Integrated Organic-Inorganic Fertilizer Management for Rice Production on the Vertisols of the Accra Plains of Ghana

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Abstract

Studies were conducted at the Agricultural Research Centre, Kpong, of the University of Ghana, to find solution to the problem of low rice yields on the Vertisols of the Accra Plains. Rice yields from continuously cropped fields have been observed to decline with time, even with the application of recommended levels of inorganic fertilizers. The decline in yield has been attributed to low inherent soil fertility, which is partly the result of low levels of soil organic matter (OM). As part of the study, cow dung (CD) and poultry manure (PM) were separately applied to the soil at 20 t ha^{-1} solely and also 5, 10 and 15 t ha^{-1}, in combination with urea fertilizer at 90, 60 and 30 kg N ha^{-1}, respectively. Other treatments included a control and urea fertilizer at 30, 60, 90 and 120 kg N ha^{-1}. There was a basal application of phosphorus and potassium to all plots at 45 kg P_2O_5 ha^{-1} and 35 kg K_2O ha^{-1}, respectively, based on the recommended fertilizer rate of 90 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1} and 35 kg K_2O ha^{-1}, on the Vertisols of the Accra Plains. Studies were also conducted on the redox potential of CD, PM and rice straw (RS). The application of 10 t ha^{-1} CD and urea fertilizer (at 45 kg N ha^{-1}) and 10 t ha^{-1} PM and urea (at 60 kg N ha^{-1}) both gave paddy yields of 4.7 t ha^{-1}, which did not differ significantly from the yield of 5.3 t ha^{-1}, obtained under the recommended inorganic nitrogen fertilizer application of 90 kg N ha^{-1}. This indicates a synergistic effect of OM and urea on soil fertility. The redox potential studies showed that RS had greater propensity to bring about reduced soil condition in paddy fields than CD and PM, while PM brought about greater reduction than CD.

Introduction

Vertisols are made up of montmorillonitic clay minerals and have clay content of 35–40%. The soils characteristically swell and become sticky when wet, and when dry they shrink, become hard and crack extensively. They are difficult to cultivate with simple implements and have a narrow moisture range within which land tilling operations can be easily accomplished with simple implements, e.g. hoe or with tractor drawn implements.

The inherent soil fertility of the Vertisols of the Accra Plains is low, partly due to low organic matter (OM) content (1–2%). Nitrogen, phosphorus and potassium contents are also low – 0.07%, 11.8 mg kg^{-1}, and 27 mg kg^{-1}, respectively (Table 3). Inherent soil fertility is an attribute that relates to the parent rock from which soil develops and from which elements that contribute to soil fertility are obtained. The Vertisols of the Accra Plains are developed from hornblende gneiss, which are high in calcium and magnesium but low in phosphorus (Brammer, 1962). Organic matter enhances soil nitrogen content and also improves the physical property of soil.

The Vertisols of the Accra Plains occur in the coastal savanna belt, which has low OM content as a result of the low rainfall (700–1100 mm) that supports lower vegetative growth and decomposition than occurs in the forest zone, and also due to annual bush fires, which destroy vegetative cover. Acquaye (1986) observed that soil fertility is closely associated with OM content of the soil, which was determined to be 1–2% (0–15 cm depth) in the savanna soils, compared with 4.5–6.0% in the forest soils where bush fires are less rampant and vegetative material is several fold more than in the savanna belt.

Prasad & De Datta (1979) observed that nitrogen recovery in the tropics is low and ranges from 30–50%. Factors found to contribute to low nitrogen recovery include losses through leaching, denitrification (especially in flooded paddy soils), microbial immobilisation, untimely application, method of placement, N source, soil fixation (especially phosphorus fixation by the montmorillonitic clay minerals found in the Vertisol), ammonia volatilisation and runoff.

Buri *et al.* (2004), in an experiment with poultry manure, cattle manure and rice husk, applied solely or in combination with mineral fertilizer (using urea or suphate of ammonia as N source), found that a combination of half rate of organic amendment and half rate mineral fertilizer significantly contributed to the growth and yield of rice.

Rao *et al.* (1976) and Oh (1979) noted that the incorporation of fresh organic materials in flooded soil, including rice straw, may develop a soil condition toxic to plants. Oh (1979) also noted that incorporation of organic materials in soil and flooding decrease the *p*H of the soil. The organic acids produced in course of decomposition under such condition, according to Konava (1966), affect the solubility of soil components (especially trace elements), bringing them to levels that are toxic to plants (Morachan *et al.*, 1972). However, draining water out of the rice basin at specific periods for land preparation and seeding, weed control, fertilizer application, maturation and harvesting aerates the soil and minimises the adverse effects of decomposition under anaerobic conditions.

Mba (1996), in his study on vermi-composting cassava peels with cow dung, poultry manure and guava leaves, using earthworm, *Eudrilus eugeniae*, observed that cowpea aerial biomass increased fivefold with the cassava-poultry manure bio-fertilizer over the untreated field plots, and available *P* increased twofold in the treatment.

On the other hand, Oh (1979) was of the view that making paddy soils more heterogeneous (the existence of aerobic and anaerobic sites), through increasing soil aggregates, may bring about low Eh value in flooded soils. He also observed that well decomposed compost has little effect on the formation of soil aggregates, but partially decomposed, or fresh organic matter, e.g. rice straw, leads to the formation of water-stable aggregates, which give interspaces to soil as well as good supply of plant nutrients.

Rice and banana are grown extensively on the Vertisols in the Kpong Irrigation Project (KIP) sites at Akuse and Asutsuare and its environs. The yield of rice has been observed to decline with time, although the recommended quantities of inorganic fertilizers were applied. Rice yield data from

Kpong Farms (a major commercial rice farm on the Vertisol), over a period of 10 years (1986–1996), indicated a yield decline from 5 t ha^{-1} to levels as low as 2.5 t ha^{-1} (Table 1). Preliminary investigations attributed the decline to low levels of OM in the soils, among other factors. However, record of rice yields obtained from KIP (Table 2), where recommended practices are implemented by farmers (including use of organic manure), showed higher and more consistent yield over a 10-year period (1998–2007).

In spite of the low levels of OM in the Vertisols of the Accra Plains, poultry manure and cow dung, which are abundant in the area, appear to be underutilised. Experiments were, thus, conducted to verify the suitability

TABLE 1
Trend in rice production on the Vertisols at Kpong Farms (1986–1996)

Year	*Area cultivated (ha)*	*Production (t)*	*Yield (t ha^{-1})*
1986	130	654	5.0
1987	133	587	4.4
1988	142	498	3.5
1989	139	558	4.0
1990	119	294	2.5
1991	116	337	2.9
1992	182	767	4.2
1993	132	423	3.2
1994	100	378	3.8
1995	93	390	4.2
Average			3.8

Courtesy of Kpong Farms, VRA, Akuse

TABLE 2
Trends in rice production on the Vertisols at Kpong Irrigation Project (1998–2007)

Year	*Area cultivated (ha)*	*Production (t)*	*Yield (t ha^{-1})*
1998	544	2,176	4.0
1999	866	3,897	4.5
2000	1,300	7,150	5.5
2001	1, 435	7,175	5.0
2002	386	1,544	4.0
2003	1,222	5,865	4.8
2004	1,840	10,304	5.6
2005	2,150	10,009	4.7
2006	733	3,812	5.2
2007	815	4,326	5.3
Average			4.1

Courtesy of Kpong Irrigation Project (KIP), Asutsuare of the two types of manure and their combinations with urea as soil amendments for rice production. The impact of the two manures and rice straw on the redox potential status of soil in flooded paddy fields, with their attendant effect on nitrogen nutrition, were also verified.

Materials and methods

The experiments were conducted at the Agricultural Research Centre, Kpong, of the University of Ghana, which is located on the Vertisols of the Accra Plains. The experimental design was randomised complete block with four replications. The treatments consisted of cow dung, poultry manure, and their combinations with urea as follows: 5 t ha^{-1} CD and PM, each combined with half the recommended rate of inorganic nitrogen fertilizer (45 kg N ha^{-1}) and also with the full rate (90 kg N ha^{-1}), 10 t ha^{-1} CD and PM, each combined with 45 and 60 kg N ha^{-1}, 15 t ha^{-1} CD and PM, each combined with 30 kg N ha^{-1}, and 20 t ha^{-1} CD and PM applied solely. Also included were inorganic nitrogen fertilizations (urea) at 30, 60, 90 and 120 kg N ha^{-1} and an unfertilized control.

The manures were partially decomposed as a result of being heaped up over a period of time. The recommended applications of phosphorus and potassium fertilizers were basally applied to each plot (i.e. 45 kg P_2O_5 ha^{-1} and 35 kg K_2O ha^{-1}, as triple supper phosphate and muriate of potash, respectively).

Soil sampling for chemical analysis was done at a depth of 0–20 cm. The chemical analyses included: *p*H, nitrogen, available phosphorus and available potassium. Soil *p*H was determined in water (1:1) and nitrogen by the Kjeldahl method. The extraction of phosphorus and potassium was done in Bray 1 solution, with phosphorus determined colorimetrically and potassium by flame photometry. Organic carbon (OC) was determined by the Walkly and Black wet digestion method. The cow dung and poultry manure were also similarly analysed for nitrogen, phosphorus and potassium.

Four-week old rice seedlings were transplanted in 8 m × 4.5 m basins, at a spacing of 20 cm × 20 cm. Data were recorded on plant heights, tillering, time of flowering, panicles per hill, time of maturity, grains per panicle and grain yield. Additionally, studies were carried out on the redox potential of soil with cow dung (farmyard manure, FYM), poultry manure, rice straw and soil without amendment (control). The materials, in quantities of 20, 40, and 60 t ha^{-1}, were incorporated in the soil in separate basins and in three replicates. They were inundated with water to a level of 5 cm. After 24 h inundation, the redox potential measurements

TABLE 3
Initial soil chemical characteristics

Depth .cm	*N%*	*Available P (mg kg^{-1})*	*Available K (mg kg^{-1})*	*Exchangeable Mg (mg kg^{-1})*	*Exchangeable Ca (mg kg^{-1})*	*pH (H_2O) 1:1*	*OC%*
0–10	0.98	11.86	27.60	9.50	23.80	7.66	1.61
10–25	0.34	6.28	19.32	9.50	23.80	7.73	1.05
25–40	0.32	3.49	14.72	–	–	8.12	0.74

were conducted in each basin, *in situ*, using a *p*H meter with mV output and redox potential electrode. Water temperature and pH were also measured alongside. Data analysis was by analysis of variance (ANOVA), using the Genstat analytical software.

Results

The nitrogen and organic carbon contents of CD were more than that of PM, while the available phosphorus and potassium contents of PM were higher than that of CD (Table 4). Plants at flowering were significantly taller under 20 t ha^{-1} PM, 90 kg N ha^{-1} and 120 kg N ha^{-1} than under 20 t ha^{-1} CD and the unfertilized control, but plants under CD were taller than those under the unfertilized control (Table 5). Flowering occurred earlier in the unfertilized control than in the other treatments with higher nitrogen levels (Table 5). The dates of maturity, however, showed no significant differences (Table 5). Increased N led to

TABLE 4

Nutrient content of cow dung and poultry manure

Treatment/Nutrient	*N%*	*OC%*	*Available P%*	*Available K%*
Cow dung	1.9	20.58	0.38	0.28
Poultry manure	1.1	4.73	4.08	0.49

TABLE 5

Growth response of rice under combinations of cow dung, poultry manure and urea

Treatment	*Days to flowering*	*Days to maturity*	*Plant Height at flowering (cm)*	*Tillers at flowering*
Control	92	127	77.2	8
30 kg N ha^{-1}	97	126	94.8	8
60 kg N ha-1	100	128	94.4	9
90 kg N ha-1	99	127	101.3	10
120 kg N ha-1	102	129	102.9	10
20 t ha^{-1} CD	93	125	89.3	8
20 t ha-1 PM	99	125	99.3	8
5 CD + 45 kg N ha-1	99	126	100.4	9
5 CD + 90 kg N ha^{-1}	101	129	97.0	10
10 CD + 45 kg N ha^{-1}	97	127	97.6	9
10 CD + 60 kg N ha^{-1}	100	127	96.7	10
15 CD + 30 kg N ha^{-1}	98	126	98.7	9
5 PM + 45 kg N ha^{-1}	99	127	97.1	9
5 PM + 90 kg N ha^{-1}	101	127	102.0	10
10 PM + 45 kg N ha^{-1}	99	126	97.1	8
10 PM + 60 kg N ha^{-1}	99	129	99.8	10
15 PM + 30 kg N ha^{-1}	96	125	107.7	9
LSD (P = 0.05)	5.3	ns	9.5	2

prolonged vegetative phase and delayed flowering.

On average, some combinations of manure with inorganic N fertilizer (e.g. 10 t ha^{-1} CD plus 60 kg N ha^{-1} and 10 t ha^{-1} PM plus 60 kg N ha^{-1}) and the higher levels of inorganic N application (90 and 120 kg N ha^{-1}) gave greater tiller numbers than observed in the unfertilized control and sole CD and PM (Table 5). However, there were no differences between 20 t ha^{-1} CD and 20 t ha^{-1} PM, or between their combinations with urea.

Paddy yields under sole CD and PM were not significantly different and were lower than yield under the recommended 90 kg N ha^{-1} inorganic N application. However, the 10 t ha^{-1} CD plus 45 kg N ha^{-1} urea and 10 t ha^{-1} PM plus 60 kg N ha^{-1} urea gave yields comparable to those under 90 and 120 kg N ha^{-1} inorganic N fertilizer (Table 6). The combination of half the organic materials (i.e. 10 t ha^{-1} CD and PM) and half inorganic N (i.e. 45 kg N ha^{-1}) gave more panicles per hill than the control, similar to values under the recommended 90 kg ha^{-1} inorganic N fertilizer application (Table 6). On the other hand, grains per panicle and harvest index gave no clear significant differences.

Studies on redox potential of FYM, PM and RS, incorporated in flooded soil, showed that quantities of materials incorporated beyond 20 t ha^{-1} (i.e. 40 and 60 t ha^{-1}) did not significantly affect the redox potential levels (Fig. 1). The control had the highest redox potential, followed by FYM, PM and RS, in the order: Control > FYM > PM > RS.

With 20 t ha^{-1} addition of organic material, the redox potential of the control reduced

TABLE 6

Paddy yield and yield characteristics under combinations of cow dung, poultry manure and urea

Treatment	*Panicles/Hill*	*Grain/Panicle*	*Harvest index*	*Paddy yield (t ha^{-1})*
Control	9	108	0.42	3.2
30 kg N ha^{-1}	10	106	0.44	4.5
60 kg N ha^{-1}	10	98	0.44	4.5
90 kg N ha^{-1}	12	118	0.41	5.3
120 kg N ha^{-1}	10	97	0.40	4.7
20 t ha^{-1} CD	9	104	0.41	3.8
20 t ha^{-1} PM	11	118	0.39	4.3
5 CD + 45 kg N ha^{-1}	12	107	0.43	4.6
5 CD + 90 kg/N ha^{-1}	13	107	0.40	4.6
10 CD + 45 kg N ha^{-1}	12	108	0.43	4.7
10 CD + 60 kg N ha^{-1}	10	114	0.41	4.1
15 CD + 30 kg N ha^{-1}	13	100	0.40	4.6
5 PM + 45 kg N ha^{-1}	13	112	0.45	4.5
5 PM + 90 kg N ha^{-1}	11	107	0.37	4.9
10 PM + 45 kg N ha^{-1}	13	93	0.41	4.2
10 PM + 60 kg N ha^{-1}	12	122	0.44	4.7
15 PM + 30 kg N ha^{-1}	11	106	0.43	4.9
LSD (P = 0/05)	3	21	ns	0.8

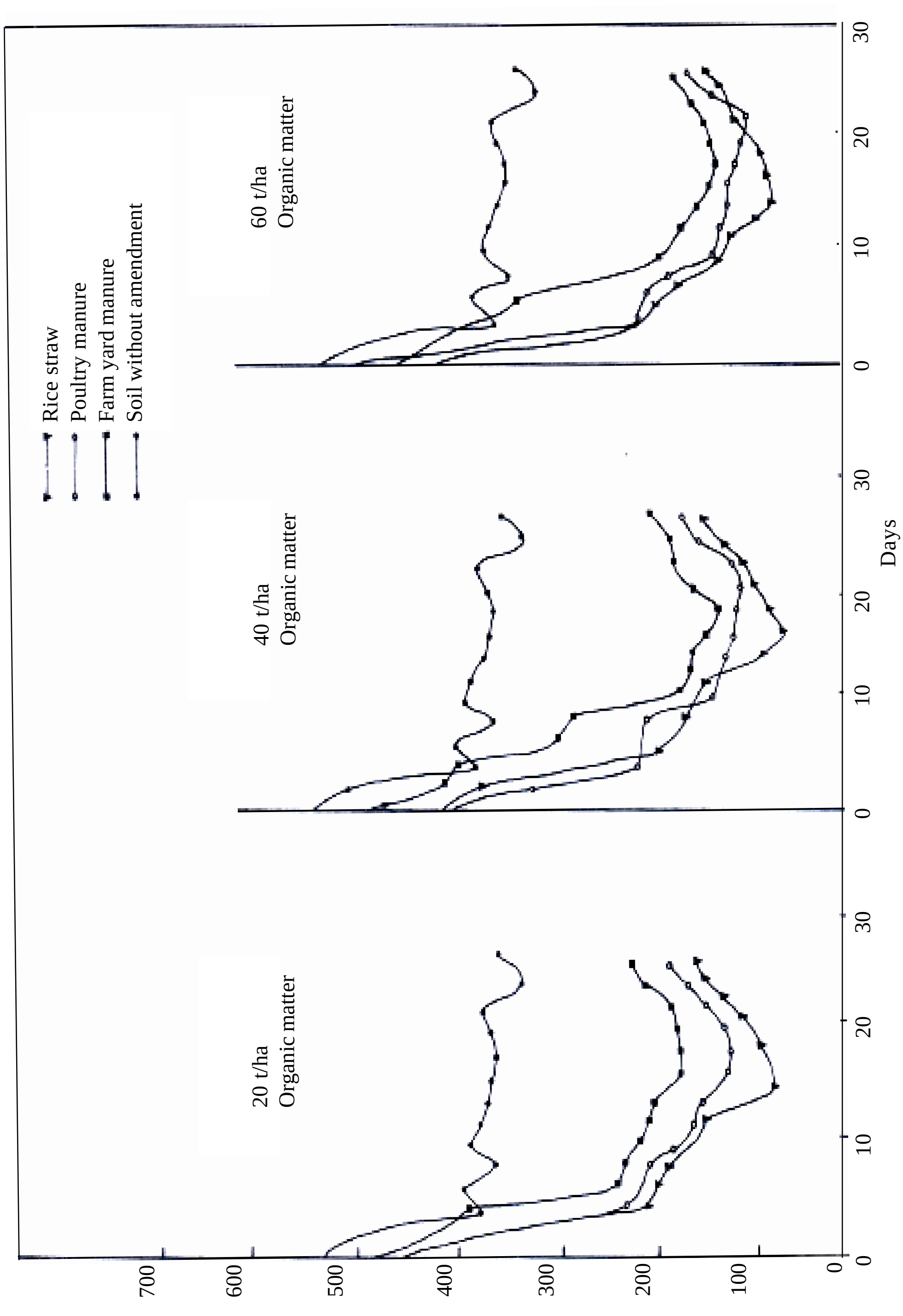

Fig. 1. The effect of different levels of organic matter on the redox potential of the Akuse soils

rapidly from about 530 mV and leveled off to about 380 mV in 5 days. Within 7 days of inundation, the redox potential of FYM decreased rapidly from about 480 mV to 240 mV and then reduced gradually to 180 mV after 15 days of inundation. The redox potential of PM reduced from about 450 mV to 220 mV after 5 days and then decreased to a value of about 120 mV after 15 days. Rice straw also had redox potential levels decreasing from about 450 mV to 200 mV after 5 days and then decreased gradually to a value of 80 mV after 15 days of inundation.

Discussion

The delay in flowering in the treatments with high N levels could be because the allocation of assimilates for reproductive growth were obstructed by highly fertile growing conditions that resulted in higher vegetative growth, as explained by Dantuma (1983). Combining 10 t ha^{-1} of cow dung with 45 kg N ha^{-1} urea, or 10 t ha^{-1} poultry manure with 60 kg N ha^{-1}, gave yields comparable to those under the highest levels of nitrogen application (i.e. 90 and 120 kg N ha^{-1}), similar to the findings of Buri *et al.* (2004).

Cattle consume much more roughage than poultry and this reflected in the higher level of organic carbon in cow dung than poultry manure. Poultry, on the other hand, are fed mainly on grains compounded with balanced levels of protein and mineral supplements. Phosphorus and potassium levels are, consequently, higher in poultry manure than in cow dung, and are in more readily available forms. In spite of these, crop performance and yield did not differ significantly between cow dung and poultry manure fertilizations.

Composting of the amendments (particularly cow dung) before incorporation could enhance their nutrient availability, as explained by Mba (1996). On the other hand, Oh (1979) observed that gradual decomposition of the organic matter source could enhance soil physical properties while releasing nutrients gradually.

Similarly, Bijay-Singh *et al*. (1997), by applying poultry manure alone or in combination with urea, found that, in the first year, the manure did not perform better than urea, but by the third year, poultry manure, when applied in quantities of 120 and 180 kg N ha^{-1}, produced significantly greater grain yield of rice than the same rates of urea fertilizer. He also found that poultry manure sustained high grain yield of rice during the 3 years while the yield decreased with urea. This finding further explains the yield decline observed at Kpong Farms, in spite of the regular application of inorganic N fertilizer, and the stable yields at KIP, where both organic matter and inorganic N fertilizer are applied.

Hossain (1995), in his studies on growth and development of *Dalbergia sissoo* seedlings, grown under different potting media, indicated that cow dung mixed with forest topsoil significantly increased the growth of the seedlings, in comparison with the control and inorganic fertilizer treatments.

In spite of the expected decrease in *p*H and Eh values when OM is applied to flooded soils and the adverse effects they have on plant growth, as indicated by Rao *et al.* (1976), Konava (1966), Morachan *et al*. (1972) and Oh (1979), the Vertisols of the Accra Plains have high levels of Ca (Table 3), which could have mitigating effect on *p*H levels.

Conclusion

Cow dung and poultry manure, applied at half their recommended rates, i.e. 10 t ha^{-1} CD plus 45 kg N ha^{-1} urea and 10 t ha^{-1} PM plus 60 kg N ha^{-1} urea, performed as well as the recommended inorganic nitrogen fertilizer level of 90 kg N ha^{-1}. In such combinations, both soil physical properties (particularly under upland condition) and soil fertility are enhanced. This could help solve the problem of low inherent fertility, which has been identified as the cause of yield decline on the Vertisols of the Accra Plains. Incorporation of cow dung and poultry manure, under flooded condition, could bring about low soil *p*H/redox potential. However, the high level of Ca in the Vertisols of the Accra Plains and the aeration of soil that goes with drainage at certain periods of crop growth minimise such tendency.

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