African Journal of Environmental Science and Technology Vol. 3 (9), pp. 234-238, September, 2009
Available online at http://www.academicjournals.org/AJEST
DOI: 10.5897/AJEST09.074
ISSN 1991-637X

Full Length Research Paper

On farm evaluation of the contribution of three green manures to maize yield in the semi-deciduous forest zone of Ghana

J. O. Fening[1]*, E. Yeboah[1], T. Adjei-Gyapong[2] and E. Gaizie[1]

[1]Soil Research Institute, Academy Post Office, Kwadaso, Kumasi, Ghana.
[2]Kwame Nkrumah University of Science and Technology, Crops Science Department, Kumasi, Ghana.

Accepted 11 August, 2009

Low soil fertility is one of the major factors responsible for low crop yields on small-scale farms in Africa. The use of *Chromolaena odorata, Crotalaria juncea* and *Panicum maximum* and their combination with NPK for improving soil fertility and maize yield was investigated in the semi-deciduous forest zone of Ghana. Each plant material was applied at two application rates, 1 and 3 t ha^{-1}. The field design was a randomized complete block with three replications. The plant materials caused an initial immobilization of nutrients which negatively affected maize grain yield in the major season. The plant materials plus $N_{45}P_{30}K_{60}$ however, was able to provide nutrients that were sufficient to increase maize yields by over 85% relative to the control for the two consecutive seasons. $N_{90}P_{60}K_{60}$ application alone produced the highest grain yield of 4.65 t ha^{-1} in the major season but less so in the minor season. Maize grain yield was not influenced by the quantity of plant materials application but was higher during the minor season than in the major season. The results of the study provide soil fertility management options for sustainable food production in the semi-deciduous forest zone of Ghana.

Key words: Fertilizer, maize, organic residues, soil fertility.

INTRODUCTION

The use of mineral fertilizers to overcome declining soil fertility in small scale farming in sub Saharan Africa is limited by economic constraints (Drechesel and Gyiele, 1999). The integration of farmer available organic resources in these cropping systems is therefore being regarded as an alternative to mineral fertilizers. Farmer available organic resources such as manure (cowdung and poultry manure) are however severely limited particularly in the semi-deciduous forest zone where livestock is not fully integrated in the farming system. The greater proportion of livestock feed on extensive range land where manure is difficult to collect. Another limiting factor is the cost of transporting manure to farms as farms are getting further and further away. Crop residues also have alternative uses as fodder, fuel and building materials for which there are often no substitutes (Quedraogo et al., 2005). Other organic resources such as high biomass producing plants are therefore needed as soil amendments to address the declining soil fertility under continuous cropping systems (Vanlauwe and Giller, 2006).

The use of plant biomass for soil fertility replenishment also requires the identification of species found in the farm vicinity to reduce labour cost. Such plant species should have the ability to increase P availability to crops since organic inputs have low P contents (Palm et al., 1997). Also the plant material must be able to produce a large pool of mineral N before the period of rapid N uptake by a crop (Magdoff, 1991). This will mean application of large amounts of the plant material which may not be available. Combining plant biomass and mineral fertilizers may therefore provide an intermediate solution allowing the most efficient use of scarce

*Corresponding author. E-mail: kofifening@yahoo.com. Tel.: +233-51-50353/4. Fax: +233-51-50308.

resources (Vanlauwe et al., 2004). The outcome of the combination may however depend on the quality of the plant biomass (Palm et al., 1997), and underline the need to test them experimentally. Most of the studies on resource quality characterization, decomposition and nutrient release have mainly concentrated on leguminous plant species which are considered as high quality materials (Cadisch and Giller, 1997; Palm et al., 1997), Mafongoya et al., 1998). However, biophysical characterization of African farming systems has shown that organic resources accessible to farmers are highly heterogeneous. It is apparent that most of the resources utilized on farm are low or intermediate in quality since the resources are often used in mixtures. There is a need therefore to improve our understanding of resource quality and soil organic matter management interactions under different climatic and edaphic conditions and translate the available knowledge into practical management solutions that are adaptable on farm. In the semi deciduous forest zone of Ghana, *Chromolaena odorata, Panicum maximum* and *Crotalaria juncea* abound on farmer's field. Farmers clear and burn these plants during land preparation. This study aimed at assessing the resource quality of *C. odorata, P. maximum* and *C. juncea* and quantifying their contribution to maize production.

MATERIALS AND METHODS

Study site

The study was located at Ayuom (6°35'N1°35'W) in the Bosumtwi Atwima Kwanwomma District of the Ashanti Region of Ghana. The area receives bimodal mean rainfall of 1200 mm per year with peaks in June (major season) and September (minor season). The major soil of the area is Ferric Acrisol. Some of the initial soil chemical properties in the surface 15 cm are as follows; pH 1:1 (H_2O) 6.6, total N 0.15%, organic C 0.6%, exchangeable acidity 0.1 cmol kg^{-1} soil, exchangeable Ca 7.7 cmol kg^{-1} soil, Mg 0.8 cmol kg^{-1} soil, Na 0.1 8 cmol kg^{-1} soil, K 0.4 8 cmol kg^{-1} soil, available P 2.9 mg kg^{-1}. The loamy sand soil contains 74% sand, 6.5% silt and 19.5% clay.

Plant materials

The plant materials (*C. odorata, P. maximum and C. juncea*) were characterized for quality parameters according to the recommendations of Palm and Rowland (1997). Total N and P were determined colorimetrically (Parkinson and Allen, 1975) and K by flame photometry (Anderson and Ingram, 1993). The C contents were determined using the Nelson and Sommers (1982) wet combustion procedure, while Ca and Mg contents were estimated using the procedure of Anderson and Ingram (1993). Lignin was determined according to the acid detergent fiber method of van Soest (1963). Total extractable polyphenols was analysed following the method described by Constantinides and Fownes (1994a).

Field experiment

The trial consisted of 11 treatments in a randomised complete block design with three replications. The treatments were (1) a control with no inputs; (2) 1 t ha^{-1} *C. juncea* (3) 3 t ha^{-1} *C. juncea* (4) 1 t ha^{-1} *C. odorata* (5) 3 t ha^{-1} *C. odorata* (6) 1 t ha^{-1} *P. maximum* (7) 3 t ha^{-1} *P. maximum* (8) 1 t ha^{-1} *C. juncea* + $N_{45}P_{30}K_{60}$, (9) 1 t ha^{-1} *C. odorata* + $N_{45}P_{30}K_{60}$, (10) 1 t ha^{-1} *P. maximum* + $N_{45}P_{30}K_{60}$, and (11) $N_{90}P_{60}K_{60}$. The plot size was 12 x 30 m with 1.5 m border between plots and 2 m between blocks. The plant materials were broadcast and incorporated into the soil manually with a hoe to a depth of 15 cm. Treatments were applied in May, 2008, the beginning of the long rainy season and maize (Hybrid *Mamaba*) sown at a spacing of 0.25 x 0.75 m. The inorganic fertilizers were applied banded, two weeks after planting. The N fertilizer (urea) was split applied. A third was applied at two weeks after planting and two-thirds applied 6 weeks after planting. The P source was triple super phosphate and the K was applied in the form of muriate of potash. Hand weeding was done twice. A second crop was planted in September, 2008, (the short rainy season) with no application of plant materials or NPK in order to observe residual effects. Crop residues from the major season cropping were removed at harvest to reduce confounding effects from additional inputs of different qualities.

Maize grain yields were determined for the two seasons harvested in August, 2008 and December, 2008. A total of 18 plants were harvested per plot leaving one border row on all sides. Total fresh weight of the cobs and stover per plot was taken in the field. Sub-samples were taken to the laboratory for oven drying at 65°C to constant weight to determine dry matter content. In order to compare the treatment effects of the two seasons, yields were converted to relative increase compared to the control:

$$\text{Yield increase \%} = \frac{(\text{Yield treatment} - \text{Yield control})}{\text{Yield Control}} \times 100$$

Soil samples were taken from the treatment plots at 0 - 10 cm depth after the second harvest for analysis of N P K and organic carbon by the method of Anderson and Ingram (1993).

Data analysis

Analysis of variance was conducted using the ANOVA procedure of SAS (SAS Institute Inc, 1995) to determine the effects of treatments on crop yields. The Least Significant Differences (LSDs) were computed and used to separate the treatment means at 5% level of significance.

RESULTS

Plant materials

P. maximum had the highest N and K content with *C. odorata* showing the highest, P and Ca contents. The Mg concentration among the organic materials ranged narrowly from 20 to 24 mg g^{-1} (Table 1). The N concentration of *C. odorata* and *P. maximum* were within the critical level of 20 to 25 mg g^{-1}, below which point net N immobilization from soil would be expected. That of *C. juncea* was below the critical level. The P concentration of all the materials on the other hand was above the critical level of 2.5 mg g^{-1} for P immobilization (Palm et al., 2001). The C/N ratios of *P. maximum* and *C. odorata* were less than 20 with *C. juncea* indicating a C/N ratio of

41. Even though the N concentration of *C. juncea* was very low, its lignin and polyphenol contents were below 15 and 4% respectively, levels that would not significantly reduce decomposition rates (Palm et al., 2001).

Maize yields

Maize grain yields for the two seasons differed among

Table 1. Initial nutrient contents of the plant residues.

Plant material	N	P	K	Ca	Mg	C	C/N	Lignin	Polyphenol
	---------mg g^{-1}		--------------					------------%-----------	
C. odorata	24.6	4.2	25.6	32.1	23.3	336.4	14.89	10.78	1.62
C. juncea	10.7	3.8	13.8	27.4	24.2	434.7	40.80	12.44	0.73
P. maximum	24.9	3.3	26.1	26.0	20.2	452.5	18.17	13.24	1.48

Table 2. Maize grain yield response to the application of green manure and their combination with NPK.

Treatment	Major season	Minor season	Total yield	% Yield Increase: Major season	% Yield Increase: Minor season	% Yield Increase: Total
	-------------------- t ha^{-1} ---------------------------			------------------t ha^{-1}------------------		
Control	3.08^{bc}	1.38^{c}	4.46^{c}			
C. juncea 1 t/ha^{-1}	2.72^{bc}	3.42^{b}	6.14^{bc}	-11.7	147.8	37.7
C. juncea 3 t/ha^{-1}	2.10^{c}	4.84^{ab}	6.94^{b}	-31.8	250.7	55.6
C. odorata 1 t/ha^{-1}	3.38^{bc}	3.50^{b}	6.88^{b}	7.9	153.6	54.3
C.odorata 3 t/ha^{-1}	3.07^{bc}	3.92^{a}	7.02^{b}	-2.3	184.1	57.4
P. maximum 1 t/ha^{-1}	3.20^{bc}	3.50^{b}	6.70^{b}	3.9	153.6	50.2
P. maximum 3 t/ha^{-1}	2.48^{c}	4.17^{ab}	6.65^{b}	-19.5	202.2	49.1
C. juncea 1 t/ha^{-1} + $N_{45}P_{30}K_{60}$	3.24^{bc}	5.00^{a}	8.24^{ab}	5.19	262.3	84.8
C. odorata 1 t/ha^{-1} + $N_{45}P_{30}K_{60}$	3.60^{b}	5.12^{a}	8.72^{a}	16.9	271.0	95.6
P. maximum 1 t/ha^{-1} + $N_{45}P_{30}K_{60}$	3.70^{b}	5.08^{a}	8.78^{a}	20.1	268.1	96.9
N_{90} $P_{60}K_{60}$	4.65^{a}	3.60^{b}	8.25^{ab}	51.0	160.9	85.0

Means followed by same letters in a column are not significantly different at 0.05 level.

the treatments. Application of $N_{90}P_{60}K_{60}$ produced the highest grain yield of 4.65 t ha^{-1} in the major season while *C. juncea* application at 3 t ha^{-1} gave the lowest yield of 2.10 t ha^{-1} which was 32% less than the no input control (Table 2). Yields obtained with *C. odorata* were higher than with *P. maximum* and *C. juncea* for each season though the difference was not significant in all cases. Grain yields for the major and minor seasons showed a better response to the combined application of organic and inorganic inputs than the sole plant material application. The sole application of the plant materials at 3 t ha^{-1} showed a greater increase in relative yield for the minor season compared to 1 t ha^{-1}. The average grain yield of 3.2 t ha^{-1} for the major season was lower than that of the minor season (4.0 t ha^{-1}) and relative yield increase of between 37 and 97% was achieved for the total yield of maize during the two seasons (Table 2).

The chemical properties of the surface soils from the treated plots showed improvement in organic carbon and total nitrogen contents relative to the initial levels (Table 3). Organic carbon from the inorganic application treatment (N_{90} P_{60} K_{60}) was however observed to be reduced.

DISCUSSION

The focus of soil fertility research in recent years have shifted towards the combined application of organic and inorganic nutrient sources to reverse the negative nutrient balances in cropping system in agriculture in Sub-Saharan Africa (Vanlauwe et al., 2001). While mineral fertilizers supply plant nutrients, organic residues are a precursor of soil organic matter which maintains the physical and physico-chemical components contributing to soil fertility such as cation exchange capacity and soil structure. Another more practical reason for advocating the use of organic and inorganic nutrient sources is that either one of them may not be available or affordable in sufficient quantities.

Organic materials differ considerably in their ability to supply nutrients to the soil and crop. These differences are controlled in part by the resource quality of the material. The resource quality analysis of C. odorata, P. maximum and C. juncea in this study indicates that they contain appreciable quantities of nutrients which suggest their suitability for soil fertility management. Several studies have focused on P content as the key parameter for selecting plant materials. Blair and Boland (1978) put forward a threshold of 2.5 g kg^{-1}, Palm et al. (1999), 2.4 g kg^{-1} and Tossah (2000), 3.0 g kg^{-1}. Going by these threshold values, the plant materials used in this study would all be classified as suitable. Other commonly used indices for determining relative rates of N immobilization and mineralization from organic materials include initial tissues nitrogen concentration, lignin to nitrogen concentration and various carbon to nutrient ratios (Melillo et al., 1982; Swift et al., 1979; Constantinides and Fownes, 1994b; Tian et al., 1995). Of these indices the initial N concentration of the material serves as the best criteria to predict N release (Palm et al., 2001). The N concentration of *C. odorata* and *P. maximum* were within the critical level of 20 to 25 mg g^{-1}, below which point net N immobilization from soil would be expected (Palm et al., 1999). The N content of *C. juncea* which was a legume was less than 12 mg g^{-1} and its C/N ratio 41. This is unexpected; however, the resource quality of plant materials varies with the plant parts and their maturity (Palm et al., 2001). Studies on the resource quality of the various parts of *C. juncea* showed that the N content of the leaves and stem were 33.4 and 8.0 mg g^{-1} respectively (Yeboah, personal communication). According to the decision tree for selecting organic materials developed by Palm et al. (2001), *C. odorata, C. juncea* and *P. maximum* should be mixed with fertilizers for annual crops because they contained <2.5% N,<15% lignin and <4% phenol.

Table 3. Chemical properties of the surface soil after the minor season harvest.

	Nutrient Concentration			
Treatment	**C%**	**N%**	**P mg kg^{-1}**	**K mg kg^{-1}**
Initial soil	0.6	0.15	2.9	0.48
C. juncea 1 t/ha^{-1}	1.02	0.86	3.0	0.08
C.juncea 3 t/ha^{-1}	1.00	0.53	3.2	0.09
C. odorata 1 t/ha^{-1}	0.96	0.86	6.0	0.092
C.odorata 3 t/ha^{-1}	1.06	0.46	6.2	0.145
P. maximum 1 t/ha^{-1}	1.05	0.60	4.8	0.102
P. maximum 3 t/ha^{-1}	1.01	0.68	4.2	0.125
C. juncea 1 t/ha^{-1} + $N_{45}P_{30}K_{60}$	0.94	0.53	3.8	0.087
C. odorata 1 t/ha^{-1} + $N_{45}P_{30}K_{60}$	0.97	0.60	3.2	0.082
P. maximum 1 t/ha^{-1} + $N_{45}P_{30}K_{60}$	0.95	0.51	3.6	0.085
N_{90} $P_{60}K_{60}$	0.45	0.48	3.3	0.068
Control	0.5	0.44	2.52	0.032
LSD (0.05)	0.21	0.19	2.90	0.031

Nutrient availability in the right quantities, ratios and in synchrony with crop demand is important for good crop yields. The green manure of *C. juncea, C. odorata* and *P. maximum a*t 3 t ha^{-1} caused an initial immobilization of nutrients which in no doubt negatively affected yields in the major season. The plant materials plus $N_{45}P_{30}K_{30}$ was able to provide nutrients in quantities and rates sufficient to increase yield for the two consecutive crops following a single application. The addition of the mineral fertilizer improved synchrony by increasing the nutrient supply at the initial stages of net immobilization resulting from application of the plant materials. Several studies have demonstrated such additive effects between organic and inorganic mineral fertilizers (Palm et al., 1997; Giller, 2001). The question of whether there was an additive interaction is important for researchers, but what counts for farmers is that with the mixed treatment one needs to purchase only half the quantity of fertilizer and still get the same yield.

The $N_{90}P_{60}K_{60}$ treatment showed increased yields but less so in the minor season probably due to gaseous losses and leaching which mineral fertilizers are subjected to under field conditions (Christianson et al., 1990), or probably because crop recovery was low. An improvement in the nutrient capital of the soil was also observed after the second cropping in the plant material treatment plots. This is an indication of a build up of the nutrient capital and buffering capacity of the soil due to improvement in the soil organic matter content and because the process is slow, related potential benefits are likely to become visible in the long term compared with a pure fertilizer treated plot. The decline in organic C with inorganic fertilizer could be due to destabilization of soil aggregates. A similar observation has been observed by Khan et al. (2007).

Conclusion

This study has shown that the biomass of *C. juncea*, *C. odorata* and *P. maximum* are potential sources of nutrients for maize crop production and there is clear incentive for farmers to use them in combination with inorganic fertilizers. As the quantity of traditional organic inputs such as animal manures decline in many tropical

farming systems the use of diverse organic inputs including trees, shrubs and cover crops should be exploited.

REFERENCES

Anderson JM, Ingram JSI (1993). Tropical Soil Biology and Fertility: A Handbook of Methods CAB Int., Wallingford, England, 221 pp.

Blair GH, Boland OW (1978). The release of phosphorus from plant material added to soil. Australian J. Soil Res. 16: 101-111.

Cadisch G, Giller, KE (1997). Driven by nature: Plant Litter Quality and Decomposition. CAB Int., U. K.

Constantinides M, Fownes JH (1994a). Nitrogen mineralization from leaves and litter of tropical plants: relationship to nitrogen, lignin and soluble polyphenol concentrations. Soil Biol. Biochem, 26: 49-55.

Constantinides M, Fownes JH (1994b). Tissue-to-solvent ratio and other factors affecting determination of soluble phenolics in tropical leaves. Community Soil Sci. Plant Analysis.25: 3221-3227.

Christianson CB, Bationo A, Vlek PLG (1990). Fate and efficiency of N fertilizers applied to pearl millet in Niger. Plant and Soil 125:221-231.

Drechsel P, Gyiele LA (1999). The Economic Assessment of Soil Int. Board for Soil Res. and Management. Issues in Sustainable Land Management No. 7, Bangkok, Thailand, 80 pp.

Giller KE (2001). Targeting management of organic resources and mineral fertilizers: Can we match scientists' with farmers' realities? In: Vanlauwe B, Sanginga N, Diels J, Merckx R (eds) Balanced Nutrient Management Systems for the Moist Savanna and Humid Forest Zones of Africa). CAB Int., Wallingford.

Khan SA, Mulvaney RL, Ellsworth TR, Boast CW (2007). The myth of nitrogen fertilization for soil carbon sequestration. J. Environ. Qual. 36: 1821-1832.

Mafongoya PL, Giller KE, Palm CA (1998). Decomposition and nitrogen release patterns of tree prunings and litter. Agroforestry Systems 38: 77-97.

Magdoff F (1991). Understanding the Magdoff pre-sidedress nitrate test from conrn. J. Prod. Agric. 4: 297-305.

Melillo JM, Aber JD, Muratore JF (1982). Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. Ecology 63: 621-626.

Nelson DW, Sommers LE (1982). Total carbon, organic carbon and organic matter. In Page, AL, Miller RH, Keeney, DR (eds.), Methods of Soil Analysis. Part 2. Agronomy 9, (2nd edn.), pp. 539-579. Am. Society of Agronomy; Madison, U. S. A.

Palm CA, Rowland AP, (1997). Chemical characterization of plant quality for decomposition. In: Cadisch G, Giller KE, (eds.), Driven by Nature: Plant Litter Quality and Decomposition, pp. 379-392. CAB Int., Wallingford, England.

Palm CA, Myers RJK, Nandwa SM (1997). Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. In: Buresh, RJ, Sanchez PA (eds), Replenishing Soil Fertility in Africa. SSSA Special Publication 51. SSSA, Madison, WI, U. S. A. pp. 193-217.

Palm CA, Nziguheba G, Gachengo CN, Gacheru E, Rao MR (1999). Organic materials as sources of phosphorus. Agroforestry Forum 9:30-33. Parkinson JA, Allen SE (1975). A wet oxidation procedure suitable for the determination of nitrogen and mineral nutrients in biological materials. Communications in Soil Sci. and Plant analysis 6: 1-11.

Palm CA, Gachengo CN, Delve RJ, Cadish G, Giller K (2001). Organic inputs for soil fertility management in tropical agroecosystems: application of organic resource database. Agric., Ecosystems and Environ. 83:27-42.

Quedraogo E, Mando A, Stroosnijder L .(2005). Effects of tillage, organic resources and nitrogen fertilizer on soil carbon dynamics and crop nitreogen uptake in semi-arid West Africa. Soil & Tillage Res. 91:57-67.

SAS Institute (1995). SAS/Stat Users Guide, Version 6.1, SAS Institute, Cary, NC U. S. A.

Swift MJ, Heal OW, Anderson, JM (1979). Decomposition in Terrestrial Ecosystems. Blackwell Scientific Publication Oxford, 372 pp.

Tian G, Brussard L, Kang B T (1995). An index for assessing the quality of plant residues and evaluating their effects on soil and crop in the sub-humid tropics. Appl. Soil Ecol. 2: 25-32.

Tossah BK (2000). Influence of soil properties and organic inputs on phosphorus cycling in herbaceous legume-based cropping systems in the West Africa derived savanna. PhD thesis, Katholieke Universiteit Leuven, Leuven, 104 pp.

Vanlauwe B, Wendt J, Diels J (2001). Combined application of organic matter and fertilizer. In: Tian G, Ishida F, Keatinge, J D H, (eds.), Sustaining Soil Fertility in West Africa, SSSA Special Publication no. 58, Soil Sci. Society of Am., Madison, Wisconsin, U. S. A., pp. 247-279.

Vanlauwe B, Sanginga N, Giller KE, Merckx R (2004). Management of nitrogen fertilizer in maize-based systems in subhumid areas of sub-Saharan Africa. In: Mosier AR, Syers JK, Freney JR (eds). Agriculture and the nitrogen cycle: SCOPE No. 65. Island Press, Washington, USA, pp 115-127.

Vanlauwe B, Giller KE (2006). Popular myths around soil fertility management in sub-Saharan Africa. Agric. Ecosyst. Envt. 116:34-46.

Van Soest PJ (1963). Use of detergents in the analysis of fibrous feeds. II: A rapid method for the determination of fibre and lignin. J. Association of Agric. Chemists 46: 829-835.