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Integrated Manure and Fertilizer Use, Maize Production and Sustainable Soil Fertility in Sub Humid Zone of West Africa

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Abstract: In the sub-humid zone of northern Ghana, maize is a high rated crop and farmers use various technologies for soil fertility maintenance and to increase grain yield. Technology chosen usually depends on the resources available to the farm household. We conducted a three-year field study (1996-1998) at Nyankpala, Ghana in the sub humid zone of West Africa. The study evaluated the effect of manure applied at 0, 4 and 8 t ha^{-1} with or without inorganic fertilizer at suboptimal rate of 60-17.5-33 kg ha^{-1} N-P-K, respectively. Corn yield was increased from 55.6% in 1996 more than 120% in 1998 because of manure application compared with corn yield from control. Application of manure plus fertilizer resulted in significant corn yield increases over the control. Manure plus fertilizer application resulted in increased fertilizer use efficiency compared with application of fertilizer alone. Sustainability yield index, a quantitative assessment of yield sustainability overtime, was highest with manure plus fertilizer. Soil fertility indicators such as soil organic carbon, cation exchange capacity and soil pH improved with repeated manure application.

Key words: Fertilizer, manure, maize yield, sustainability, savanna, Ghana

INTRODUCTION

In many smallholder farms in the savanna zone of West Africa, decline in soil fertility resulting in low crop production is a major reason affecting food security. In the past, a long fallow period (5-10 years) allowed natural restoration of soil fertility. However, because of pressure on land to increase food production and other socio-economic activities, the fallow period is almost nonexistent in many farming communities in the zone.

Most farmers in the savanna zone of West Africa keep livestock besides arable farming (Tarawali *et al.*, 2004). Manure therefore serves as one of the potential sources of soil organic matter and plant nutrients in this zone. Poor quality of crop residue and fodder, inappropriate method of manure collection and storage and the high environmental temperature on the excreted dung and urine has resulted in low and variable nutrient content of manure in the zone (Kwakye, 1980; Romney *et al.* 1994; Harris, 2002; Lekase *et al.*, 2003). The quantities of manure needed to supply enough nutrients for crop production can be large and often difficult for smallholder farmer to produce (Snapp *et al.*, 1998; Jama *et al.*, 2000). The difficulty of getting such large quantities coupled with transport and application challenges make such recommendations unattractive to many smallholder farmers. Manure is usually broadcast but when it is scarce, may be placed at the base of the crop (Harris, 1995; Enyong *et al.*, 1999).

Fertilizer use is recommended as a means of resolving the poor soil fertility problem in the sub-saharan Africa (Vlek, 1990; McIntire and Powell, 1995). The removal of fertilizer subsidy, the poor road and storage infrastructure in many sub-saharan African countries has resulted in low fertilizer use, reduced food production and smaller farm incomes (Sanchez *et al.*, 1997). Subsistent farming in the zone is thus characterized by low external input, low crop yield, food insecurity, nutrient mining and land degradation (Stoorvogel and Smaling, 1990; Gruhn *et al.*, 1995). Crop production systems in many smallholder farm households are therefore not environmentally sustainable. Strategies must be developed to restore soil fertility, to reduce erosion and to reduce environmental degradation. This will increase food production and alleviate chronic hunger in the zone (Vagen *et al.* 2005).

In the predominantly subsistent household farming system of sub humid zone of Ghana, West Africa, maize

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(*Zea mays*, L.) is considered a high valued crop and resources are judiciously allocated to its cultivation. Since majority of these farmers have low income, technical packages to increase and sustain agricultural production must be affordable, profitable and applicable to ensure its acceptability (Harris, 2002). Combined use of manure and inorganic fertilizer is an approach that seeks to reduce cost of external inputs, increase food production and safeguard the environment for future generation (Bukert *et al.*, 2000; Yamoah *et al.*, 2002).

The objective of this study was to evaluate the effect of different rates of manure with or without sub-optimal rates of inorganic fertilizer on maize grain yield, soil fertility status and sustainable yield index.

MATERIALS AND METHODS

Description of the study site: The study was conducted at the Savanna Agricultural Research Institute experimental fields at Nyankpala, near Tamale, in the sub humid zone of West Africa. The study site is located at latitude 9°25' 14'N, longitude 0° 58' 42'W and at an altitude 183 m above sea level (NAES, 1992). Annual total rainfall of 1049, 1180 and 847 mm for 1996, 1997 and 1998, respectively was recorded during the study period. The soil of the study site is a typical upland soil, developed from iron stone gravel and ferruginized ironstone brash (Adu, 1957). The soil is classified as a Haplic Lixisol (FAO/UNESCO, 1997) and locally referred to as the Tingoli series (Serno and van de Weg, 1985). Prior to the start of the study, the land had fallowed for a period of five years after continuous maize cultivation.

Soil and manure analysis: Composite soil samples were taken to a depth of 20 cm at the start of the study. Several core soil samples were taken randomly from each plot, bulked and sub-sampled for laboratory analysis before manure application each year. The sub-sampled soils were air dried, ground, passed through a 0.02 cm mesh sieve and stored for physico-chemical analysis. Soil pH was determined in 0.01 M $CaCl_2$ solution in a ratio of 1: 2.5 soil: solution. Soil organic carbon was estimated using the Walkley-Black method and total nitrogen by the Kjeldhal method as described by Anderson and Ingram (1998a). Soil available phosphorus (Bray-P) was determined by the Bray-1 procedure, exchangeable potassium by ammonium acetate extraction and Atomic Absorption Spectrophotometry (AAS). Cation Exchange Capacity (CEC) determination followed the method described by Anderson and Ingram (1998b). Total nitrogen, phosphorus, potassium and organic carbon contents of the manure were determined by the method described by Anderson and Ingram (1998a).

Cattle manure and fertilizer application: At the beginning of the farming season each year, manure was collected from an unroofed kraal with no straw bedding and heaped under shade. To determine plant nutrient content, the manure was thoroughly mixed and three sub-samples of 5 g each were taken for chemical analysis. The manure was applied on dry a matter basis at the rate of 0, 4 and 8 t ha^{-1} seven days before planting corn. Two methods of manure application used were by broadcast (B) and by spot placement (S) 10 cm from the seed. Two rates of inorganic fertilizer, 0-0-0 (F0) and 60-17.5- 33 kg N-P-K ha^{-1} (F1), were superimposed on the manure rates. The inorganic fertilizer used was nitrogen from urea, phosphorus from single-super-phosphate and potassium from muriate of potash. Half the quantity of N and the full rate of P and K were applied fourteen Days After Emergence (DAE) and the remaining N fertilizer applied 70 DAE by incorporation. The experimental layout was factorial Randomized Completely Block Design (RCBD) with four replications.

Maize planting and agronomic practices: In the second week of June each year, a full-season (120-days) local improved maize variety (*Zea mays* L. var. Okomasa) was planted at a spacing of 0.80 m inter-row and 0.5 m intra-row. After emergence, the seedlings were thinned to two plants per stand resulting in a plant population of 50,000 plants ha^{-1}. The first weeding was done 14 Days After Emergence (DAE), the second weeding 42 DAE and the third at 70 DAE. Each treatment was repeated on the same plot each year. Maize grain was harvested at physiological maturity and the grain weight was recorded at 15% moisture content.

Statistical analysis: The data collected was subjected to analysis of variance (ANOVA) to establish treatment and the interactions effect on maize grain yield, soil pH, total nitrogen, soil organic matter and cation exchange capacity. Statistical analyses were performed with the Statistical Program SAS for Windows 9.1® (SAS Institute Inc., Cary, NC, USA). Treatment means were separated where appropriate at $p<0.05$. Regression analysis was done to establish if there was a relationship between manure, inorganic fertilizer and maize grain yield. Fertilizer Use Efficiency (FUE) was calculated as yield of the inorganic fertilizer treatment (F_1) minus yield of the control treatment divided by the quantity of inorganic fertilizer applied in kg ha^{-1} (Cassman *et al.*, 1996).

Sustainability Yield Index (SYI), was calculated by using a formulae developed by Singh *et al*. (1990).

SYI - (Y - SD)Y_{max}^{-1} where Y is the average yield across treatments, SD is the standard deviation and Y_{max} is the maximum treatment mean observed over the number of years.

RESULTS

Soil and manure analysis: Initial soil analysis showed that the soil is sandy loam and moderately acidic. Soil organic carbon content was 6.4 g kg^{-1}, total nitrogen, 0.45 g kg^{-1}, available phosphorus (Bray-1 P), 2.45 g kg^{-1} and Cation Exchange Capacity, (CEC), 3.08 $Cmol_{(+)}$ kg^{-1}. Soil total nitrogen content, available phosphorus and exchangeable potassium were not noticeably influenced by treatment or interaction. There was high variability in plant nutrient content of the manure used in the three-year period. Total nitrogen content in the manure ranged between 8.6 and 12 g kg^{-1} and C:N ratio ranged between 13.7 and 16.2. The manure used in 1998 had the least total N and the highest C:N ratio compared with manure used in 1996 and 1997 (Table 1).

Maize grain yield, fertilizer use efficiency and sustainability yield index: In all three years, manure application significantly increased maize grain yield. However, doubling manure application did not result in corresponding significant yield increase (Table 2). Continuous manure application on the same plot each year showed a trend for higher grain yield than the previous year (Table 2). Broadcasting manure consistently resulted in trends for higher grain yield than spot application. Generally, manure broadcast plus fertilizer out yielded manure spot placement plus fertilizer (Fig. 1).

Increased maize grain yields as a result of 4 t ha^{-1} manure applied over control treatment were 55.6% in 1996, 132% in 1997 and 121% in 1998. Doubling manure application rate to 8 t ha^{-1} resulted in increase over control by 67.6% in 1996, 133 in 1997 and 225% in 1998 (Table 2). Regression analysis of manure rates on maize grain yield showed that manure application alone explained 40, 39 and 37% of the variation in maize grain yield in 1996, 1997 and 1998, respectively. Understandably, inorganic fertilizer (F_1) application resulted in significant yield increase in all three years. However, unlike the progressive improvement in grain yield observed with repeated manure application, fertilizer application on the same plot did not increase grain yield significantly over the years (Table 2).

Table 1: Some chemical characteristics of cattle manure used for the study at Nyankpala, Ghana, in the sub-humid zone of West Africa

Years	pH	Org. C	Total N	Total P	Total K	C:N
		------ (g kg^{-1}) ------		---- (mg kg^{-1}) ----		
1996	9.34	138	10.1	1136	16520	13.66
1997	9.48	165	12.3	4260	23400	14.41
1998	9.16	148	8.6	3800	17887	16.23

Table 2: Interactive effect of manure and fertilizer rates on maize grain yield (t ha^{-1}) at Nyankpala, Ghana, sub-humid zone of West Africa in a 3-year period

Treatments	Maize grain yield (Mg ha^{-1}) 1996	1997	1998
M0F0	1.08a	0.84a	0.70a
M0F1	1.73b	1.87b	1.81b
M4F0	1.68b	1.95b	1.55b
M4F1	2.83c	2.98c	2.59c
M8F0	1.81b	1.96b	2.28bc
M8F1	3.02c	3.17c	3.02d
LSD, $p \leq 0.05$	0.45	0.44	0.51

Inorganic fertilizer application rate F0 and F1 = 0 and 60-17.5-33 kg N-P-K, respectively. Cattle manure application rate M0, M4 and M8 = 0, 4 and 8 t ha^{-1} manure, respectively, Values followed by different letter(s) in the same year are significantly different at p = 0.05

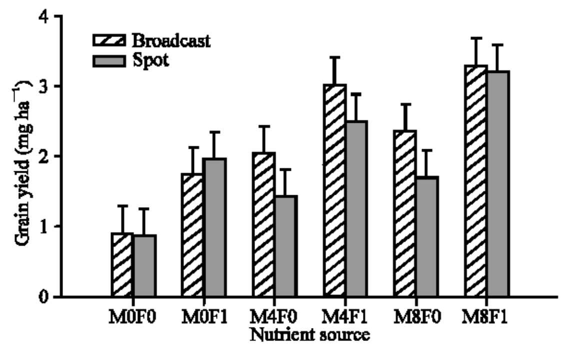

Fig. 1: Interaction effect of sources of nutrient and method of application on maize grain yield in the sub-humid savanna zone of Ghana, West Africa. Manure M, at 0, 4 and 8 t ha^{-1}, fertilizer F, at 0 and 60-17-33 kg ha^{-1} N-P-K, respectively. LSD bars that do not overlap indicate treatment means that are significantly different at a probability of 0.05 or less

Maize grain yield on the control treatment reduced 22 and 35% in 1997 and 1998, respectively compared with the yield obtained in 1996 (Table 2). Application of manure plus fertilizer resulted in significant grain yield increase in both 1997 and 1998 compared to the yield in 1996 (Table 2). Percent increases in grain yield due to manure plus fertilizer over fertilizer only (F_1) application ranged from 64 to 75% in 1996, 59 to 69.5% in 1997 and 43 to 66.8% in 1998. The application of manure plus fertilizer significantly explained the variations observed in maize grain yield and the coefficient of determination improved over the years (Table 3).

Table 3: Response of maize grain to combined manure plus fertilizer application at Nyankpala, Ghana, sub-humid zone of West Africa in a 3-year period

Year	Response equation	Probability
1996	Y = 1.1 + 0.14 manure† + 0.013 fertilizer (kg ha^{-1}), R^2 = 0.71	0.006
1997	Y = 0.84 + 0.15 manure + 0.02 fertilizer (kg ha^{-1}), R^2 = 0.86	0.0001
1998	Y = 1.1 + 0.14 manure + 0.02 fertilizer (kg ha^{-1}), R^2 = 0.87	0.0001

†Rate of manure application = (t ha^{-1})

Table 4: Fertilizer nitrogen use efficiency (FUE) and Sustainability Yield Index (SYI) at Nyankpala, Ghana, in the sub-humid zone of West Africa in a 3-year period

	FUE (Mg ha^{-1} kg^{-1} ha^{-1})			
Treatment†	1996	1997	1998	SYI
M0F0	-	-	-	0.05
M0F1	10.8	17.2	20.2	0.27
M4F0	-	-	-	0.24
M4F1	29.2	35.7	31.5	0.54
M8F0	-	-	-	0.32
M8F1	32.0	38.8	38.7	0.62

-: Not applicable. †Inorganic fertilizer nitrogen application rate F_0 and F_1 = 0 and 60 kg N ha^{-1}. Manure rate 0, 4 and 8 Mg ha^{-1}, (M0, M4 and M8), respectively

Table 5: Effect of cattle manure application rate and fertilizer on soil organic carbon content (g kg^{-1}) at Nyankpala, Ghana, in the sub-humid zone of West Africa in a 3-year period

	Soil organic carbon (g kg^{-1})		
Treatments	1996	1997	1998
M0F0	6.30a	6.10a	5.95a
M0F1	6.20a	6.00a	6.00a
M4F0	6.33a	6.15a	7.10b
M4F1	6.40a	6.50ab	7.02b
M8F0	6.49a	6.60ab	7.06b
M8F1	6.50a	6.74b	7.14b
LSD, $p \leq 0.05$	0.72	0.57	0.57

Inorganic fertilizer application rate F0 and F1 = 0 and 60-17.5-33kg N-P-K, respectively, Cattle manure application rate M0, M4 and M8 = 0, 4 and 8 t manure ha^{-1}, respectively, Values followed by different letter(s) in the same year are significantly different at $p \leq 0.05$

Fertilizer Use Efficiency (FUE) was raised significantly when fertilizer was applied with manure. However, doubling the rate of manure applied did not result in a corresponding increase in FUE (Table 4). Sustainability Yield Index (SYI) was highest on the manure plus fertilizer treatment. It was more than two times that of sole fertilizer or manure (Table 4). Increasing the rate of manure applied from 4 to 8 t ha^{-1} raised SYI marginally from 0.24 to 0.32 and from 0.54 to 0.62 when applied with fertilizer. The SYI of sole manure and fertilizer treatments were in deceasing order of M8>F1>M4 ranging between 0.24 and 0.32 (Table 4).

Soil organic carbon, pH and cation exchange capacity: Soil Organic Carbon (SOC) content on the absolute control plot had reduced by 6 percent in 1998 compared with SOC content at the start of the trial. On the other hand, continuous application of manure plus fertilizer raised SOC content to between 9 and 11% (Table 5).

Table 6: Effect of manure application and inorganic fertilizer interaction on Cation Exchange Capacity (CEC) and soil pH at Nyankpala, Ghana, in the sub-humid zone of West Africa in a 3-year period

Fertilizer rate (kg ha^{-1})†		
Manure rate (t ha^{-1})‡	CEC Cmol$_{(+)}$ kg^{-1}	pH
M0F0	3.10a	5.24a
M0F1	2.91a	5.29a
M4F0	3.91b	5.65bc
M4F1	4.18b	5.50b
M8F0	3.98b	5.72c
M8F1	3.91b	5.65bc
LSD, P≤kg ha^{-1}0.05	0.47	0.21

† Inorganic fertilizer application rate F0 and F1 = 0 and 60-17.5-33 kg N-P-K, respectively. ‡ Cattle manure application rate M0, M4 and M8 = 0, 4 and 8t manure ha^{-1}, respectively, Values followed by different letters are significantly different at $p \leq 0.05$

Continuous application of manure alone or manure plus fertilizer during the three year period resulted in 21 to 26% increase in Cation Exchange Capacity (CEC) and a significant reduction in soil acidification (Table 6).

DISCUSSION

Though the land used for the study had been fallowed for five years before start of the study, low level of Soil Organic Carbon (SOC) and total Nitrogen (N) observed could be attributed to low vegetation cover and annual bush burning prevalent in many farming communities in the sub humid zone of West Africa. An improved fallow system using nitrogen fixing legumes such as pigeon pea (*Cajanus cajan*) and leucaena (*Leucaena leucocephala*) raised SOC content higher than a natural fallow system (Lal, 2000; Bationo *et al*., 2000; Abunyewa and Karbo, 2005). The marginal increase in the SOC was due to continuous application of manure or manure plus fertilizer. Bationo *et al*. (2000) reported higher SOC in a crop residue plus fertilizer or manure plus fertilizer treatment and fallow treatment compared with areas under cultivation. According to Manlay *et al*. (2004), the rate of SOC reduction depends on several factors including climate, cropping system and fertility management strategy.

The manure applied varied widely in total nitrogen content ranging from 34 to 98 kg N ha^{-1}. Most kraals in the zone are not roofed and have no bedding to absorb urine. Manure and urine are therefore exposed to the intense sunlight, high temperature throughout the year and intensive rainfall in part of the year. These factors may account for the poor quality of manure (Kwakye, 1980; Crowder and Chheda, 1982; Lekase *et al*., 2003). High variability of manure nitrogen content has been reported in the savanna zone of West Africa (Harris, 2002; Tarawali *et al*., 2004). Besides the climatic and handling effect on manure, quality and quantity of fodder available to livestock could affect the proportion of nitrogen in manure (Powell *et al*., 1994; Romney *et al*., 1994). The length of time manure was exposed to environmental temperature, sunlight and rainfall before collection from the kraal for field application could be partly responsible for the variations observed. Improving manure collection and storage may reduce the wide variability observed.

In the sub-humid zone of Ghana, farmers who own livestock keep them in a kraal near the homestead or graze and tethered the animals in their harvested compound farms. When animals are kept by a hired Fulani herdsman, the livestock owner can have access to manure in the kraal. Farmers who do not have livestock can get manure either free or trade a bag or two of 50 kg inorganic fertilizer for manure. The number of bags of inorganic fertilizer exchanged for manure depends on its availability and the importance attached to manure in the community. According to Hilhorst and Muchena (2000), farmers in different farming communities in Africa have different means of getting manure, but rarely purchase it outright. Farm households with adequate manure usually apply large amount. From this study, yearly application of smaller amount plus fertilizer will be more effective in terms of crop utilization and sustainable productivity. Frequent application of smaller amounts of manure plus light fertilizer application was found to be superior to heavy fertilizer application alone (Williams *et al*., 1995; Brouwer and Powell, 1998; Esse *et al*., 2001). An increase in maize grain yield could be attributed to the overall improvement in soil chemical, physical and biological properties (Egawe, 1975; Rodel *et al*., 1980; Ram, 1998; Sahoo *et al*., 1998). The cumulative effect of the manure application in improving soil fertility status and sustainable crop production is demonstrated clearly in the increased grain yield recorded in the subsequent years (Patra *et al*., 2000). Appreciable grain yield was obtained in 1998 in spite of the low total annual rainfall amount. This could be attributed to the cumulative effect of manure application in the build up of SOC, moisture retention as well as enhanced nutrient availability (Bukert *et al*., 2000). The observed higher grain yield on the control plot in the first year compared with subsequent years could be as a results of improved soil fertility status during the five-year fallow period. This build up was however short-lived as the subsequent year's reduction in grain yield is an indication of reduced soil fertility status. Lal and Kang (1982) reported that soil organic matter and total N reduced significantly after first year cultivation under tropical conditions when no organic inputs are applied. Reduction in soil organic carbon results in reduction in effective CEC, implying a reduction in the ability of the soil to retain nutrients (De Ridder and Van Keulen, 1990).

The repeated application of manure may have improved the soil physical, chemical and microbiological properties. The inorganic fertilizer applied supplemented the nutrient requirement of the crop. This obviously resulted in improved nutrient availability and uptake, increased fertilizer use efficiency, which resulted in increased grain yield (Vanlauwe *et al*., 2002; Yamoah *et al*., 2002; Saleque *et al*., 2004).

The increased soil organic carbon and CEC and reduced acidification recorded could be attributed to continuous application of manure (Glaser *et al*., 2000; Yadav *et al*., 2000; Lal, 2001). However, high rate of organic matter turnover in tropical soils adversely affect significant buildup and maintenance of soil organic matter. Organic manure must be applied continuously to maintain a sustainable agricultural system with increased productivity. Though SYI of all the treatments were higher than the control, SYI of manure plus fertilizer was almost double that of either manure or fertilizer alone. Yadav *et al*. (2000) and Yamoah *et al*. (2002) reported higher SYI and FUE with application of organic and inorganic fertilizer compared with application of either alone. Though higher rates of manure application may improve both FUE and SYI, the difficulty of obtaining large quantities of manure coupled with transportation and application challenge in the small holder farming system could be disincentives for increased manure use in maize production.

CONCLUSION

Continuous application of smaller amount of manure plus fertilizer would increase grain yield and sustain soil fertility in the sub-humid zone. The practice will ensure food security, reduced nutrient mining and reduced environmental degradation. In this study, it was more productive to apply 4 t ha^{-1} of manure and supplement plant nutrient requirement with inorganic fertilizer. This is evidenced by the fact that raising the manure application to 8 t ha^{-1} did not result in corresponding increase in maize grain yield or improvement in soil carbon stock to merit the extra cost that may be incurred. It must be noted that recommendation of manure rate can only serve as a guide due to the high variability of nitrogen content of manure in the zone.

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