Soil Organic Amendments and Mineral Fertilizers: Options for Sustainable Lowland Rice Production in the Forest Agro-ecology of Ghana

M. M. Buri [1†], *R. N. Issaka* [1], *T. Wakatsuki and E. Otoo* [3]
[1] *CSIR - Soil Research Institute, Academy Post Office, Kwadaso Kumasi, Ghana.*
[2] *Faculty of Life and Environmental Science, Shimane University, Japan.*
[3] *CSIR - Crops Research Institute, Post Office Box 3785, Kumasi, Ghana.*
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Résumé

Buri, M. M., Issaka, R. N., Wakatsuki T., & Otoo E. *Rectification Organique Des Sols Et Engrais Chimiques : Options Pour La Production Durable Du Riz Dans Les Terrains Bas Dans L'agro-ecologie Des Forets Du Ghana.* La technologie " Sawah" (les terrains du riz irrigués et aplanis) a été amenée aux cultivateurs dans l'agro- écologie forestières du Ghana. Pour améliorer la productivité des sols et pour réduire la dépense sur les engrais chimiques, l'effet de trois rectifications organiques sur la production du riz a été utilisés entièrement à part ou en combinaison avec l'engrais chimique sur le riz à trois lieux différentes dans la zone agro écologique forestière à Potikrom, Biemso No. 1 et Biemso No. 2. Des rectifications organiques entières ont été appliquées au taux de 7,0 t ha^{-1} et l'engrais chimique entier a été appliqué comme N-P-K à 90- 60 - 60 kg ha^{-1}. La source de N était soit l'urée ou sulfate ammonique. La source de P était Phosphate Super triple et la source de K était le murie de Potash. Les combinaisons étaient au niveau du demi du taux (rectifications organiques, engrais chimiques). Les résultats ont porté à croire que les rectifications organiques, engrais chimiques et leurs combinaisons ont continué de manière significante à la croissance et la production des graines du riz. Une combinaison du fumier de la volaille (demie portion) et de l'engrais chimique (demie portion) ont aménée à une meilleure production des graines que tous les traitements sauf l'engrais chimique (pleine portion) à deux ou trois emplacements. La production des graines du riz était 6,2, 7,3 et 3,7 t ha^{-1} pour le fumier des volailles à demie portion + l'engrais chimique à demie portion à Potikrom, Biemso No. 1 et No.2 respectivement tandis que l'engrais chimique à pleine portion a mené à 6,6, 7,3 et 3,9 t ha^{-1} à ces trois lieux respectivement. En plus une combinaison des rectifications organiques avec l'engrais chimique a produit plus que la rectification organique entière dans tous les trois lieux. Les rectifications organiques appliqués à elles seules ont eu les résultats suivants: fumier des volailles > fumier des bovins > enveloppe du riz.

Mots clés : Agro-écologie, forêt, rectifications organiques, "sawah".

† *Corresponding author*

Abstract

The "sawah" technology (bunded and leveled irrigated rice field) was introduced to some farmers within the forest agro-ecology of Ghana. To improve the productivity of their soils and also to minimize expenditure on mineral fertilizers, the effect of three organic amendments on rice yield was evaluated. Poultry manure, cattle manure and rice husk were used either solely or in combination with mineral fertilizer on rice at three different locations within the forest agro-ecological zone at Potrikrom, Biemso No. 1 and Biemso No. 2. Sole organic amendments were applied at a rate of 7.0 t ha^{-1} and sole mineral fertilizer was applied as N-P-K at 90-60-60 kg ha^{-1}. The N source was either urea or sulphate of ammonia, P source was triple super phosphate and K source was muriate of potash. Combinations were half rate (organic amendments + mineral fertilizer). Results showed that organic amendments, mineral fertilizer and their combinations significantly contributed to the growth and grain yield of rice. A combination of poultry manure (half rate) and mineral fertilizer (half rate) gave significantly greater grain yield than all the treatments except mineral fertilizer (full rate) at two out of the three locations. Rice grain yields were 6.2, 7.3 and 3.7 t ha^{-1} for half rate poultry manure + half rate mineral fertilizer at Potrikrom, Biemso No. 1 and Biemso No. 2 respectively, while full rate mineral fertilizer gave 6.6, 7.3 and 3.9 t ha^{-1} at the three sites respectively. In addition, a combination of organic amendments with mineral fertilizer out-yielded sole organic amendments at all the three sites. Organic amendments applied solely performed in the order: poultry manure > cattle manure > rice husk.

Keywords: Agro-ecology, forest, organic amendments, "sawah", sustainability.

Introduction

Even though Ghana has the potential (over 700,000 ha of lowlands) not only to produce enough rice for local consumption but also for export, the country still imports large quantities of the crop (US $100m annually) to meet local demand. Despite recent efforts at encouraging or promoting increases in production, rice yields per unit area are still very low - about 1.0 t ha^{-1} (Andriesse *et al.*, 1995). Among identified causes for the low yields are declining soil fertility and the inability of farmers to use mineral fertilizers (due to high cost). Farmers therefore rely solely on natural soil fertility. For any integrated sustainable nutrient management system, plant nutrient supply packages need to be developed and fine-tuned with efficient economic and environmentally sound production principles that lead to proper management of soil fertility. For proper rice growth and optimum yields, the necessary nutrients (N, P, K, S) must not only be present and available but must also be in balanced quantities.

In Ghana and indeed at the West African sub-regional level, environmental problems have led to more attention and emphasis being placed on cost effective, sustainable and environmentally friendly crop production systems. IFDC (1998) reported that, annual rate of nutrient depletion from soils of Ghana between 1993 and 95 in kilogrammes of N + P_2O_5 + K_2O ha^{-1} was 51-100 while the average annual rate of nutrients required to achieve optimum levels of crop production in kilograms of N + P_2O_5 + K_2O ha^{-1} was greater than 80. Buri *et al.* (1996, 1998, 1999), Issaka *et al.* (1996a,b, 1997) and Weidmeijer and Andriesse (1993) have reported that not only are the rice growing environments of the West African sub-region low in inherent fertility but also are actually very deficient in some nutrients. Notable among such nutrients is soil sulfur, a major ingredient in rice nutrition.

During the launching of the African Rice Initiative (ARI, 2002), emphasis has been placed on promoting complimentary technologies that will enhance soil fertility, making rice farming sustainable and improving the nutritional status of farm families. With the introduction of the "sawah" concept in Ghana, there has been improvements in water conservation and utilization and hence improvement in nutrient retention under rice cultivation (JICA/CSIR, 2001). In addition, organic fertilizer sources are quite common within southern Ghana. It is therefore possible to explore integrated nutrient management options, which will not only improve rice yields but also generally improve and/or maintain soil productivity.

The objectives of this study are to (i) investigate the effectiveness of common and available farm organic amendments as nutrient sources, (ii) investigate the extent to which sulfur deficiency, if any, affects rice growth and yield within the forest ecology and (iii) provide integrated nutrient management options based on availability and affordability of such nutrient materials and sources.

Materials and methods

Experimental sites

The experiments were conducted at three sites (site 1-Potrikrom; site 2-Biemso No. 1; site 3-Biemso No. 2) within the forest ecology of Ghana during the 2000 major season. Trials at Biemso Nos. 1 and 2 were located on lands, which were left fallow for the previous season while the Potrikrom site had been previously cropped to rice.

Land preparation

After an initial land clearing and manual removal of stumps, the sites were ploughed with a power tiller and demarcated into four macro-plots (replications) at Potrikrom and Biemso No.1 while Biemso No. 2 had only three replications. These macro-plots were further divided into smaller plots (treatments). Treatment plots were then flooded and rotivated thoroughly using a power tiller.

Laboratory analysis

Soil samples (0-15 and 15-30 cm depths) were collected after land clearing. Samples were air dried, ground and passed through a 2-mm mesh sieve. Soil pH (H_2O) was determined using a pH meter (with a glass electrode) in a soil to water ratio of 1:2.5 (IITA, 1979a). Organic carbon content was determined by the wet combustion method (Walkley and Black, 1934 cited by IITA, 1979b). Total nitrogen content was determined by the Macro-Kjeldahl method (Bremner, 1965 cited by IITA 1979c). Available P was determined by the Bray No. 2 method (Bray and Kurtz,1945 cited by IITA 1979d). Exchangeable cations were first extracted with ammonium acetate (1.0 M NH_4OAc). The contents of various cations in the extract were determined by Atomic Absorption Spectrophotometer (Thomas, 1962). Samples of organic amendments were also air-dried and contents of various elements determined through the same process as soil samples.

Fertilization

Three organic amendments {poultry manure (PM), cattle manure (CM), rice husk (RH)} were applied at 7.0 t ha^{-1}. Mineral fertilizer (MF) as N-P-K (90-60-60) kg ha^{-1} was applied using urea or sulphate of ammonia as N sources, triple super phosphate as P source and muriate of potash as K source. Organic amendments and mineral fertilizers were also combined at half rates {3.5 t ha^{-1} organic amendments + N-P-K (45-30-30) kg ha^{-1}}. The design was an RCB with four replications at Potrikrom and Biemso No. 1 and three replications at Biemso No. 2. Organic fertilizers were worked into the soil during land preparation at least three weeks before transplanting.

Transplanting

Rice was transplanted manually in August at a square spacing of 20 cm x 20 cm and at three seedlings per stand. Seedlings were transplanted at 3-4 weeks after nursing. Weed control was mainly by water (maintaining a minimum water level of about 5-10cm above soil surface). However, there was occasional handpicking of water-resistant weeds. Harvesting was also done manually in December.

Results and Discussion

Initial soil and organic amendments characteristics

Table 1 shows the initial soil characteristics of the experimental sites (Potrikrom, Biemso No. 1 and Biemso No. 2). Topsoil (0-15cm) was slightly acidic within a pH range of 5.4 to 6.5. Subsoil (15-30cm) also showed a similar trend. Organic matter, total N and available P levels were low in all locations even though Biemso No. 2 (freshly cleared land) showed comparatively greater levels of these soil characteristics. Topsoil exchangeable Ca and Mg levels were relatively moderate while exchangeable K was low particularly at Biemso No. I. Nutrient content of the organic amendments used is shown in Table 2. Apart from organic

Table 1. Some properties of soils of the experimental sites.

Location	Depth (cm)	pH (H_2O	OM (%)	TN (%)	Av. P mg kg^{-1}	Ex. Cations {cmol (+)kg^{-1}} K	Ca	Mg	Na	Soil texture
Potrikrom	0-15	5.6	2.01	0.17	1.80	0.32	5.92	2.24	0.19	Clay loam
	15-30	5.7	1.37	0.09	1.45	0.10	4.16	2.08	0.08	Loam
Biemso No. 1	0-15	5.4	2.16	0.13	3.95	0.10	3.68	1.60	0.19	Loam
	15-30	5.6	0.46	0.06	1.05	0.05	2.56	1.28	0.24	Sandy clay loam
Biemso No. 2	0-15	6.5	2.58	0.18	8.95	0.30	6.88	1.28	0.11	Sandy loam
	15-30	6.8	2.11	0.09	1.65	0.09	5.12	2.24	0.20	Sandy loam

Table 2. Some properties of the organic amendments used in the experiment.

Organic amendments	*% O. M*	*% TN*	*% P*	*% K*	*% Ca*	*% Mg*
Poultry Manure	23.08	2.6	0.61	1.09	8.45	7.00
Cattle Manure	17.71	1.12	0.59	0.40	0.56	6.87
Rice Husk	27.35	1.10	0.28	0.36	0.40	1.80

matter, which was fairly high for all the organic nutrient sources, poultry manure showed greater concentrations of other nutrients than cattle manure and rice husk.

Agronomic parameters

Tiller number and plant height

Fertilizer (organic or mineral) application significantly affected tiller number over the control (Table 3). The effect of mineral fertilizer, organic amendments and their combinations were, however, mixed with no clear pattern across locations. PM, CM, PM + MF and RH + MF with urea as N source gave the largest tiller numbers at Potrikrom. At Biemso No. 1, PM and RH + MF gave the largest tiller numbers while at Biemso No. 2, ammonium sulphate as N source gave the largest tiller number.

There was a significant effect of mineral fertilizer and the application of organic amendments on plant height over the control (Table 4). The pattern of response to plant height by both mineral fertilizer and organic amendments was, however, similar across locations but with greatest response at Potrikrom indicative of nutrient mining (previously cropped for several seasons to rice). The weaker response of plant height to fertilization at Biemso No. 2 was partially due to initial water shortage, which probably affected early crop growth. In addition, soils of this site (Table 1) showed greater levels of nutrients at the initial stage than the

Table 3. Effect of organic amendments and mineral fertilizers on rice tiller number.

Treatment	*Potrikrom*	*Biemso No. 1*	*Biemso No. 2*
Control (no organic amendment or mineral fertilizer added)	9.7a	11.5a	9.1a
N90P60K60 kg ha^{-1} using urea as N source	12.9bc	14.2bc	12.0b
N90P60K60 kg ha^{-1} using S/A as N source	12.1b	14.7bc	13.0c
Poultry Manure (7.0 t ha^{-1})	13.7c	16.4d	12.5b
PM (3.5 t ha^{-1}) + N45P30K30 kg ha^{-1} - using urea as N source	13.2c	15.9c	12.2b
Cattle Manure (7.0 t ha^{-1})	12.7bc	13.5b	10.7ab
CM (3.5 t ha^{-1}) + N45P30K30 kg ha^{-1} - using urea as N source	11.8b	13.8b	10.5ab
Rice Husk (7.0 t ha^{-1})	11.4b	14.8bc	11.1b
RH (3.5 t ha^{-1}) + N45P30K30 kg ha^{-1} - using urea as N source	13.2c	16.4d	11.5b

DMRT at $P \leqslant 0.05$; S/A - Sulphate of Ammonia; PM - Poultry Manure; CM - Cattle Manure; RH - Rice Husk, P and K sources were Triple Super Phosphate and Muriate of Potash, respectively.

Table 4. Effect of organic amendments and mineral fertilizers on rice plant height (cm).

Treatment	*Potrikrom*	*Biemso No. 1*	*Biemso No. 2*
Control (no organic amendment or mineral fertilizer added)	114.3a	118.5a	95.6a
$N_{90}P_{60}K_{60}$ kg ha^{-1} using urea as N source	133.9b	132.8bc	111.9cd
$N_{90}P_{60}K_{60}$ kg ha^{-1} using S/A as N source	136.7b	136.3c	116.2d
Poultry Manure (7.0 t ha^{-1})	135.4b	140.6c	109.1bc
PM (3.5 t ha^{-1}) + $N_{45}P_{30}K_{30}$ kg ha^{-1} - using urea as N source	135.3b	139.0c	108.5bc
Cattle Manure (7.0 t ha^{-1})	129.9b	136.0c	102.6ab
CM (3.5 t ha^{-1}) + $N_{45}P_{30}K_{30}$ kg ha^{-1} - using urea as N source	124.8ab	131.6bc	109.3bc
Rice Husk (7.0 t ha^{-1})	126.1ab	125.2ab	104.0b
RH (3.5 t ha^{-1}) + $N_{45}P_{30}K_{30}$ kg ha^{-1} - using urea as N source	126.6ab	138.8c	108.6bc

DMRT at $P \leqslant 0.05$; S/A - Sulphate of Ammonia; PM - Poultry Manure; CM - Cattle Manure; RH - Rice Husk, P and K sources were Triple Super Phosphate and Muriate of Potash, respectively.

other two sites. These differences at Biemso No. 2 could be due to initial inadequate water.

Grain yield

Rice grain responded positively and significantly to fertilization from both mineral and organic sources (Table 5 and Table 6). Both organic amendments and mineral fertilizer application significantly affected 1000 grain weight over the control at all sites. However, there were no significant differences between mineral fertilizer and organic amendments treatments at Potrikrom and Biemso No. 1. Differences between treatments at Biemso No. 2 were, however, not clear due to reasons stated earlier.

Mineral fertilizer at N-P-K (90-60-60) kg ha^{-1} gave the greatest grain yields irrespective of the source of N being urea or sulphate of ammonia. However, rice grain yields for poultry manure (7.0 t ha^{-1}), poultry manure + mineral fertilizer combination and N-P-K (90-60-60) kg ha^{-1} were comparable. For the organic amendments, poultry manure gave the greatest grain yields while both cattle manure and rice husk gave comparable yields at Potrikrom. However, PM produced comparable yields with CM at Biemso No. 1 but greater than RH. At Biemso No. 2. no clear pattern of response to grain yield was obtained. In general terms, the order of response to grain yield by the sole organic amendments was: poultry manure > cattle manure > rice husk. Poultry manure with relatively greater nutrient levels (Table 2) probably supplied enough nutrients and at the time required by the plant. Synchrony in nutrient release and crop demand was probably better for poultry manure than the other two organic amendments. Poultry manure treatments out-yielded the control by 250%, cattle manure by 170% and rice husk by 96% at Potrikrom and by 77, 74 and 53 at Biemso No. 1 and by 118, 125 and 85 at Biemso No. 2, respectively.

Sulphur (S) application

The lack of response to sulphur application at all the sites (Tables 3-6) could be due to the provision of the element from earlier fertilization (Potrikrom) and the higher levels of organic matter at Biemso No. 1 and Biemso No. 2. Even though Buri *et al.* (1999), Yamauchi (1989), Kang *et al.* (1981) and Aquaye and Kang (1987) reported that sulphate S was quite limiting across the sub-region, no response to S application was observed from this study within the forest agro-ecology. Nonetheless, with continuous and intensive rice cultivation coupled with the non-existence of main S mineral fertilizers (presently, sulphate of ammonia is being phased out), S could become a limiting nutrient in the near future. This effect could, however, be minimized with improvements in organic matter management and tapping of traditional S sources (precipitation

Table 5. Effect of organic amendments and mineral fertilizers on 1000 grain weight (gm).

Treatment	*Potrikrom*	*Biemso No. 1*	*Biemso No. 2*
Control (no organic amendment or mineral fertilizer added)	25.1a	26.9a	24.6a
$N_{90}P_{60}K_{60}$ kg ha $^{-1}$ using urea as N source	28.2b	32.9b	28.3bc
$N_{90}P_{60}K_{60}$ kg ha $^{-1}$ using S/A as N source	28.4b	32.9b	27.0b
Poultry Manure (7.0 t ha^{-1})	28.6b	32.4b	28.1bc
PM (3.5 t ha^{-1}) + $N_{45}P_{30}K_{30}$ kg ha $^{-1}$ - using urea as N source	28.8b	32.1b	29.6c
Cattle Manure (7.0 t ha^{-1})	28.1b	33.6b	26.7ab
CM (3.5 t ha^{-1}) + $N_{45}P_{30}K_{30}$ kg ha $^{-1}$ - using urea as N source	27.9b	31.6b	26.8b
Rice Husk (7.0 t ha^{-1})	27.7b	32.0b	27.2bc
RH (3.5 t ha^{-1}) + $N_{45}P_{30}K_{30}$ kg ha $^{-1}$ - using urea as N source	28.0b	33.5b	27.0bc

DMRT at $P \leqslant 0.05$; S/A - Sulphate of Ammonia; PM - Poultry Manure; CM - Cattle Manure; RH - Rice Husk, P and K sources were Triple Super Phosphate and Muriate of Potash, respectively.

Table 6. Effect of organic amendments and mineral fertilizers on rice paddy grain yield (kg ha^{-1}).

Treatment	*Potrikrom*	*Biemso No. 1*	*Biemso No.2*
Control (no organic amendment or mineral fertilizer added)	1675a	2587a	1500a
$N_{90}P_{60}K_{60}$ kg ha^{-1} using urea as N source	6962d	7450d	4033ef
$N_{90}P_{60}K_{60}$ kg ha^{-1} using S/A as N source	6575d	7337d	3900def
Poultry Manure (7.0 t ha^{-1})	5962d	6362c	3283bc
PM (3.5 t ha-1) + $N_{45}P_{30}K_{30}$ kg ha^{-1} - using urea as N source	6250d	7300d	3683cde
Cattle Manure (7.0 t ha^{-1})	4537c	6250c	3383cd
CM (3.5 t ha^{-1}) + $N_{45}P_{30}K_{30}$ kg ha^{-1} - using urea as N source	4862c	6237c	3717cde
Rice Husk (7.0 t ha^{-1})	3287b	5487b	2783b
RH (3.5 t ha^{-1}) + $N_{45}P_{30}K_{30}$ kg ha^{-1} - using urea as N source	4425c	6287c	3317c

DMRT at $P \leqslant 0.05$; S/A - Sulphate of Ammonia; PM - Poultry Manure; CM - Cattle Manure; RH - Rice Husk, P and K sources were Triple Super Phosphate and Muriate of Potash, respectively.

and irrigation water).

Conclusions

With improved soil and water management under the newly introduced "sawah" system, results from this study show that organic amendments could serve as effective and efficient fertilizer materials for project farmers who cannot afford mineral fertilizers due to high cost. A combination of both mineral fertilizers and organic amendments has been observed to be very effective. However, where farmers have greater difficulty in obtaining mineral fertilizer, sole organic amendments can be relied upon when used at higher rates. Poultry manure is quite rich in nutrients and also available and affordable within the forest agro-ecology. The encouraged use of such available and affordable organic materials will not only promote the concept of sustainability but they are also environmentally friendly. Their use should therefore be promoted for a positive change in the socio-economic lives of peasant rice farmers through increased yields and hence increased income and improved living conditions.

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