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INCREASING RICE PRODUCTIVITY THROUGH INTEGRATED NITROGEN SOURCES UNDER THREE SOIL MANAGEMENT SYSTEMS ON A VERTISOL

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Abstract

Rice production in Ghana is relatively low partly due to poor nitrogen and soil management. To increase rice productivity in the country, a field experiment was carried out to assess the effect of nitrogen sources and soil management systems on grain yield, plant nitrogen uptake, nitrogen use efficiency, and chemical properties of the soil. The experiment was conducted at the Soil and Irrigation Research Centre, University of Ghana, Kpong during the 2015 and 2016 cropping seasons and laid out in a split plot design with three replications. Soil management systems and nitrogen (N) sources were the main and sub plot factors respectively. Soil management systems included; continuously flooded (S1), alternate wetting and drying (S2) and aerobic (S3) while the nitrogen sources included no nitrogen fertilizer (N0), urea fertilizer (N1), compost fertilizer (N2) and integrated urea and compost fertilizer (N3). Results from the study revealed that S2 recorded similar grain yield, plant N uptake and N use efficiency of rice as S1. Treatment N3 produced the optimum grain yield and nitrogen use efficiency. S2N3 treatment interaction produced the highest grain yield and N use efficiency. Crop residues left after harvest should be composted and used to improve soil chemical properties as well as increase rice yield.

Keywords: Compost, nitrogen use efficiency, rice, soil chemical properties, vertisol

Introduction

Vertisols are deep black soils which contain more than 30% clay which is often dominated by smectite mineralogy (Soil Survey Staff, 1999). They have very high clay content and the dominant clay minerals are 2:1 type minerals (Smectite and montmorillonites). The soils become sticky and swell when wet while shrink and crack extensively when dry due to their montmonllonitic nature. In Ghana, the total nitrogen concentration in these soils is very low due to their low organic matter content, 1-2% (Nyalemegbe *et al*. 2009). The yield of rice in the country is low partly due to the low concentration of nitrogen in the soils especially vertisols. Duxbury and his associates (2000) reported that 1kg of nitrogen is needed for 11 to 22kg of rice. Farmers apply inorganic fertilizers to support the inherent fertility of the soils. However, there has been 50% increase in inorganic fertilizer prices in the country (Ministry of Food and Agriculture, 2014) and consequently most farmers cannot apply fertilizer at the recommended rate for a good crop yield. Moreover, the continuous application of inorganic fertilizers leads to deterioration in soil properties (Dick, 1992; Mahajan, 2008) and crop yield (Bhandari *et al*., 2002). Crop residues that are incorporated into the soil during land preparation cause severe nitrogen immobilization (Chandra, 2005) and methane (CH_4) emission which contributes to greenhouse gases (Dobermann and Fairhurst, 2002). However, these crop residues can be composited and used to improve the soil properties. The incorporation of compost into the soil has been reported to increase the soil organic carbon content (Xin *et al*., 2016) which is low in vertisols, soil structure, water stable aggregate and water holding

capacity by increasing the total storage pore number of the soil (Bhatacharyya *et al*., 2008).
Numerous water saving methods have been suggested to farmers due to the decrease in available fresh water for irrigation as a result of the rapid population growth (Molden, 2007) and climate change (Zwart, 2013). There is scanty information on response of rice to integrated nitrogen sources under different soil management on the vertisol of Accra Plains. This study was therefore conducted to assess the effect of nitrogen sources and soil management systems on rice yield, nitrogen use efficiency and chemical properties of the soil.

Materials and Methods

Description of the Experimental Site

The experiment was carried out at the Soil and Irrigation Research Centre, University of Ghana, Kpong in the Eastern Region of Ghana. The Centre is located within the lower Volta basin of the Coastal Savannah agro-ecological zone at latitude 6° 09' N, longitude 00° 04' E, and an altitude of 22m above mean sea level. The soil at the experimental site was a vertisol and it has the following chemical properties; total nitrogen (0.07%), available phosphorus (2.09%), available potassium (4.72%), calcium (22.8mg kg^1), magnesium (1.26mg kg^1), pH in water 1:1 (7.88), organic carbon (1.63%), C/N ratio (24.3), organic matter (2.81%) and electrical conductivity (0.54).

Land Preparation, Field Layout and Experimental Design

The land was cleared and puddled to reduced percolation of water. 36 experimental plots of an area $6m^2$ each were measured out. 60cm long metallic barriers with an area of $6m^2$ were inserted in each plot at a depth of 30cm to prevent lateral movement of nutrient and water from one plot to another. A 3 x 4 factorial experiment was laid out in a split plot design and replicated three times. Soil management was the main plot factor while nitrogen source was the sub plot factor. The sub-plot treatments were completely randomized in each main plot while the main plot treatments were also completely randomized in each replication. The levels of the soil management were; continuously flooded (S_1), alternate wetting and drying (S_2), aerobic (S_3). The levels of the nitrogen source included: no nitrogen application, (control, N_0), urea fertilizer application (N_1), compost fertilizer application (N_2), and integrated compost and urea fertilizer application.

Nutrient Application and Crop Establishment

Recommended dose of Nitrogen (90kg N/ha) was applied to all the plots with the exception of the control. Urea fertilizer was split (50%) and applied at one week after transplanting as basal application, and at six weeks after transplanting (panicle primordial stage) as top-dress application. 12.8 tons of compost was broadcasted and incorporated into the soil to supply 90kg N/ha at one week before transplanting. For the integrated compost and urea treatment, 6.4 tons of compost was incorporated into the soil one week before transplanting and 45kg N/ha of urea fertilizer was applied at six weeks after transplanting (panicle primordial stage). Triple Superphosphate (P_2O_5) and muriate of potash (KCl) were applied at 45kg N/ha each on all the plots including the control at two weeks after transplanting of rice seedlings. Compost was prepared with water hyacinth (*Eichhornia crassipes)*, rice straw (*Oryza sativa* L.*),* ash, cow dung, *Leucaena leucocephala* leaves*,* and top soil. The compost had the following chemical properties; total nitrogen (0.7%), available phosphorus (0.4%), available potassium (0.5%), organic carbon (8.9%), pH (6.5) and C/N ratio (12.7). Twenty - one day old seedlings were transplanted at a planting distance of 20cm × 20cm and two seedlings were transplanted per hill.

Soil Management Systems

Polyvinyl chloride (PVC) pipes with a diameter of 3cm and a height of 60cm were perforated at 2cm apart. The perforated plastic pipes were then inserted in all the plots with the exception of the flooded soil management plots to monitor the level of water below the soil surface. A wooden rule was used to measure the level of water below and above the soil surface. For the continuously flooded soil management system, water was always kept above the soil surface from transplanting to ten days before harvest. The water level was maintained between 3cm to 5cm above the soil surface from transplanting to maximum tillering stage and then increased from 5cm to 7cm from maximum tillering stage to ten days before harvest. For the alternate wetting and drying soil management system, the plots were only flooded at 5cm above the soil surface when the level of water in the soil dropped to 25cm below the soil surface. The plots were kept moist from transplanting to booting stage in the aerobic soil management system. Water was maintained between 20cm to 25cm below the soil surface. All the irrigation treatments were flooded from booting stage to ten days before harvest.

Soil and Plant Sampling and Analysis

Soil samples from a depth of 0cm –15cm were collected before the experiment in 2015 and after harvest in 2016. The samples were air-dried, ground and sieved through 2mm mesh. Soil organic matter content percentage in the samples was determined using the Walkley & Black (1934) method, total N content by Kjeldahl digestion (Bremner, 1996), available K content (Chapman, 1965) and available P content (Bray and Kutz, 1945). Soil pH and EC were measured by using Eijkelkamp 18.21 multi-parameter analyser (Germany).

Grain and straw samples were oven dried at a maximum temperature of 70 ^{O}C to a constant weight, then ground and sieved through a 2mm mesh. The samples were analyzed for total N content using micro Kjeldahl digestion (Bremner, 1996). Shoot N uptake at harvest was calculated as the sum of N uptake in grain yield and N uptake in straw yield. Nitrogen use efficiency (NUE) was determined based on agronomic N use efficiency (ANUE) and physiological N use efficiency (PNUE). ANUE was calculated as the ratio of the difference between grain yield with N fertilization and grain yield without N fertilization to the amount of N applied. PNUE is the ratio of the difference between grain yield with N fertilization (kg) and grain yield without N fertilization (kg) to the difference between total N uptake with N fertilization (kg) and total N uptake without N fertilization (kg).

Data Collection and Statistical Analysis

Leaf area index (LAI) was calculated as the ratio of the total leaf area of the plant to the land surface area covered by the plant. Plants were selected and cut from five hills randomly in each plot at harvest and oven dried at 70^{o}C to a constant weight and their dry matter accumulation was recorded using an electronic scale. Rice straws were cut and oven dried to a constant weight and used to determine the straw yield by weighing the straws on an electronic scale. Ten plants were selected at the centre of the plot randomly and used to determine the yield components: test weight, percentage of filled grains, spikelet number per panicle and effective tillers. While grain yield was determined by weighing grains from 5m^2 at 14% moisture level. Data were also taken on chemical properties of the soil (pH, EC, OM, N, P and K), N uptake and N use efficiency (ANUE and PNUE). The data collected were subjected to Analysis of Variance using GenStat statistical software package (12th Edition). Where significant differences were observed among treatments, least significant difference (LSD) at 5% was used to separate the means.

Results

Effect of Nitrogen Sources and Soil Management Systems on Grain Yield and Yield Components of Rice.

The main effects of nitrogen sources and soil management systems significantly ($p<0.01$) influenced grain yield in both seasons (Table 3). S_1 produced the highest grain yield, followed by S_2 and S_3 soil management respectively. Nitrogen sources were ranked as: $N_3>N_1>N_2>N_0$. There was significantly ($p<0.01$) interaction between nitrogen sources and soil management systems on grain yield in both seasons. S_1N_3 and S_3N_0 treatment interactions produced significantly the highest and lowest grain yield in both seasons.

The main effects of nitrogen sources and soil management systems significantly ($p<0.01$) influenced straw yield (Table 3). S_2 produced similar straw yield as S_1 while S_3 had significantly the lowest straw yield in both seasons. Nitrogen sources followed the order: $N_3>N_1>N_2>N_0$. There was a significant ($p<0.05$) interaction between nitrogen sources and soil management systems on straw yield in both seasons. S_2N_3 treatment interaction had the highest straw yield while S_3N_0 produced the lowest straw yield in both seasons.

The main effects of nitrogen sources and soil management systems had significant ($p<0.01$) effect on harvest index in both season (Table 3). S_2 and S_3 treatments had the highest harvest index while S_1 soil management recorded significantly the lowest harvest index. Harvest index recorded under N_0, N_2 and N_3 were not significantly different from each other. Treatment N_1 however, had the significantly lowest harvest index. There was also a significant ($p<0.01$) interaction between nitrogen sources and soil management systems on harvest index. S_3N_0 and S_2N_0 treatment interactions had significantly the highest harvest index in 2015 and 2016 seasons, respectively.

Table 3: Effect of Nitrogen Sources and Soil Management Systems on Grain Yield, Straw Yield, and Harvest Index of Rice for 2015 and 2016 Seasons

Soil management systems	Nitrogen source	Grain yield (t/ha)		Straw yield (t/ha)		Harvest index (HI)	
		2015	**2016**	**2015**	**2016**	**2015**	**2016**
	N_0	3.0c	2.7d	1.4d	1.2f	0.44d	0.45c
S_1	N_1	6.5a	6.6a	2.9a	2.9bc	0.44d	0.44c
	N_2	4.6b	5.3b	2.0bc	2.4de	0.44d	0.45c
	N_3	6.7a	6.8a	3.1a	3.2ab	0.47bc	0.47b
	Average	**5.2A**	**5.4A**	**2.3A**	**2.4A**	**0.45B**	**0.45B**
	N_0	2.9c	2.6d	1.5d	1.3f	0.51a	0.49a
	N_1	6.4a	6.6a	2.9a	3.0ab	0.45d	0.45c
S_2	N_2	4.6b	5.2b	2.3b	2.5cd	0.52a	0.49a
	N_3	6.7a	6.9a	3.3a	3.4a	0.49b	0.48ab
	Average	**5.2A**	**5.3A**	**2.5A**	**2.6A**	**0.49A**	**0.48A**
	N_0	2.2d	2.0d	1.2d	1.0f	0.53a	0.48ab
	N_1	4.4b	4.5c	2.1b	2.1de	0.47bc	0.47b
S_3	N_2	3.4c	4.0c	1.7c	1.9e	0.49b	0.48ab
	N_3	4.3b	4.5c	2.0bc	2.1de	0.46cd	0.47b
	Average	**3.6B**	**3.8B**	**1.8B**	**1.8B**	**0.49A**	**0.48A**

Means followed by the same letter within a column are not significant from each other. S_1: continuously flooded soil management; S_2: alternate wetting and drying soil management; S_3: aerobic soil management; N_0: no nitrogen application (control); N_1: urea nitrogen application; N_2: compost nitrogen application; N_3: combined compost and urea nitrogen application.

Effect of Nitrogen Sources and Soil Management Systems on Plant N uptake, N use efficiency and Chemical Properties of the Soil after the Study

The main effects of nitrogen sources and soil management systems significantly ($p<0.01$) influenced plant N uptake (PNU), agronomic N use efficiency (ANUE), and physiological N use efficiency (PNUE) in both seasons (Table 4). S_1 and S_2 treatments had statistically similar PNU, ANUE and PNUE while S_3 recorded the lowest values in both seasons. N_1 and N_3 recorded similar PNU, ANUE and PNUE in both seasons. N_0 produced significantly the lowest PNU while N_2 recorded the lowest ANUE and PNUE in both seasons. The interaction between nitrogen sources and soil management systems had a significant ($p<0.01$) effect on only PNU and ANUE in both seasons. S_1N_1

and S_2N_3 treatment interactions had the highest PNU and ANUE, respectively while S_3N_0 and S_3N_3 treatment interaction recorded the lowest PNU and ANUE, respectively in both seasons.

The main effects of nitrogen sources and soil management systems as well as their interactions did not significantly ($p>0.05$) affect the chemical properties of the soil (total soil nitrogen, soil organic matter, EC, available phosphorus and available potassium) after the study in 2016. However, soil reaction (pH) was significantly ($p<0.05$) influenced by the min effect of nitrogen treatments (Table 5). The control recorded significantly the highest soil pH, followed by N1, N3 and N2 treatments, respectively.

Table 4: Effect of Nitrogen Sources and Soil Management Systems on Plant Nitrogen Uptake (PNU), Agronomic Nitrogen Use Efficiency (ANUE) and Physiological Nitrogen Use Efficiency (PNUE) of Rice for 2015 and 2016 Seasons.

Soil management systems (S)	Nitrogen Sources (N)	Plant nitrogen uptake (kg/ha)		Agronomic N use efficiency (kg/kg)		Physiological N use efficiency (kg/kg)	
		2015	2016	2015	2016	2015	2016
	N_0	47.3d	41.6d	-	-	-	-
S_1	N_1	128.4a	131.2a	37.3b	43.3a	41.3bc	43.5ab
	N_2	86.1b	102.3b	16.7d	28.9b	39.0c	42.8ab
	N_3	124.3a	130.2a	40.3a	46.6a	47.3ab	47.4a
	Average	**96.5A**	**101.3A**	**31.4A**	**39.6A**	**42.5A**	**44.6AB**
	N_0	45.3d	41.8d	-	-	-	-
	N_1	126.9a	128.5a	38.0ab	44.4a	42.7bc	46.1a
S_2	N_2	85.2b	99.7b	18.3d	28.9b	42.7bc	44.9a
	N_3	123.7a	128.3a	41.0a	46.7a	48.3a	48.6a
	Average	**95.3A**	**99.6A**	**32.4A**	**40.0A**	**44.6A**	**46.5A**
	N_0	31.6e	29.6e	-	-	-	-
	N_1	92.9b	94.1b	23.3c	27.8b	35.7cd	38.8b
S_3	N_2	68.8c	81.8c	12.3e	22.2c	32.0d	38.3b
	N_3	85.0b	93.5b	22.0c	27.8b	37.7cd	39.1b
	Average	**69.6B**	**74.8B**	**19.2B**	**25.9B**	**35.1B**	**38.7B**

Means followed by the same letter within a column are not significant from each other. S_1: continuously flooded soil management; S_2: alternate wetting and drying soil management; S_3: aerobic soil management; N_0: no nitrogen application (control); N_1: urea nitrogen application; N_2: compost nitrogen application; N_3: combined compost and urea nitrogen application.

Table 5: Effect of Nitrogen Sources and Soil Management Systems on Soil Reaction (Ph), Electrical Conductivity (EC), Organic Matter (OM), Total Nitrogen (TN), Available Phosphorus (AP) and Available Potassium (AK) after 2016 Season Harvest

Soil magt. systems	Nitrogen sources	pH (H_20) 1:1	EC (dS/m^2)	OM (%)	TN (%)	AP (%)	AK (%)
Initial value		7.88a	0.54a	2.81a	0.067a	2.09a	4.72a
	N_0	7.44a	0.68a	2.75a	0.059a	2.88a	5.13a
S_1	N_1	7.42a	0.65a	2.86a	0.073a	2.86a	5.09a
	N_2	7.29a	0.62a	3.15a	0.084a	3.04a	5.27a
	N_3	7.35a	0.64a	3.09a	0.082a	2.98a	5.24a
	Average	**7.38A**	**0.65A**	**2.96A**	**0.075A**	**2.94A**	**5.18A**
	N_0	7.51a	0.66a	2.73a	0.057a	2.86a	5.13a
	N_1	7.48a	0.64a	2.86a	0.071a	2.85a	5.07a
S_2	N_2	7.32a	0.60a	3.13a	0.082a	3.03a	5.26a
	N_3	7.39a	0.62a	3.05a	0.081a	2.96a	5.21a
	Average	**7.43A**	**0.63A**	**2.94A**	**0.073A**	**2.93A**	**5.17A**
	N_0	7.59a	0.63a	2.70a	0.054a	2.85a	5.10a
	N_1	7.54a	0.62a	2.81a	0.070a	2.83a	5.06a
S_3	N_2	7.38a	0.59a	3.13a	0.082a	3.03a	5.26a
	N_3	7.43a	0.62a	3.04a	0.081a	2.96a	5.21a
	Average	**7.49A**	**0.62A**	**2.92A**	**0.072A**	**2.92A**	**5.16A**

Means followed by the same letter within a column are not significant from each other. S_1: continuously flooded soil management; S_2: alternate wetting and drying soil management; S_3: aerobic soil management; N_0: no nitrogen application (control); N_1: urea nitrogen application; N_2: compost nitrogen application; N_3: combined compost and urea nitrogen application

Discussion

Nitrogen treatments produced significantly higher straw and grain yield than the control in both seasons and it may be due to the addition of nitrogen from the fertilizers to the plants. This is in conformity with findings from previous studies (Tadesse *et al*., 2013: Agegnehu *et al*., 2016: Ofori & Anning, 2017) that nitrogen application, increased rice grain yield. N_3 produced the highest straw and grain yield in both seasons and it may be attributed to the continuous release of nutrients from the compost to the plants as well as the instant release of N from the urea fertilizer. This is supported by Jagadeeswari & Kumaraswamy (2000) and Sarwar *et al*. (2007) who asserted that integrated organic and inorganic fertilizer application increased rice grain yield than applying the fertilizers separately. The absence of yield loss under S_2 compared with S_1 may be attributed to the fact that S_2 facilitates root growth, accelerates organic matter mineralization and inhibits soil nitrogen immobilization rate (Bouman *et al*., 2007; Dong *et al*., 2012). S_2N_3 treatment interaction had the optimum grain yield in both seasons due to the additional nitrogen from the fertilizers to the plants as well as the absence of soil water restriction from transplanting to booting stage.

Treatments with nitrogen fertilizer application had significantly higher plant nitrogen uptake (PNU) than the control. This may be attributed to the additional N from the fertilizers to the soil. This finding is in conformity with a previous studies by Ofori & Anning (2017).

N_3 produced similar PNU and nitrogen use efficiency (NUE) as N_1 and it could be due to their similar dry matter accumulation and leaf area index. N_2 had significantly lower PNU and NUE than N_1 and N_3 treatments. This could be the due to N immobilization and slow release of N from the compost to the soil (Mwale *et al*., 2000; Odlare & Pell, 2009). S_2 had similar PNU and NUE as S_1 and it may be attributed to the greater access of water and nitrogen by plant roots as a result of the improved root growth (Yang *et al*., 2009). S_1N_1 and S_2N_1 treatment interactions had the highest PNU and NUE and it may be attributed to their high dry matter accumulation as a result of the absence of water stress throughout the growth period and the additional N from the fertilizers to the soil.

Nitrogen treatments did not significantly affect the soil chemical properties after the second season. However, nitrogen fertilizer application has been reported to significantly influence soil chemical properties (Singh *et al*., 2009; Tadesse *et al*., 2013; Ding *et al*., 2016). Ding *et al.* (2016) reported a significant increase in total nitrogen, pH and organic matter content of the soil when nitrogen fertilizer was applied for 35 years. The discrepancy between the current study and the previous studies may be due to the duration of the experiment since this study was conducted for only two seasons. Soil management systems did not significantly affect the soil chemical properties after the study. This may be due to the flooding of all the treatments continuously from booting stage to ten days before harvest.

Conclusion

Results from the study revealed that continuous flooding the soil throughout the plant cycle (S_1) did not significantly increase grain yield, plant N uptake and N use efficiency. Maintaining soil moisture content between field capacity and permanent wilting point from transplanting to booting stage (S_3) also significantly reduced grain yield, plant N uptake and N use efficiency. The solely application of compost (N2) significantly reduced grain yield, plant N uptake and N use efficiency. However, the integrated compost and urea fertilizer application (N_3) improved the chemical properties of the soil marginally and produced the highest grain yield and N use efficiency. Thus, compost should not be applied alone but it should be supplemented with a chemical fertilizer to have a positive effect on rice yield, N use efficiency as well as the chemical properties of the soil. Integrated compost and urea fertilizer application, and alternate wetting and drying soil management system produced the highest grain yield, N use efficiency as well as improved the chemical properties of the soil marginally. Crop residues left after harvest should be composted and used to improve soil chemical properties overtime, increase rice productivity as well as reduced the urea fertilizer input.

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