report of Cassava Programme: Annual Report for 1981; CIAT: Cali, Columbia.

El-Sharkawy MA (1993). Drought-tolerant cassava for Africa, Asia and Latin America: breeding projects work to stabilize productivity without increasing pressures on limited natural resources. Bioscience 43: 441-451.

Fermont AM (2009). Cassava and soil fertility in intensifying smallholder farming systems of East Africa. Published doctoral dissertation. Wagenigen University and Research Centre, Wageningen

Howeler RH, (1985). Mineral nutrition and fertilization of cassava. In: Cassava: Research, Production and Utilization. UNDP-CIAT Cassava Programme, Cali, Columbia: pp.249-320.

Howeler RH (2001). Long-term effect of cassava cultivation on soil productivity. Field Crops Res. 26: 1-18.

Howeler RH (2002). Cassava mineral nutrition and Fertilization. In Cassava: Biology, Production and Utilization, Hilocks, R.J. Thresh J.M. and Bellotti A.C. (eds): 115-147. CAB International, Wallingford, UK.

Howeler RH, Cadavid LF 1983. Accumulation and distribution of dry matter and nutrients during a 12-month growth cycle of cassava. Field Crops Res. 7: 12-139.

Howeler RH, Sieverding E (1983). Potentials and limitations of mycorrhizal inoculation illustrated by experiments with field-grown cassava. Plant Soil 75: 245-261.

ISSER (2005). The state of the Ghanaian Economy in 2004. Institute of Social, Statistical and Economic Research, University of Ghana, Legon.

MOFA (2004). Cassava Production Guide. A resource and Reference Manual. Root and Tuber Inprovement Programme (RTIP), Ministry of Food and Agriculture, Kumasi, Ghana.

Pellet DM, El-Sharkawy MA, (1997). Cassava varietal response to fertilization: growth dynamics and implications for cropping sustainability. Experimental Agriculture 33: 353-365.

Putthacharoen S, Howeler RH, Jantawat S, Vichukit V (1998). Nutrient uptake and soil erosion losses in a Psamment in eastern Thailand. Field Crops Res. 57: 113-126

Saidou A, Kuyper TW, Kossou DK, Tossou R, Richards P, (2004). Sustainable soil fertility management in Benin: Learning from farmers. NJAS-Wageningen J. Life Sci. 52: 349-369.

SAS (1996). SAS User’s Guide: Statistics, SAS Institute, Cary, NC.

Zingore S, Manyame C, Nyamugafata P, Giller KE (2005). Long-term changes in organic matter of woodland soils cleared for arable cropping in Zimbabwe. Eur. J. Soil Sci. 56: 727-736.