Influence of Composted Organic Waste and Urea Fertilization on Rice Yield, N-Use Efficiency and Soil Chemical Characteristics

J. Ofori[1] and D. K. Anning[2]
[1] *Soil and Irrigation Research Centre, University of Ghana*
[2] *School of Graduate Studies, University of Ghana*
Corresponding author's email: *oforijos@yahoo.com*

Abstract

Nutrient mining in rice-rice cropping system due to inadequate amount of chemical fertilizer applied is one of the reasons for low rice yield in Ghana. To address this challenge, a field trial was initiated to determine the best nutrient management option to improve yield of rice and soil fertility. The field experiment was conducted at the University of Ghana's Soil and Irrigation Research Centre - Kpong during 2014 and 2015 cropping seasons to evaluate the influence of composted organic waste and urea fertilization on rice yield, Nitrogen-use efficiency and soil chemical characteristics. The study was laid out in a randomized complete block design (RCBD) with three replications and six treatments as follows; N1: Control (no nitrogen application), N2: 100% N from compost, N3: 50% N from compost + 50% N from urea, N4: 70% N from compost + 30% N from urea, N5: 30% N from compost + 70% N from urea, N6: 100% N from urea. N fertilization through compost or urea increased grain yield, yield components, N uptake, N use efficiency and also improved the chemical properties of the soil than the control. Although grain yield under 100% Urea N, and combination of compost N + Urea N at ratio of 50:50 and 30:70 were at par, the soil chemical property significantly improved through integrated compost- urea application. The study indicated that substituting 30 or 50% of the required urea N with the same amount of N through compost improved both soil chemical property and rice yield.

Introduction

Nitrogenous Fertilizer (N) has become the key input in food production worldwide. Cereals (rice, wheat, maize, millet, etc.) account for more than half of the total N fertilizer consumption in the world, and approximately 50 – 70% more cereal grain will be required by 2050 to feed over 9 billion world population (Wise, 2013). This will further increase demand for N fertilizer at greater magnitude unless the N fertilizer recovery efficiency in cereals is improved through better production technologies.

Increasing cropping intensity with modern rice varieties in irrigated rice farming system in Ghana, has enhanced nutrient mining from the soil because nutrient removal has exceeded annual replacement, even if the national recommended fertilizer doses are applied. Long-term studies done by Bhandari *et. al.* (2002) attributed the reduced productivity of the rice system to declining soil organic matter (SOM), decreased soil fertility, and occurrence of nutrient imbalances. The cultivation of rice under continuously flooded conditions for several years, hinder the decomposition of organic matter (Cassman *et al.* 1995). Hence less nitrogen and other nutrients are released to the plants. Therefore, to maintain the required yield, that larger amount of manures and fertilizers must be added. Adding organic matter to the paddy soil may increase the soil fertility. And as far as plant nutrition is concern, organic matter can be critical in the supply of nitrogen, sulphur and micronutrients to the rice plant. These are released in plant available form as the organic matter mineralizes (Greenland,1997).

The potentiality of organic waste in crop production systems is very limited due to its slow release of plant nutrient to synchronize with crop demand a particular stage of growth. Only one fifth to half of the nutrient supplied from manure was recovered in the first year and the rest released gradually to succeeding crops, thus showing residual effect of OM application (Miah, 1994). However, Eghball *et al.* (2004) asserted that residual effect of N- and P-based manure and compost application on corn yield and N uptake can last at least one growing season, while Dick (1992) stated that long term cultivation without the application of organic fertilizers decreased organic carbon and total N contents of the soil. Moreover, the incorporation of compost into the soil increases the soil organic carbon content (Xin *et al*. 2016).

This present study was, therefore, conducted to evaluate the influence of various combinations of composted organic waste and chemical nitrogen fertilizer on grain yield, nitrogen-use efficiency and soil chemical characteristics of irrigated rice.

Materials and methods

Descriptions of the experimental site

A field experiment was conducted at the Soil and Irrigation Research Center – Kpong of the University of Ghana, during 2014 minor and 2015 major cropping seasons. The centre is located within the lower Volta basin of the Coastal Savannah agro-ecological zone on latitude 6° 09' N, longitude 00° 04' E, and at an altitude of 22 m above mean sea level. The site experiences a bi-modal seasonal rainfall distribution with an annual precipitation of about 1200 mm and a mean annual temperature of 27.2 ^{o}C. The soil at the experimental site is a black clay (vertisol) and the chemical properties of the soil presented in Table 1.

TABLE 1

Chemical properties of the soil at the beginning of the experiment in August, 2014

Depth (cm)	*TN (%)*	*AP (%)*	*AK (mg kg^{-1})*	*Ca (mg kg^{-1})*	*Mg (mg kg^{-1})*	*pH in H_2O 1:1*	*OM (%)*	*C/N ratio*	*ECd S/m*
0 - 20	0.07	1.97	2.34	22.8	1.26	7.8	1.55	24.3	0.76

TN – Total nitrogen; AP – available phosphorus; AK – available potassium; Ca – calcium; Mg – magnesium; pH – power of hydrogen; H_2O – water; OM – organic matter; C/N – carbon and nitrogen ratio; EC – electrical conductivity

Experimental design and field management

The experiment was laid out in a randomized complete block design (RCBD) with three replications and six treatments as follows: N1: Control (no nitrogen application), N2: 100% N from compost, N3: 50% N from compost + 50% N from urea, N4: 70% N from compost + 30% N from urea, N5: 30% N from compost + 70% N from urea, N6: 100% N from urea. All the treatments, except the control, received the recommended dose of N (90 kg N/ha) through different plant nutrient sources. Triple Superphosphate (P_2O_5) and muriate of potash (K_2O) were applied at 45 kg N/ha each on all the experimental units as basal application at a week after transplanting of seedlings. Plot size of 4 m × 5 m was measured out with 2 m interval between the plots and 3 m between replications. The field was ploughed and puddled after which the mature compost was incorporated as per treatment a week before 21-day old seedlings (Ex Baika variety*)* were transplanted at spacing of 20 cm × 20 cm. Weeds were controlled by the application of pre-emergence (Stomp) and post-emergence (propanil + 2,4 –D) herbicides. Grain yield was determined from 12 m^2 area after removing the border rows in each experimental unit. The harvested produce was threshed manually and grain yield was expressed as t/ha at 14% grain moisture. Twenty-five plants were selected at the center of the plot randomly and used to determine the yield components: test weight, percentage of filled grains, spikelet number per panicle and effective tillers. Harvest index was calculated as the ratio of grain yield to total biological yield.

Soil sampling and analysis

Soil samples from a depth of 0–20 cm were collected before the experiment in 2014 and after harvest in 2015. The soil samples were air-dried and ground and passed through 2 mm sieve. Percentage of organic matter content in the soil was determined using the Walkley and Black (1934) method, total N content by Kjeldahl digestion (Nelson and Sommers, 1982), total K content (Watson *et al*., 1990) and available P content (Mills and Jones, 1996). Soil pH and EC were measured by using Eijkelkamp 18.21 multi-parameter analyzer (Germany).

Plant sampling and analysis

Grain and straw samples were oven dried at a temperature of 70 °C to a constant weight, then ground through a 2 mm sieve. The samples were analyzed for total N content using micro Kjeldahl digestion (Nelson and Sommers,1982). Total N uptake at harvest was calculated as the sum of N uptake in grain and 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 application and grain yield with no N application to the amount of N applied. Physiological efficiency is the ratio of the difference between grain yield with N application (kg) and grain yield with no N application (kg) to the difference between total N uptake with N application (kg) and total N uptake with no N application (kg). Mathematically they were calculated as below;

$$\text{ANUE} = \frac{\text{Grain yield with N application} - \text{Grain yield with no N application}}{\text{Amount of N applied}}$$

$$\text{ANUE} = \frac{\text{Grain yield with N application} - \text{Grain yield with no N application}}{\text{Total N uptake and N application} - \text{Total N uptake and no N application}}$$

Data analysis

Data collected were subjected to analysis of variance using GenStat statistical software package (12th edition). Where significant differences were observed among the treatment means, least significant difference (LSD) at 5% probability level was used to separate the means.

Result

Effect of compost and urea fertilizer on grain yield and yield components

Nitrogen fertilizer application significantly ($P < 0.05$) increased grain yield in both seasons (Table 2). Grain yield was higher in 2015 cropping season than in 2014 with the exception of the control. N6 and N5 treatments produced the highest grain yield in 2014 and 2015 seasons, respectively. However, N3 treatment produced similar grain yield as N6 and N5 in both seasons. Grain yield ranged from 2.4 t/ha to 5.7 t/ha in 2014 cropping season and 2.0 t/ha to 5.8 t/ha in 2015 cropping season. The control produced significantly the lowest grain yield in both seasons.

TABLE 2

Effect of compost and urea fertilizers on panicles per m², spikelets per panicle, 1000 seeds weight, percentage of filled grains and grain yield

Year	*Treatment*	*Panicles Per m²*	*Spikelets per panicle*	*1000 grains weight*	*Filled grains(%)*	*Grain yield (t/ha)*
2014	N1	183c	96c	25.1a	87.5a	2.4d
	N2	200c	103c	25.7a	93.5b	3.2c
	N3	363ab	122a	25.3a	94.7b	5.1a
	N4	342b	115b	25.3a	91.8b	3.9b
	N5	373a	123a	26.6a	92.7b	5.4a
	N6	381a	120a	25.9a	86.9a	5.6a
2015	N1	178d	91d	25.4a	89.1ab	2.1d
	N2	265c	104c	26.3a	92.6bc	3.9b
	N3	376ab	124a	26.0a	93.4c	5.6a
	N4	3480b	116b	25.5a	90.6b	4.5b
	N5	383a	126a	25.7a	90.9b	5.9a
	N6	380a	124a	26.1a	86.5a	5.7a

N1: Control, N2: 100% compost, N3: 50% compost + 50% urea, N4: 70% compost + 30% urea, N5: 30% compost + 70% urea, N6: 100% urea, PI: panicle initiation stage. Means followed by the same letter in a column within a year are not significant (P>0.05).

There was a significant ($P < 0.01$) effect of N fertilizer application on panicles per m^2 in both seasons (Table 2). Panicles per m^2 ranged from 183 to 381 in 2014 and 178 to 383 in 2015. N6 and N5 treatments produced the highest panicle per m^2 in both 2014 and 2015 cropping seasons, respectively. N3 treatment produced similar panicles per m^2 as N5 and N6 treatments in both seasons. The control produced significantly the lowest panicles per m^2 in both seasons. N2 produced similar panicles per m^2 as the control (N1) in 2014, however it differed significantly from N1 in 2015 cropping season.

Spikelet number per panicle was significantly ($P < 0.01$) influenced by N fertilizer application in both cropping seasons (Table 2). Spikelet number per panicle ranged from 96 to 123 in 2014 cropping season and 91 to 126 in 2015 cropping season. N5 treatment produced higher spikelet number per panicle than N3 and N6 treatments, however these treatments did not differ significantly from each other. The control produced significantly the lowest spikelet number per panicle in both seasons. Spikelet number per panicle was marginally higher in 2015 than in 2014 cropping season.

The effect of N fertilizer application on 1000 grains weight was not significant ($P > 0.05$) in both seasons. 1000 grains weight ranged from 25.1 g to 26.6 g in 2014 and 25.4 g to 26.3 g in 2015. The control produced the lowest 1000 grains weight in both 2014 and 2015 cropping seasons.

Percentage of filled grains was significant ($P < 0.05$) affected by N fertilizer application in both seasons (Table 2). Percentage of filled grains ranged from 86.9 to 94.7% in 2014 and 86.5 to 93.4% in 2015. N6 treatment produced similar percentage of filled grains as the control, however these treatments had significantly lower percentage of filled grains than the compost (N2, N3, N4 and N5) treatments in both cropping seasons. Compost treatments did not differ significantly from each other in 2014, however N3 treatment differed significantly from N4 and N5 in 2015 season. N6 treatment had the lowest percentage of filled grains in both seasons.

Effect of compost and urea fertilizer application on plant N uptake and N use efficiency

N fertilizer application significantly ($P < 0.05$) increased plant N uptake (PNU) in both seasons (Table 3). Plant N uptake ranged from 41 to 113 in 2014 and 38 to 122 in 2015. Plants grown in 2015 season had higher PNU than plants grown in 2014 season except the control. N6 had significantly a higher PNU than the other treatments in both seasons except N5 in 2015 season. The control had significantly the lowest PNU in both seasons.

N fertilizer application had significant ($P < 0.05$) effect on agronomic N use efficiency (ANUE). ANUE ranged from 8.8 to 35.4 in 2014, and 20 to 42.2 in 2015 season (Table 3). ANUE in 2015 was marginally higher than that of 2014. N3 had similar ANUE as N5 and N6, however these treatments were significantly higher than the other treatments in both seasons. N2 had the significantly the lowest ANUE in both 2014 and 2015 seasons

TABLE 3

Total N uptake and N use efficiency under compost and urea fertilizer treatments

Year	*Treatment*	*TNU*	*ANUE*	*PNUE*
2014	N1	41d	–	–
	N2	75c	8.8c	23.2c
	N3	98b	30a	47.4a
	N4	79c	16.7b	39.5b
	N5	104b	33.3a	47.6a
	N6	113a	35.6a	44.4ab
2015	N1	38e	–	–
	N2	90d	20.0b	32.7b
	N3	113b	39.3a	45.4a
	N4	101c	26.7b	36.4b
	N5	119ab	42.2a	45.2a
	N6	122a	40.0a	41.4a

N1: Control, N2: 100% compost, N3: 50% compost + 50% urea, N4: 70% compost + 30% urea, N5: 30% compost + 70% urea, N6: 100% urea. TNU: total N uptake, ANUE: agronomic N use efficiency, PNUE: physiological N use efficiency. Means followed by the same letter in a column within a year are not significant ($P > 0.05$)..

N fertilizer application had significant ($P < 0.05$) effect on physiological N use efficiency (PNUE) in both seasons (Table 3). PNUE ranged from 23.2 to 47.6 kg/kg in 2014, and 22.7 to 45.4 kg/kg in 2015 season. PNUE in 2015 was marginally higher than that of 2014. N3 recorded similar PNUE as both N5 and N6, however these treatments were significantly higher than the other treatments (N2 and N4) in both seasons. N2 recorded significantly the lowest PNUE in both seasons.

Effect of compost and urea treatments on some chemical properties of soil after 2015 harvest.

N fertilizer application significantly ($P < 0.05$) decreased soil EC (Table 4) and ranged between 0.57 and 0.72 and were all lower than the value before the initial trail in 2014 season. N4 had significantly the lowest EC while N1 recorded the highest EC value.

N fertilizer application had significant ($P < 0.05$) effect on soil pH (Table 4). Soil pH ranged from 7.62 to 7.75. Compost

TABLE 4

Effect of compost and urea fertilizer treatments on some chemical properties of soil after harvest in 2015.

Treatment	*EC(dS/m)*	*pH:$H_2$01:1*	*Organic Matter (%)*	*P (ppm)*	*K (ppm)*	*N (%)*
N1	0.72a	7.72bc	1.33a	0.04a	2.01a	2.37a
N2	0.65b	7.67ab	1.78d	0.14b	2.29a	2.63b
N3	0.63b	7.62a	1.66c	0.12ab	2.18a	2.55b
N4	0.57c	7.70bc	1.74d	0.13ab	2.23a	2.59b
N5	0.64b	7.64a	1.62bc	0.10ab	2.13a	2.44a
N6	0.63b	7.75c	1.57b	0.08a	1.99a	2.38a
Initial	**0.76**	**7.80**	**1.55**	**0.07**	**1.97**	**2.34**

N1: Control, N2: 100% compost, N3: 50% compost + 50% urea, N4: 70% compost + 30% urea, N5: 30% compost + 70% urea, N6: 100% urea.EC: electrical conductivity, pH: power of hydrogen, AN: available nitrogen, AP: available phosphorus, AK: available potassium. Means followed by the same letter in a column within a year are not significant ($P > 0.05$).

incorporation treatments recorded lower pH than the other treatments (N1 and N6).

The effect of N fertilizer application on soil organic matter was significant ($P < 0.05$). N fertilized treatments improved organic matter as compared to the initial amount before experiment in 2014 (Table 4). The control had a reduction in organic matter as compared to the initial organic matter content in the soil. Organic matter ranged from 1.33 to 1.78. N3 and N4 treatments had a similar organic matter which was significantly higher than the other treatments. The control had significantly the lowest soil organic matter.

The effect of compost and urea fertilizer increased available K significant ($P < 0.05$). All the treatments increased available K when compared with the initial (Table 4). Compost treated soils had higher available K content than the soils without compost incorporation. N2 and N1 had the highest and the lowest available K, respectively.

There was no significant ($P > 0.05$) effect on available P (Table 4) when either compost or urea or their combinations were applied. However, they were marginally higher than initial value in 2014. Compost treatments had higher available P than the other treatments. The control also recorded higher available P than the sole urea treatment marginally.

N fertilizer application had significant ($p<0.05$) effect on soil total N (Table 4) which ranged from 0.04 to 0.14%. All the treatments increased available N except the control. N2 treatment recorded the highest total N while the control recorded the lowest significantly. Compost treated soils had higher total N than the sole urea treated soil.

Discussion

Effect of compost on rice yields and yield components

N fertilization increased grain yield when compared to the control in both seasons due to the additional N from the fertilizers to the soil. The added N from the fertilizers increased the spikelets per panicle and panicles per m^2 and consequently increased the grain yield. This finding is in conformity with Das *et al*, (2010), Rahaman and Singh (2013) and Tadesse *et al.*(2013) who asserted that N fertilizer application increase rice yield and yield components. Treatments with compost incorporation had higher percentage of filled grains than the urea treatment and the control due to the release of N to the plants during grain filling stage as a result of their continuous release (Mwale *et al*, 2000). Nitrogen fertilization did not affect 1000 grains weight in both seasons and it could be attributed to the fact that it is a genetic trait and it is less influenced by environment (Yoshida,1981). This outcome is in line with previous studies that, 1000 grains weight is not much affected by the application of nitrogen fertilizer (El-Refaee *et al.*2007; Mannan *et al,* 2012). N6 treatment produced the highest rice yield (5.6 t/ha) in 2014 season, whiles the best yield (5.9 t/ha) was recorded under N5 in 2015 season. The yield improvement of rice in 2015 over the previous year could be due to improvement of the soil properties by the compost and positive residual effect caused by the gradual mineralization of plant nutrients (Ebid, 2008). N3 treatment had similar grain yield as N5 and N6 treatments due to their similar grains per panicle and panicles per m^2 in both seasons. N2 produced the lowest grain yield among the N fertilized treatments and it could be attributed to the slow mineralization and immobilization of N from the compost to plants (Odlare and Pell, 2009). This is in conformity with Bar-Tat *et al*. (2004) who stated that compost incorporation has a positive effect on crops when it is combined with an inorganic fertilizer. Mugendi *et al.* *(*1999) also found that the rate of decomposition and mineralization of organic fertilizer increased when it was combined with an inorganic fertilizer.

Effect of compost and urea fertilizer application on total plant N uptake and N use efficiency.

Nitrogen fertilizer treatments had higher total N uptake than the control and it could be due to the additional N from the fertilizer to the soil. This is in conformity with previous studies that nitrogen fertilizer application increase plant N uptake (Bejbaruha *et al* (2009); Rahaman and Sinha 2013). Among the nitrogen fertilizer treatments, N6 produced the highest plant N uptake and it could be attributed to its instant release of nitrogen to the plants (Bejbaruha *et al*. 2009). N5 (30% N Compost + 70% N Urea) treatment had similar total N uptake as N6 (100% N Urea) treatment in 2015 season and it might be due to the gradual improvement of the soil properties by the compost application in previous season and the increased in the mineralization of N as a result of the addition of urea fertilizer to the compost (Mugendi *et al,* 1999). The relatively low N uptake recorded from N2 (100% N from compost) could be attributed to the immobilization and slow mineralization of N from the compost to plant roots (Mwale *et al* 2000; Odlare and Pell 2009). N3, N5 and N6 treatments had the highest N use efficiency (ANUE and PNUE) in both seasons, which could be attributed to adequate release of N for uptake leading to production of similar grain yield.

Effect of compost and urea treatments on the chemical properties of soil after 2015 cropping season.

N fertilization increased the concentration of total nitrogen, available phosphorus, available potassium and organic matter of the soil when compared to their initial concentrations before the experiment in 2014. N2 treatment recorded the highest concentrations of total N, available P, available K and OM. This observation could be due to relatively higher amount of compost incorporated into the soil and also gradual and steady mineralization of plant nutrients. All the treatments were applied with the same rate of available P and available K, however treatments with compost incorporation had higher total N, available P, available K and OM concentrations in the soil than the control and N6 treatments, and it could be due to the addition of these elements from the compost into the soil (Tedasse *et al,* 2013). The incorporation of compost into the soil increases the number of microorganisms responsible for mobilization and mineralization of N in the soil (Tolanur and Badanur 2003; Ahmed *et al. 2006*). N6 treatment had similar total N, available P, and available K, and organic matter concentrations as the control and it could be due to the fact that inorganic fertilizers do not had significant residual effect on soil properties (Eghball *et al,* 2004; Haefele *et al,* 2004; Tadesse *et al,* 2013). All the treatments decreased in soil pH and EC after the experiment when compared to the initials values and it could be due to the continuous submergence of the treatments to ten days before harvest. Submergence brings the soil pH to neutral due to the accumulation of carbon dioxide as a result of the absence of oxygen in such condition (Ponnamperuma 1984).

Conclusion

Compost has been receiving much attention due to its ability to maintain or improve soil health. Results from the study revealed that, the application of compost as a sole plant nutrient source significantly improved the chemical properties of the soil but not much grain yield during the two seasons of the trial. Applying urea fertilizer alone increased rice yield, nevertheless it did not have any significant effect on the soil chemical properties. The combination of compost and urea fertilizer increased grain yield and also improved significantly the chemical properties of the soil. The study therefore recommends the combined application of compost N and urea N at a ratio of either 50 : 50 or 30 : 70 to farmers for sustainable production of rice, particularly, in irrigated rice ecology.

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