Improving Soil Productivity and Increasing Lowland Rice Yields through the Integration of Organic and Inorganic Fertilizers in the Savannah and Forest Agro-ecological Zones of La Cote d'Ívoire

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Abstract

Sole mineral fertilizers use by poorly resourced farmers for rice production in the lowlands is usually low and unsustainable. Field experiments were therefore conducted within two contrasting environments (Forest and Savannah), using two common organic amendments (Poultry manure and Cattle manure) to establish an effective and integrated soil nutrient management system for improved lowland soil productivity and increased rice yields. The study was also partly intended to encourage and promote the effective and sustainable use of locally available organic amendments for nutrient management in lowland rice production. Results showed that organic amendments {cattle manure (CM) and poultry manure (PM)} contributed significantly to grain yield increases and total productivity with PM having a significantly greater and positive effect on grain yield than CM. In addition, the application of organic amendments in combination with mineral fertilizer significantly contributed to increased grain yield over the application of sole mineral fertilizer. Within the savannah agro-ecological zone, there was a 130% (CM) and 203% (PM) grain yield increase over the control due to the application of organic amendments . When organic amendments were applied in combination with mineral fertilizer (MF), grain yield increased by 21% and 43% over sole MF for CM and PM respectively. However, sole CM contributed 12% increase in grain yield over the control while PM gave a 35% increase within the forest agro-ecological zone. The combined application of MF and CM resulted in an 11% increase in grain yield while MF and PM combinations produced a 30% yield increase within the ecology. The non-addition of N, P, K as mineral fertilizer resulted in a yield reduction of about 84% at both sites. Resource poor farmers within the West African sub-region should therefore be encouraged to use organic amendments, which are not only available locally but also affordable. Proper storage and handling of these organic materials is very important to minimize nutrient losses.

Keywords: agro-ecological zone, mineral fertilizer, organic amendments, lowland rice, savannah, forest

Introduction

Organic materials are fundamentally important in that they supply various kinds of plant nutrients including micro and macro nutrients. They also improve soil physical and chemical properties and hence nutrient holding and buffering capacity. Consequently, they enhance microbial activity in soils. Furthermore, unlike mineral fertilizers, organic manures slowly but continuously release N, over longer periods as the plant needs. On the contrary, mineral fertilizers are not only quite expensive, but their excessive use can also be injurious to both soil and human health, and the environment through pollution of soil and water bodies. In West Africa, soils of major rice growing sites have been described as inherently poor in nutrients and low in clay content (Abe et al, 2010, Buri et al, 1999, 2000, 2009, 2010, 2011: Issaka et al, 1996, 1997). Based on existing environmental conditions and soil type, there are variations in nutrient supply capacities of these soils across locations. However, rice has become an important major food crop, but most farmers, majority of whom are small-scale and poorly resourced cannot afford to purchase the recommended quantities of mineral fertilizers. Even though organic sources vary in type from one site to another, they are available and accessible. There is the need therefore to adopt an integrated approach to nutrient management to optimize the use of mineral fertilizer and the available organic amendments in order to sustain production. Currently most farmers concentrate on the use of organic fertilizer sources for vegetable production, and this could easily be extended to rice with effective sensitization and education. Cow dung and poultry manure are good sources of organic matter in soils. In most parts of La Cote d'Ivoire sources of these farm organic products abound and are currently under-utilized. Zinc (Zn) is also reported to be limiting nutrient at M'be and in the absence of Zn based mineral fertilizers; the contribution of organic sources in ameliorating the effect of this deficiency could also be evaluated.

For increased efficiency and effectiveness in mineral fertilizer usage, it is necessary to establish optimum levels (recommendation) of the major nutrients to serve as a guide to farmers. For any rice production systems to be sustainable under existing conditions in most parts of the country, farmers need to adopt the use of both chemical fertilizers and organic manures to improve productivity of the soil to increase crop production. The use of organic manure or chemical fertilizer alone is not enough to meet the demand of soil-plant systems (Rahman, 2013). Earlier research works has indicated that integrating the use of inorganic fertilizers with organic manures not only sustains crop production, but it is also effective in improving soil health and enhances nutrient use efficiency (Verma et al., 2005; Ali et al., 2009). However, this may vary across locations based on the types of materials available and soil conditions. Such information is scanty in La Cote d'Ivoire as mineral fertilizer recommendations in use were developed several years ago and need to be updated while information on organic amendments for rice cultivation is almost non-existent.

The objectives of the study include: (i) to identify the most limiting major nutrients, (ii) to determine the response of lowland rice to different levels of nutrient inputs, (iii) to establish optimum integrated soil nutrient management system for increased lowland soil productivity and (iv) to encourage and promote the effective use of affordable and sustainable local materials for nutrient management in lowland rice production under controlled and effective water management.

Materials and Methods

Study locations and environmental conditions

Field experiments were conducted in 2014 - 2015 at M'be near Bouake (latitude 7° 53'58" N and longitude 6° 3' 33" W) within the central Savannah agro-ecological zone and at Gagnoa (latitude 6° 7' N and longitude 5° 57' W) within the Forest agro-ecological zone in Ivory Coast. The annual rainfall amounts

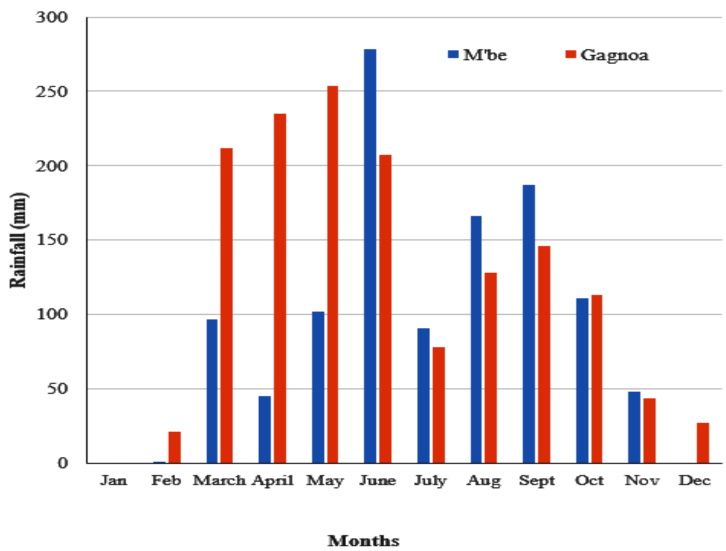

Figure 1 Monthly rainfall amounts at the experimental sites during the period

during the year is shown in Fig. 1. There was no rainfall at both sites in January. Gagnoa had small amounts of rain (Fig. 1) in February and December while Mbe had no rainfall during those months. Rainfall rose gradually and peaked at both sites in May-June, declined significantly in July and peaked again in August-September. Overall, rainfall amounts were adequate during the year to cater for the crop requirements. Temperatures remained uniform between 25^{o}-28^{o} C across both sites.

Nursery Establishment

A nursery of rice seedlings (Wita 9 and Nerica L19) was raised for the purpose. A plot measuring 2m x 1m was measured out at the site of the experiment, cleared of all vegetation, ploughed and soil pulverized with a hoe. It was then levelled and watered. Good rice seed (devoid of any mixtures obtained from a seed store) was then uniformly broadcast on the bed and worked into the soil by hand. It was covered with dried grass and regularly watered until germination. After germination, the grass was removed but regular watering continued until seedlings were ready to be transplanted. This was done for each variety based on site. At three (3) weeks old, seedlings were then transplanted onto the field as indicated in section below. The nursey was not sprayed with any agro-chemicals nor was fertilizer of any type applied to it.

Treatments

Two improved and popular rice varieties were used; Nerica L 19 in the Forest agro-ecological zone and Wita 9 in the Savannah agro-ecological zone. Both varieties have similar growth duration. Selection of varieties was based on popularity among farmers or farmers' choice. Two organic amendments (Cattle manure and poultry manure) which are commonly available and affordable were used in combination with five rates of mineral fertilizers (0-60-60, 90-0-60, 90-60-0, 90-60-60, 0-0-0) kg N-P_2O_5-K_2O ha^{-1}. Organic amendments were used at a rate of 5t ha^{-1} based on similar experiences from Ghana (Buri et al , 2010) with similar environmental conditions. Each organic amendment was obtained from farms within the respective communities. The trials were conducted under improved water management conditions (fields were bunded, puddled and levelled). A split plot design using organic amendment as main plots and mineral fertilizer as sub-plots was adopted and replicated four (4) times. Sub-plot size was 2m x 2m and separated by 50cm wide bunds. Subplots were bunded, ploughed, puddled, and levelled manually (sawah technology). Transplanting was done at a spacing of 20cm x 20cm and at three seedlings per hill but thinned to two seedling after establishment. All organic amendments were thoroughly mixed manually into plots two weeks before seeding. All P, K, and 50% N was applied soon after transplanting. The remaining 50% N was applied as topdressing (split) at maximum tiller formation and panicle initiation stages. Single or straight fertilizers: (Urea, Triple Super Phosphates applied as P_2O_5 and Muriate of Potash applied as K_2O) were used. The experiment was conducted during the raining season under rain-fed conditions. However, since the area is a lowland and depending on the stage of growth of the crop, any excess water after heavy rains was drained off by opening bunds and closing them when water level was at levels required. During mineral fertilizer application, no water was drained during the period until four days after application. In addition, no pests (insect/disease) control measures were applied as no pest incidence was observed. Weed control was manual (hand picking) as weed populations were very low, partially because of effective water management.

Soil Analysis

Initial soil samples were collected from experimental sites for laboratory analysis using an auger. Soil samples were air-dried at room temperature. Dried samples were then ground and passed through a 2mm sieve. Soil pH was measured in a soil: water ratio of 1:2.5 (IITA 1979). Total carbon was measured by the method of Nelson and Sommers (1982) and total Nitrogen by the micro Kjeldahl method

(Bremer 1965). Available P was measured by the method of Bray and Kurtz (1945). Exchangeable cations (Ca, Mg, K. Na) were extracted using a 1.0M Ammonium Acetate solution. Sodium and potassium contents in the extract were determined by flame photometry while calcium and magnesium were by atomic absorption spectrophotometry (Thomas 1982). Exchangeable acidity was also determined by the method of Thomas (1982) and effective cation exchange capacity (eCEC) was calculated as sum of exchangeable cations (K, Ca, Mg, Na) and acidity. Soil texture was measured by the pipette method of Gee and Bauder (1986).

Measurement of Growth Parameters

Number of tillers was counted after maximum tiller formation stage and mean number of tillers determined while plant height was measured at harvest (120 days after planting).

Measurement of Yield Parameters

At maturity, an area of $1m^2$ excluding border rows was measured out in each sub-plot, number of panicles counted and harvested. Harvesting was done at physiological maturity (120 days after planting) using a sickle/knife to cut from the base. Harvested rice was threshed on a concrete floor, winnowed, sun dried and weighed at 14% moisture level. Grain and Stover yield were measured and yield per hectare estimated. Panicles were also collected from non-border rows and mean individual weight per panicle determined. The weight of 1000-grains was measured using an electronic balance.

Statistical Analysis

The statistical software STATISTIX 8 was used to analyze the data and LSD (0.05) was used as the mean separator.

Results and Discussion

Soil properties and nutrient content of amendments

Soil analytical results are presented in Table 1. Soils of the Savannah agro-ecological site (M'be near Bouake) were strongly acidic (pH 4.8) whilst those of the Forest agro-ecological site (Gagnoa) were slightly acidic (6.2). Soil nutrient levels were generally low at M'be (near Bouake) site within the Savannah agro-ecological zone as compared to the Gagnoa site within the forest agro-ecological zone. Soils of Bouake were sandy loam whilst those of Gagnoa were loamy sand in texture. Generally, the Forest soil was more fertile than that of the Savanna. Nutrient content of organic amendments, both Poultry manure

TABLE 1

Initial Physico-chemical Characteristics of Soils of the Experimental Sites

Parameter	Units	Agro-ecological Zone	
		Savannah	Forest
pH	-	4.8	6.2
Total Carbon (C)	g kg^{-1}	6.0	11.9
Total Nitrogen (N)	g kg^{-1}	0.6	1.1
Available Phosphorus (P)	mg kg^{-1}	3.4	5.3
Exchangeable Potassium (K)	{cmol (+) kg^{-1}}	0.11	0.14
Exchangeable Calcium (Ca)	{cmol (+) kg^{-1}}	2.4	4.5
Exchangeable Magnesium (Mg)	{cmol (+) kg^{-1}}	0.80	2.14
Exchangeable Sodium (Na)	{cmol (+) kg^{-1}}	0.05	0.06
Exchangeable Acidity	{cmol (+) kg^{-1}}	1.40	0.10
Effective CEC	{cmol (+) kg^{-1}}	4.76	6.98
Sand	g kg^{-1}	600	760
Silt	g kg^{-1}	320	160
Clay	g kg^{-1}	80	80
Texture	-	Sandy loam	Loamy sand

TABLE 2
Nutrient Composition of Organic Amendments used in the study

Parameter	Units	Agro-Ecological Zone			
		Savannah		Forest	
		Poultry Manure (PM)	Cattle Manure (CM)	Poultry Manure (PM)	Cattle Manure (CM)
Nitrogen (N)	(%)	1.05	0.34	1.75	1.27
Phosphorus (P)	(%)	1.00	0.28	0.89	0.36
Potassium (K)	(%)	0.43	0.14	0.56	0.24
Calcium (Ca)	(%)	0.67	0.74	0.90	0.77
Magnesium (Mg)	(%)	0.57	0.48	0.55	0.53

(PM) and Cattle manure (CM) were slightly higher for the Forest site than the Savannah site (Table 2). The CM was collected from open kraals while PM (from caged birds of small-scale farmers) was obtained from enclosed structures. The all-year-round availability of both grasses and leguminous feed sources within the forest ecology could account for such differences in nutrient levels for CM. Farmers' ability to provide the right feed types to birds could be the cause for the higher nutrient level for PM sources.

Effect of Organic Amendments and Mineral Fertilizer on number of tillers per plant

The effect of organic amendments and mineral fertilizer on the number of tillers per plant at both sites are shown in Table 3. At Bouake (M'be) in the Savannah agro-ecological zone, the number of tillers per plant was significantly affected by amendments in the following order PM > CM > NA (Table 3a). At Gagnoa within the Forest Agro-ecological zone, both PM and CM had similar number of tillers per plant but produced significantly higher number of tillers per plant than NA. Mineral fertilizer also influenced tiller production significantly. At Bouake (M'be), 90-60-60 kg N-P_2O_5-K_2O ha^{-1} gave similar numbers of tillers/plant as 90-60-0 kg N-P_2O_5-K_2O ha^{-1} but significant higher numbers of tiller per plant than the other mineral fertilizer treatments. In the Forest agro-ecological zone, number of tillers per plant was in a decreasing order as follows: 90-60-60 > 90-60-0 = 90-0-60 > 0-60-60 = 0-0-0 kg N-P_2O_5-K_2O ha^{-1} respectively. At Bouake PM interacted with NPK 90-60-60; NPK 90-60-0 and NPK 90-0-60 to give significantly higher numbers of tillers than all other treatments (Table 3a). At Gagnoa, the interaction between all the amendments and NPK 90-60-60 resulted in significantly higher number of tillers than all the other interactions (Table 3b). Availability of nutrients for plant growth and tiller production largely explains the higher number of tillers per plant under both the amendments and higher rates of mineral fertilizer. As earlier reported by Heluf and Seyoum (2006), the application of both N and P fertilizers increased the magnitudes of the important yield attributes including number of panicles per m^2, number of spikelets per panicle, panicle length, dry matter accumulation, straw yield and plant height significantly. As observed in this study, grain yield was positively and significantly associated with number of panicles per m^2, number of spikelets per panicle, panicle length, dry matter accumulation, 1000-grain weight, and harvest index, and hence N and P application increased grain yield of rice as earlier reported by Heluf and Seyoum (2006). The significantly higher number of tillers per plant produced as a result of the interaction of mineral fertilizer and organic amendments justifies the need for their integration in lowland rice production in all agro-ecological zones across the country. In addition, Al-Dulaimi et al (2020) working on the effect of water stress and organic fertilization sources on maize growth and yield reported that organic fertilizing maize with poultry manure gave the highest growth characters, yield and yield attributes, grain quality characters,

TABLE 3

Interaction of Amendments and Mineral fertilizer combinations on number of tillers per plant

Treatment $N\text{-}P_2O_5\text{-}K_2O$ ha^{-1}	No Amendment (NA)	Cattle Manure (CM)	Poultry Manure (PM)	Mean
(a) Bouake (M'be)				
0 – 0 - 0	5.30	8.19	11.10	9.23
0 – 60 - 60	7.18	9.74	11.38	9.38
90 – 0 - 60	8.15	10.02	12.31	9.84
90 – 60 - 0	8.21	10.26	12.61	10.36
90 – 60 - 60	10.85	10.42	12.26	11.18
Mean	8.33	9.72	11.93	
LSD (0.05) - amendments = 0.943; mineral fertilizer = 0.869; interaction = 1.639				
(b) Gagnoa				
0 – 0 - 0	5.50	12.10	14.30	10.63
0 – 60 - 60	5.50	12.50	16.10	11.35
90 – 0 - 60	12.50	14.60	16.90	14.65
90 – 60 - 0	14.40	13.60	16.50	14.83
90 – 60 - 60	19.40	20.40	21.00	20.28
Mean	11.45	14.64	16.95	
LSD (0.05): amendments = 3.66; mineral fertilizer = 1.62; interaction = 4.43				

followed by organic fertilizing with compost then organic fertilizing with farmyard manure and therefore recommended that organic fertilizing with poultry manure maintain highest productivity and grain quality under the environmental conditions of Egypt. In this study, poultry manure had a great influence on rice growth and yield than Cattle manure and its abundance in most parts of the country should be exploited for the benefit of poorly resourced farmers.

Effect of Organic Amendments and Mineral Fertilizer on 1000 Grain Weight.

In the Savanna agro-ecological zone at Bouake, a 1000-grain weight ranged from 22.0 g to 25.5 g and was similar for all the treatment combinations (Fig. 2) Within the Forest agro-ecological zone at Gagnoa, a 1000-grain weight was higher and ranged from 25.0 g to 28.0 g (Fig. 3). Treatment interactions effects were higher at Gagnoa resulting in higher 1000-grain weight within

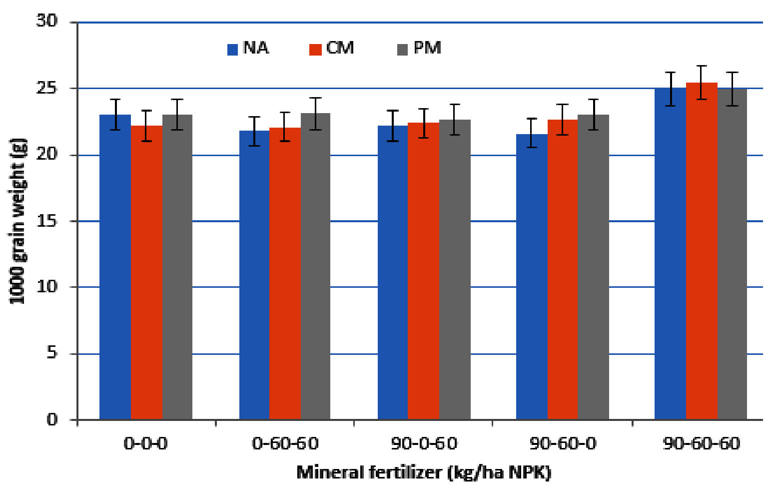

Figure 2 Weight of 1000-grains at Mbe (Error bars indicate SEM)

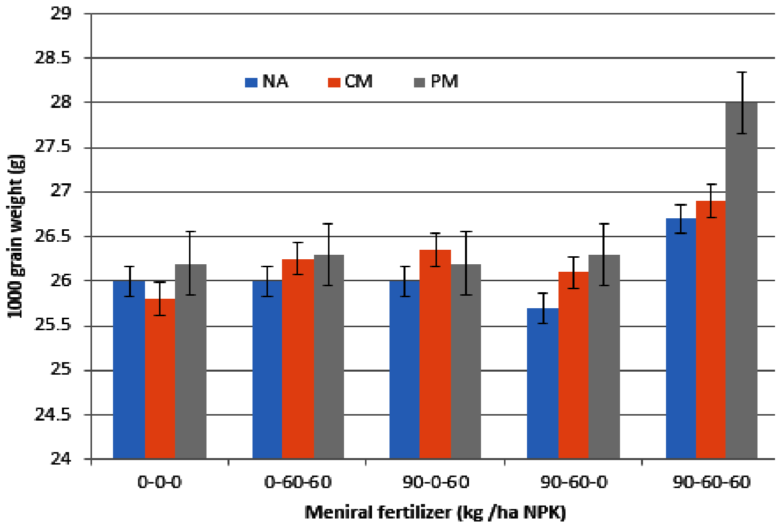

Figure 3 Weight of 1000-grains at Gagnoa. (Error bars indicate SEM)

the Forest agro-ecological zone. PM in combination with 90-60-60 kg N-P_2O_5-K_2O ha^{-1} gave the highest weight of 28.0 g which was significantly higher than all the treatment combinations (Fig. 2). Under PM and 90-60-60 kg N-P_2O_5-K_2O ha^{-1} combination, the plants probably received sufficient nutrients for proper grain filling than the other combinations. In this study, the early application of NPK and PM produced the highest 1000-grain weights at both sites thus resulting in the highest grain yields.

Interaction of Organic Amendments and Mineral Fertilizer on Grain Yield

At M'be in the Savanna agro-ecological zone, grain yield varied markedly (Fig. 4) ranging from 1.0 t ha^{-1} (under absolute control) to about 9.5 tha^{-1} (PM x 90-0-60 kg N-P_2O_5-K_2O /ha). Treatment combinations significantly affected grain yield. A combination of PM and 90-0-60 kg N-P_2O_5-K_2O ha^{-1} gave the highest grain yield over other combinations except PM x 90-60-60 and 90-60-0 kg N-P_2O_5-K_2O ha^{-1} and CM x 90-60-60 kg N-P_2O_5-K_2O ha^{-1}. The effect of treatment combinations on grain yield showed a similar trend in both the Savanna and Forest zones. At Gagnoa in the Forest zone grain yield ranged from 1.2 (under absolute control) to 10.0 t ha^{-1} (PM x 90-0-60 kg N-P_2O_5-K_2O ha^{-1}) and it was significantly influenced by treatment combinations (Fig. 5). In the Forest zone PM in combination with 90-0-60 kg N-P_2O_5-K_2O ha^{-1} gave the highest grain yield, which was similar to PM x 90-60-60: 90-60-0 kg N-P_2O_5-K_2O ha^{-1} and CM x 90-60-60 kg N-P_2O_5-K_2O ha^{-1} but higher than the other combinations. These combinations gave significantly higher number of tillers/plant (Table 3b) which resulted in the production of more grains than the other combinations. Availability of adequate nutrients from these combinations could have enabled the plants to produce more tillers, which finally affected grain yield positively. These results closely collaborate the findings of Kabil et al (2016) who reported that most growth and yield components of rice (plant height, effective tillers, panicle length, number of grains per panicle and 1000-grain weight) were significantly influenced due to application of organic manures and bio-slurries with chemical fertilizers. The combination of organic amendments and mineral fertilizer resulted in significant yield increases, a similar result as reported by Kabil et al (2016), who indicated that application of chemical fertilizers alone or in combination with organic manures or bio-slurries resulted in significant increases in grain and straw yields of rice.

Nitrogen, phosphorus and potassium are known to play key roles in crop growth and yield. As observed in this study, the combined effect of withholding the three elements resulted in over 84% grain yield reduction. Lawal et al (2020), working on the comparative analysis of organic and inorganic fertilizers on grain yield of tropical maize varieties reported that maize varieties treated with 90kg/ha NPK had the highest grain yield and was significantly comparable with maize-stalk fertilizer. The authors further indicated that the application of 120kgN + 50kgP + 40kgK of maize-stalk fertilizer to a single cross hybrid resulted in the highest benefic-cost ratio and therefore recommended that maize-stalk fertilizer was economically more viable than NPK fertilizer in addition to the hidden cost borne by the environment when inorganic fertilizers are used. From this study, 90kgN + 60kgP + 60kgK gave the highest grain yields when no organic amendments are applied, for optimum grain yields.

Considering the current economic situation (resource poor) of most lowland rice farmers, the use of organic fertilizer sources should be encouraged and promoted for sustainability and effective soil nutrient management under lowland rice production. Organic materials are not only available but also affordable within the study area and their use has proven to be environmentally friendly (Buri et al, 2010).

Effect of Missing Nutrients on Grain Yield

Tables 4a and b show the effect of nutrient omissions on grain yield. There was a general grain yield reduction wherever any of the three major elements (N, P, and K) was not

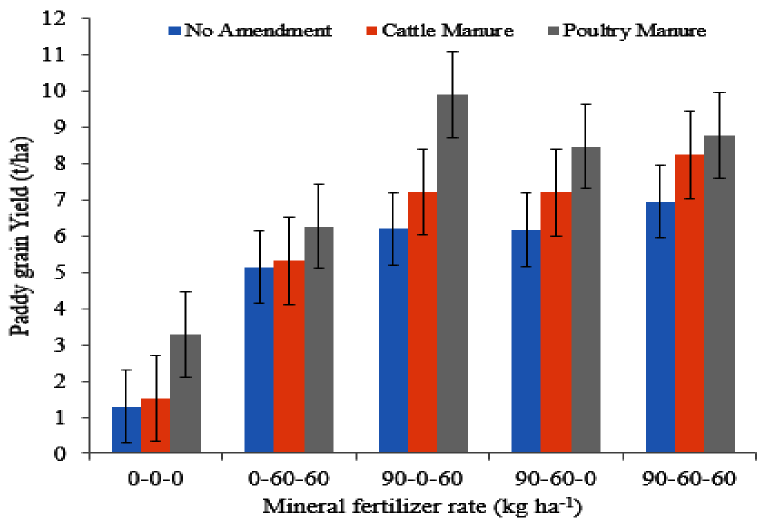

Figure 4 Effect of integration of mineral fertilizer and organic amendments on paddy grain yield at M'be (Error bars indicate SEM)

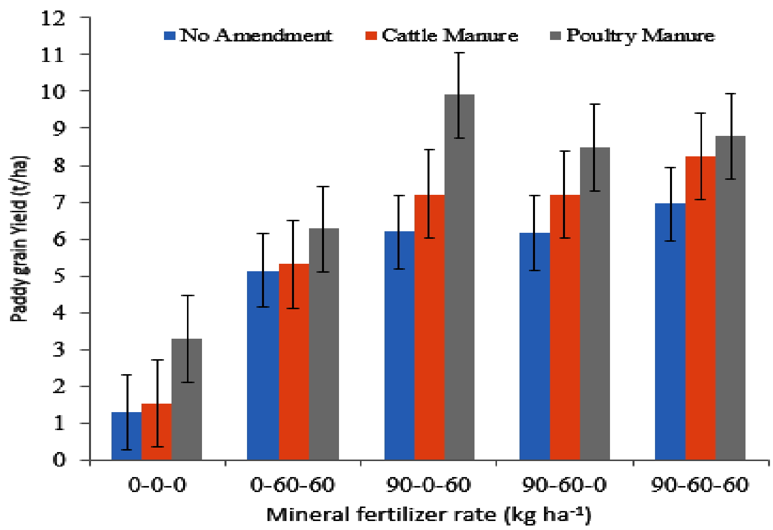

Figure 5 Effect of integration of mineral fertilizer and organic amendments on paddy grain yield at Gagnoa (Error bars indicate SEM)

applied at both locations (M'be & Gagnoa). In the Savannah agro-ecology at M'be yield reduction due to N, P and K omissions were 13%, 11% and 13 % respectively (Table 4a). The site was previously used for seed production and the residual effects of fertilizers earlier used may explain the lower reduction in grain yield when these nutrients were missing. However, at Gagnoa, where the site was previously used by a peasant farmer with no or minimal fertilizer additions, response to nutrient omission was relatively higher. There was a 27% grain yield reduction in the absence N, a 15% yield reduction in the absence of P and an 11% yield reduction in the absence of K.

At both sites, the chemical characteristics of the soils (Table 1) show that soils of Savannah agro-ecological zone were relatively more acidic (lower pH) than the Forest. However, at both sites soil nutrient levels were relatively quite low. When no mineral nutrient was applied grain yield reduction was over 80% in both ecological zones. Previous studies have shown that rice responds very well to mineral fertilization in selected lowlands in Southern Ghana (Buri et al., 2008). In addition, Heluf and Seyoum (2006) reported that the main effects of N and P fertilizer additions gave significant differences for all yield and yield components but that the effects of N by P interaction was significant only for grain yield, number of panicles per m^2, number of spikelets per panicle and plant height.

In this study, there was a grain yield reduction of 84% (Table 4) when no N, P, or K fertilizers were added at both sites, emphasizing the importance and need for mineral fertilizer additions. As earlier reported by Hasan et al (2020), N and P fertilizers were found to play a dominating role in increasing the vegetative growth and yield of the Bambara Groundnut plant, emphazing that plant height, leaf area, and number of pods per plant increased with the application of N and P. In this study, N and P application significantly affected not only grain yield but number of tillers per plant and 1000 grain weight. Hence, for good growth and higher grain yields, lowland rice must be provided with optimum levels of N, P, and K. This further corroborates Yousaf et al (2017) who reported that crop yields were increased by 19–41% (rice) and 61–76% (rapeseed) during the two years of rice-rapeseed rotation under NPK fertilization compared to PK fertilization across the study sites. They further indicated that yield responses to fertilization were ranked NPK > NP > NK > PK, illustrating that N deficiency was the most limiting condition in a rice-rapeseed rotation, followed by P and K deficiencies. The highest and lowest N, P and K accumulations were observed under

TABLE 4
Effect of Missing Nutrient Elements on Paddy Grain Yield

Mineral Fertilizer Rate ($N-P_2O_5-K_2O$ kg ha^{-1})	Mean Yield (kg ha^{-1})	Yield Difference (kg ha^{-1})	Yield Reduction (%)
(a) Bouake (M'be)			
90-60-60	6400	-	-
0-60-60	5548	852	13
90-0-60	5698	702	11
90-60-0	5593	807	13
0-0-0	1040	5360	84
LSD (0.05)	74.0		
(b) Gagnoa			
90-60-60	7837	-	-
0-60-60	5727	2110	27
90-0-60	6627	1210	15
90-60-0	6997	840	11
0-0-0	1290	6547	84
LSD (0.05)	117	-	

NPK and PK fertilization, respectively. Based on the study results, the authors recommended that a balanced nutrient application using NPK fertilization is a key management strategy for enhancing rice-rapeseed productivity and environmental safety. In this study, with over 84% yield reduction in the absence of the three major nutrient elements (N. P, and K) but a variable reduction in the absence of either one or two of them, mineral fertilizer additions are inevitable if good crop growth and optimum grain yields are to be achieved.

Contribution of Organic Amendments alone to Grain Yield

The effects of organic amendments on grain yield are shown in Table 5. At both sites, the contribution of PM to grain yield was higher than CM. At Mbe in the Savanna agro-ecological zone, the addition of CM resulted in 47% increase in grain yield over the control. Integrating CM with MF resulted in 30% increase in grain yield (Table 5a). At the same site, increases in grain yield due to the addition of PM was 204% over the control. PM also interacted with MF to give 44% increase over mineral fertilizer alone (5a). The nutrient content of PM is better than CM and may largely explain the observed differences (Table 2). At Gagnoa within the Forest agro-ecological zone, the addition of CM resulted in 19% and 5.5% increase in grain yield over control and mineral fertilizer respectively.

Application of PM brought about an increase in grain yield of 155% over control while PM interacted with MF to give 26% increase over mineral fertilizer alone (Table 5b). Ali et al (2012) working on different organic manures and fertilizers to improve paddy yield under a rice-wheat cropping system, reported that application of NPK and its combination with compost, green manure and FYM increased rice yield significantly. Among different combinations, compost at 12.5 t ha^{-1} + NPK

TABLE 5

Contribution of Soil Amendments to Paddy Grain Yield

Treatment	Mean Yield (t ha^{-1})	Yield Increase (t ha^{-1})	Yield Increase (%)
(a) M'be (Bouake) Site			
Cattle Manure			
No fertilizer (Control)	1.04	-	-
Cattle Manure	1.53	0.49	47
Mineral fertilizer	4.51	-	-
Cattle Manure + mineral fertilizer	5.89	1.38	30
Poultry Manure			
No fertilizer (Control)	1.04	-	-
Poultry Manure	3.17	2.13	204
Mineral fertilizer	4.51	-	-
Poultry Manure + mineral fertilizer	6.51	2.00	44
(b) Gagnoa Site			
Cattle Manure			
No fertilizer (control)	1.29	-	-
Cattle Manure alone	1.53	0.24	19
Mineral fertilizer alone	5.55	-	-
Cattle Manure + mineral fertilizer	5.85	0.30	5.5
Poultry Manure			
No fertilizer (control)	1.29		
Poultry Manure alone	3.29	2.00	155
Mineral fertilizer alone	5.55	-	-
Poultry Manure + mineral fertilizer	6.99	1.44	26

at 66-42-31 kg N, P_2O_5 and K_2O ha^{-1} showed superiority in yield and yield contributing parameters followed by Green manure at 12.5 t ha^{-1} + NPK at 66-42-31 kg N, P_2O_5, K_2O ha^{-1} and FYM at 12.5 t ha^{-1} + NPK at 66-42-31 kg N, P_2O_5, K_2O ha^{-1} over others. Lowest paddy yield was observed in case of FYM at 12.5 t ha^{-1} followed by Green manure at 12.5 t ha^{-1} and Compost at 12.5 t ha^{-1}. The authors further indicated that higher profit was obtained when inorganic fertilizer was combined with organic manures, suggesting the combined application of synthetic fertilizers and organic manures was more efficient in improving paddy yield and economic returns of rice as compared to their separate use.

In this study, the nutrient content of various amendments (Table 2) were relatively low and varied depending on source and location. However, these amendments are readily available and affordable across locations. Hence, for optimum rice growth, grain yields and improvement in soil productivity, a combination of both is ideal. This collaborates earlier findings by Sultan et la (2019) who indicated that application of lime and manure had significant positive effect on the yield of potato and consequently positive residual effects on mung bean and TA rice. The authors reported an average 45-59% yield benefit over control for the first crop and 41-43% yield benefit for the second crop and subsequently recommended that amendment of soil with dololime at 1 t ha^{-1} coupled with poultry manure at 3 t ha^{-1} or FYM at 5 t ha^{-1} could be an efficient practice for achieving higher crop yield due to optimization of soil acidity and nutrient uptake by plants. Further to this, Jean et al, (2021) reported that, the combination of organic fertilizers and recommended mineral fertilizer resulted in a 45% and 59% increase in cowpea yields respectively when organova and bio deposit (both organic fertilizers) were used in combination with mineral fertilizer. As such to maintain soil fertility and improve crop yields, the use of organic fertilizers as shown by results from this study and corroborated by earlier findings is crucial and need to be carefully considered.

Conclusion

The results showed significant decreases in grain yield when N, P, and K were not applied, indicating these nutrient elements are limiting. Results further showed that, under low input usage particularly with resource poor farmers, integrating both mineral fertilizers and locally available organic soil amendments improved soil productivity reflecting in significantly higher grain yields. The significant increase in rice grain yields resulting from the use of these organic amendments in combination with inorganic fertilizers could translate to increased income for farmers and hence improvement in their livelihoods if they are adapted for lowland rice cultivation in the country. Furthermore, water is key in rice production and the adoption of the sawah technology of improved water management (bunded, puddled, levelled fields), which was adopted in this study, will be of immerse benefit to farmers.

Recommendations

As observed under this study, levels of soil N, P, and K are below rice requirement levels and there is the urgent need to develop nutrient ,management systems that will ensure the adequate supply of these nutrients for rice production. Since farmers cannot afford the right recommended quantities of mineral fertilizers mainly due to high cost, additions of organic amendments to paddy rice fields is strongly recommended. It should be strongly pursued, encouraged and promoted, as these materials are not only available but also affordable across the study sites and generally across the country. Organic Amendments should be applied at average rate of 5.0t ha-1 (as this may vary depending on source, nature, and type of amendment and its management from farmer to farmer) and worked into the soil at least two weeks before seeding/transplanting. This should be supplemented with mineral fertilizers additions. Well-decomposed organic amendments could, however, be applied during seeding/transplanting.

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