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Full Length Research Paper

Effect of nitrogen rates on the growth and yield of three rice (*Oryza sativa L.*) varieties in rain-fed lowland in the forest agro-ecological zone of Ghana

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Nitrogen is not only a major nutrient but most often the most limiting nutrient element in lowland ecologies. With the introduction of improved soil and water management ('sawah system) for lowland rice production, a study was conducted to determine the optimum nitrogen rate required. A randomized complete block design arranged in a split plot consisting of five levels of nitrogen as main treatments and three improved rice varieties as sub-treatments was adopted. Results showed that total number of tillers per m^2 increased significantly with increasing levels of N as was total dry matter production. However, total number of panicles did not show the same relationship. Total biomass yield increased significantly and linearly with increasing levels of N. Paddy yield significantly increased from 1.7t ha^{-1}(control) to a maximum of 9.4t ha^{-1} (90kgN ha^{-1}) before declining to 5.8 t ha^{-1} (150kgN ha^{-1}) in the order: 0 < 30 < 60 < 150 < 120 < 90kgN ha^{-1}respectively. This result significantly and positively reflected on grain harvest index (GHI) in the order: 0.27 < 0.38 < 0.46 < 0.47 < 0.57 < 0.68 for 0, 30, 60, 150, 120 and 90kgNha^{-1}respectively. Nitrogen at 90 kgN ha^{-1}was therefore recommended.

Key words: Forest agro-ecology, Ghana**,** rain-fed lowland, nitrogen fertilization, yield.

INTRODUCTION

Poor and declining soil fertility remains the most important biophysical (abiotic) stress that accounts for the decline in agricultural productivity particularly in rice growing environment in Sub-Saharan Africa and in Ghana in particular (Sanchez et al. 1997; Issaka et al., 1996; 1997, 2008; Senayah et al., 2008; Buri et al., 1999, 2000, 2009, 2010, 2011; Abe et al., 2010). Another notable and critical factor contributing to low agricultural productivity especially rice in Ghana is the low use of fertilizers (Buri et al., 2010; IFDC,2012). In highly weathered soils with low clay content and low activity clay minerals (Abe et al 2010) as those of West Africa including Ghana, technology development for increased and sustainable nutrient management under improved soil and water management are very paramount. In Ghana where over 80% of rice farmers are poorly resource, rice production levels will continue to be low unless technology development for increased and efficient use of inputs such as fertilizer is critically and urgently promoted.

Rice consumption has been on the increase in Ghana over the past few decades. According to the Ministry of Food and Agriculture, Ghana (MoFA 2010), rice has become the second most important staple food after maize and its consumption keeps increasing. This has led to large annual imports of the crop as production constantly falls short of demand. On the average, annual rice import for Ghana is about 400,000 tons. The self-sufficiency ratio of rice in Ghana declined from 38% in

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1999 to 24% in 2006. Rice yields in Ghana average about two tons per hectare due to inherent poor soils and improper soil management practices (Senayah et al., 2008; Buri et al., 2009, 2004). With a potential available lowland area of over 700,000 ha, rice is cultivated across all the agro-ecological zones of Ghana. However, there are significant differences in the production potential (area available and suitability) among these ecosystems due to differences in soil, climate and economic conditions.

The Equatorial Forest zone has a comparative advantage due to its good rainfall and better water availability. While the impact of fertilizer use for crop production is considered large in regions of extremely low soil fertility (particularly N and P) the application of chemical fertilizer to crops in Ghana is one of the lowest in West Africa (FAO, 2011, Buri and Issaka, 2010). Rice is grown within the zone with very little or no application of mineral fertilizers. There are also no structures put in place to manage water. Efficiency of applied fertilizer is therefore very low due to poor water control. With the recent introduction of improved soil and water management, framers 'yield of at least 4.0tha^{-1} is ensured (Buri et al., 2004; Issaka et al., 2008). However, for higher yields and improved/sustained productivity, mineral fertilization is necessary. Previous studies have shown that rice response to mineral fertilization in these lowlands (Buri et al., 2008). Hence, for site specific management and the bulk of rice growers being resource poor small-scale farmers, it is necessary to develop technologies (optimum levels of critical nutrients such as nitrogen) that are easily transferrable and adaptable.

MATERIALS AND METHODS

Location: Field experiments were conducted in a rain-fed lowland located near the CSIR-Soil Research Institute (SRI), Kumasi, in the Forest agro-ecological zone of Ghana. The site lies on Latitude 6^{o}"40'59" and Longitude 1^{o} 37' 0". It is a narrow but very long wet valley that runs several kilometers but measures less than 300m across with water being available throughout the growing season.

Land preparation and experimental design: The site was initially slashed and vegetative cover removed. The area was then ploughed using a power tiller. The ploughed site was demarcated into four main blocks through the construction of bunds. Each block was divided into six (6) main plots using major bunds (100cm wide and 50cm high). The experimental design was a randomized complete block in a split plot arrangement. Nitrogen rates formed the main treatments. Viz: F_1 (0kgN ha^{-1}); F_2 (30kgN ha^{-1}); F_3 (60kgN ha^{-1}); F_4 (90kgN ha^{-1}); F_5 (120kgN ha^{-1})and F_6 (150kgN ha^{-1}). Rice variety formed the subplot treatment. Each main plot was again sub-divided to three (3) plots, each measuring 2m x 2m for the three rice varieties (Sikamo, Jasmine 85, Marshall). Each sub-plot was then puddled and manually levelled. A composite soil sample (0-30cm) was collected from the site for laboratory analysis before land preparation.

Transplanting: Three weeks old rice seedlings were transplanted to their respective plots using the specified varieties. Spacing adopted was 20cm x 20cm at two seedlings per hill.

Mineral fertilizer application: A uniform level of 60kg $P_2O_5ha^{-1}$ as Triple Super Phosphate,60kgK_2Oha^{-1} as Muriate of Potash and 50% N using Urea was applied to each sub-plot immediately after transplanting as basal fertilization. The remaining 50% N was applied 5 weeks after transplanting.

Weed control: Weed control was manual mainly by hand picking. Crop growth was then monitored until harvest.

Soil Analysis: Soil sample was air dried at room temperature. Dried sample was 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 and determined by atomic absorption spectrometry (Thomas 1982). Sodium and potassium contents in the extract were determined by flame photometry while calcium and magnesium were by atomic absorption spectrophotometry. 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).

Growth characteristics: Number of tillers was counted after maximum tiller formation stage and mean number of tillers determined while plant height was measured at harvest.

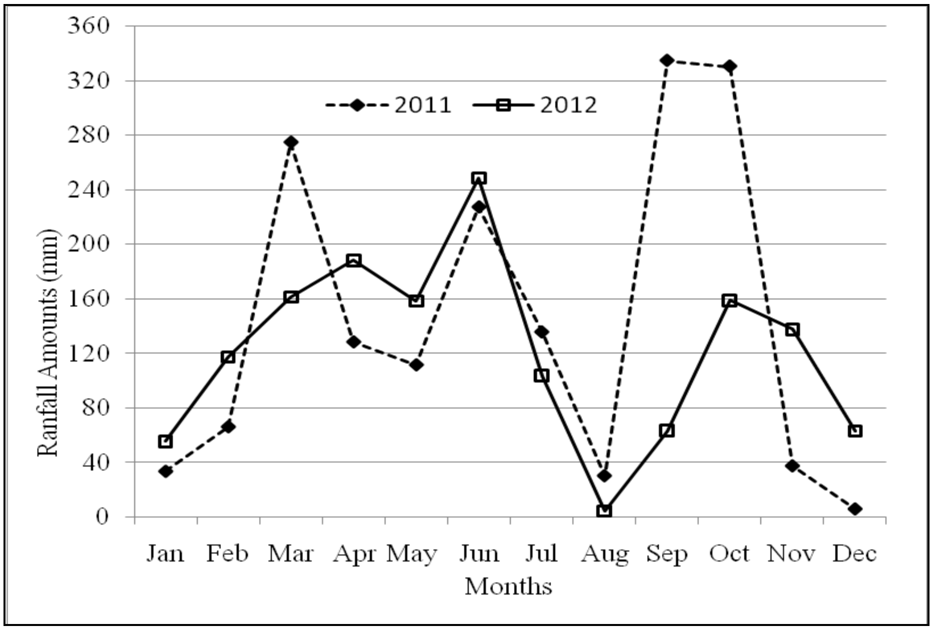
Yield characteristics: At maturity, an area of $1m^2$ excluding border rows was measured out in each sub-plot, number of panicles counted and harvested. Grain and Stover yield were measured and yield per hectare estimated. Panicles were also collected from non-border rows and mean individual weight per panicle determined. The weight of 1000 grains was measured using an electronic balance. Grain harvest index (GHI) was calculated as ratio of grain yield to total yield (grain + stover).

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

The Forest agro-ecological zone has a bi-modal rainfall pattern (Fig. 1) and therefore has two main cropping seasons (major and minor). The major season has its peak rainfall in June-July while that of the minor is in September-October. The ecology has a comparative advantage over other ecologies due to its good rainfall

Figure 1. Rainfall amounts and distribution during the experimental period.



and higher water availability throughout a greater part of the growing season. The physico-chemical properties of the soils of the site are shown in Table 1. The site which is typical of lowlands is low in inherent fertility and poor in plant nutrients particularly total Nitrogen (N) and available phosphorus (P). The texture was loam with low clay content. Under such low levels of fertility,
improved/efficient nutrient management is critical if higher rice yields are to be obtained and increased/sustained total productivity is to be achieved.

Effect of Non growth parameters

Number of tillers m^{-2}: The number of effective tillers produced is a good indicator as it is a major determinant of yield. Tiller number increased with increasing N levels but the increased was more pronounced from 0kg N to 30kg N than from 30 to 60, 60 to 90, 90 to 120 and 120 to 150 kgN ha^{-1} (Table 2). Generally, total number of tillers per m^{-2}significantly increased by 53%, 70%, 72%,77% and 103% over the control for 30, 60, 90, 120 and 150kgN ha^{-1} respectively. There was also a corresponding increase in total dry matter production with increasing levels of N. However, paddy yield did not show a similar trend with increasing levels of N. At higher levels of N (>90kg ha^{-1}), more tillers tended to be unproductive resulting in lower paddy yield. There were also no significant differences in number of effective tillers produced in the variety x N rate interaction in line with an observation earlier made by Kamara et al (2011) who noted that interactions between N and variety were not significant for all measured traits for four lowland NERICA varieties in Nigeria.
(Table 2)

Plant height: Plant height was significantly affected by N application (Table 3). Plant height was similar for 0kg N ha^{-1} and 30kgNha^{-1} levels but significantly shorter than for 60, 90, 120 and 150kg N ha^{-1}. The initial nutrient levels were probably good enough to produce plants of similar height to 30kg N ha^{-1}. Nitrogen is a major contributor to crop growth, size and total dry matter production. The increase in height with increasing levels of N could not be explained better. While Ethan et al (2011) in a similar study in Bida, Nigeria observed that there were significant increases in plant height with increasing levels of N when compared with the control, Memory et al (2013), however, reported that there were no significant differences in N rates x variety interaction while significant N effects were only found in plant height. In this study, comparing the three varieties, Sikamo and Jasmine 85 had similar plant heights which were significantly taller than Marshall. Two varieties (Sikamo and Jasmine 85) interacted with 60kg N ha^{-1}level and above to give significantly taller plants. Similar taller plants were also observed when Marshall interacted with 60kg N ha^{-1} level and above. Generally when N was not applied, plants were significantly shorter (Table 3).

Effect of Nitrogen on Yield Parameters

Total biomass*:* The total biomass (straw + grain) increased with increasing levels of N (Table 4). Total biomass increased from 9.9t ha^{-1}at 0 kg N ha^{-1} to a maximum

Table 1. Physico-chemical properties of soils of the experimental site.

Parameter	Units	Level
pH (water)	-	7.0
Total Carbon (TC)	g kg^{-1}	21
Total Nitrogen (TN)	g kg^{-1}	2.3
Available Phosphorus (P)	mg kg^{-1}	5.4
Exchangeable Potassium (K)	cmol (+) kg^{-1}	0.24
Exchangeable Calcium (Ex. Ca)	cmol (+) kg^{-1}	7.5
Exchangeable Magnesium (Ex. Mg)	cmol (+) kg^{-1}	3.6
Exchangeable Sodium (Ex. Na)	cmol (+) kg^{-1}	0.1
Exchangeable Acidity (Ex. Acid.)	cmol (+) kg^{-1}	0.1
Effective Cation Exchange Capacity (eCEC)	cmol (+) kg^{-1}	11.54
Clay	g kg^{-1}	80
Silt	g kg^{-1}	620
Sand	g kg^{-1}	300

Table 2. Effect of the interaction of Nitrogen levels and rice varieties on number of tillersm^{-2}.

Nitrogen rate (kg ha^{-1})	**Rice Variety**			
	Sikamo	**Jasmine 85**	**Marshall**	**Mean**
0	218	198	232	216
30	303	358	333	331
60	368	377	358	368
90	385	370	368	374
120	383	410	355	383
150	440	407	475	440
Mean	350	353	354	

LSD (0.05): Fertilizer = 86
LSD (0.05) Variety = 36
LSD (0.05) Fertilizer x Variety = 112

of 18.5t ha^{-1}at150kg N ha^{-1}. At N rates of 30, 60 and 90 kg N $ha^{-1,}$ biomass yields were significantly higher than 0 kg N ha^{-1}. At higher N rates of 120 and 150 kg N ha^{-1} significantly higher biomass yields were produced. Total biomass increased by 4.0, 5.4, 6.1, 8.4 and 8.6 tha^{-1} over the control for 30, 60, 90, 120 and 150 kgN ha^{-1} respectively. Between varieties, total biomass production for Sikamo was similar to Jasmine 85 but significantly higher than Marshall. Effect of both N and variety interaction showed that Sikamo at 120 and 150 kg N ha^{-1} gave significantly higher biomass than Sikamo or Jasmine 85 fertilized at 0 or 30 kg N ha^{-1}. Marshall fertilized from 0 to 90 kg N ha^{-1}produced lower total biomass than both Sikamo and Jasmine 85.Generally Sikamo and Jasmine 85 were taller than Marshall (Table 2) and higher N rates had more tillers than the control (Table 3). This largely explains the observed differences in biomass production. Ethan et al (2011) while looking at the effect of water management and N rates in a similar study reported that there were significant differences in straw and grain yield in other treatments compared with the control. According to the authors yield and N use efficiency generally increased with increasing levels of N but declined at 80kg N ha^{-1}. In this study, while total biomass increased with increasing levels of N up to 150kgN ha^{-1}, grain yield declined after 90kg N ha^{-1}. After 90kg N $ha^{-1,}$ further N addition seemed to contribute more to vegetative growth (greater straw production) at the expense of reproductive growth (grain production).

Mean panicle weight*:* The mean weight of individual panicles was determined for each level of N applied (Fig. 2).Panicle weight was significantly affected by N application. Lowest individual panicle weights (< 3.0g $panicle^{-1}$) were obtained under the control where N was not applied. Individual panicle weight increased significantly (> 4.0g $panicle^{-1}$) with 30kgN ha^{-1} additions, rising to above 5.0g per $panicle^{-1}$at 90 and 120 kgN ha^{-1}. Significantly lower panicle weights were recorded at 150

Table 3. Effect of the interaction of Nitrogen levels and rice varieties on plant height (cm).

Nitrogen rate (kg ha^{-1})	**Rice Variety**			
	Sikamo	**Jasmine 85**	**Marshall**	**Mean**
0	84	85	72	80
30	101	95	94	97
60	119	105	99	108
90	122	117	105	115
120	128	118	110	119
150	124	115	112	117
Mean	108	105	99	

LSD (0.05) Fertilizer = 14
LSD (0.05) Variety = 5
LSD (0.05) Fertilizer x Variety = 16

Table 4. Effect of different levels of Nitrogen on total biomass (t ha^{-1}) for the three varieties.

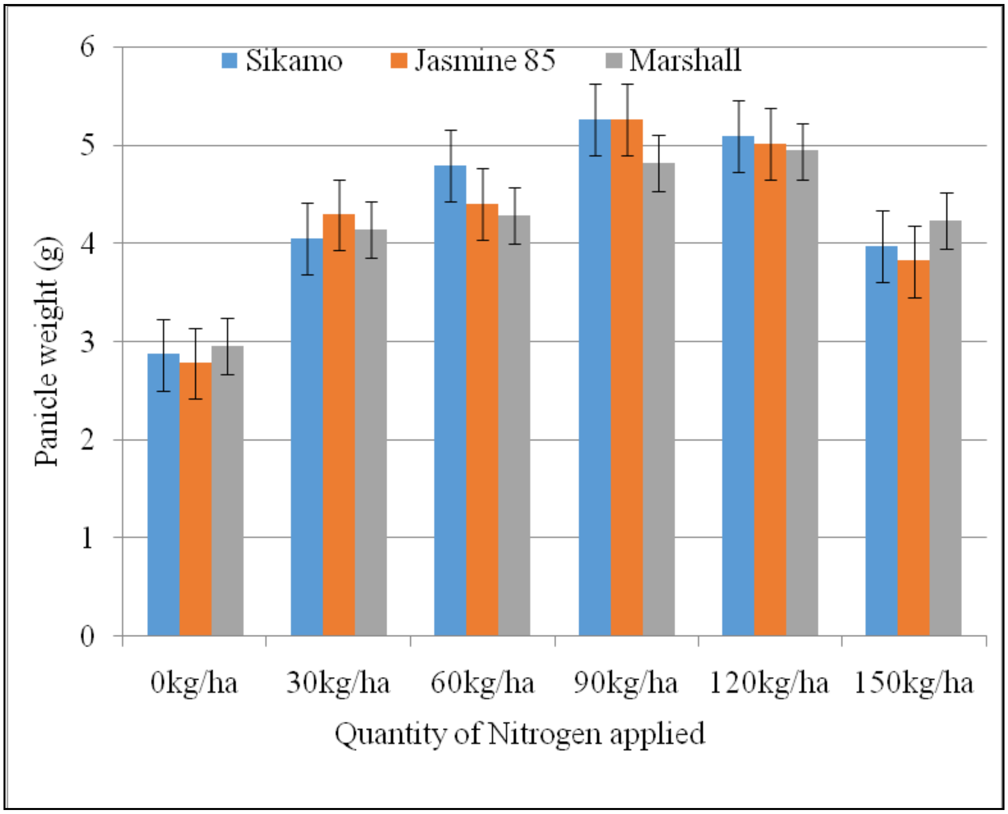
Nitrogen rate (kg ha^{-1})	Rice Variety			
	Sikamo	Jasmine 85	Marshall	Mean
0	10.27	9.60	9.90	9.92
30	14.30	14.47	13.00	13.92
60	16.73	16.70	13.17	15.53
90	16.57	15.97	15.47	16.00
120	20.20	18.03	16.67	18.30
150	19.67	17.77	18.00	18.50
Mean	16.29	15.42	14.37	

LSD (0.05) Fertilizer = 2.612
LSD (0.05) Variety = 1.148
LSD (0.05) Fertilizer x Variety = 3.475

kgN ha^{-1} than 90 and 120 kgN ha^{-1}. Fageria and Santos (2015) reported that plant height, grain yield, panicle weigh, 1000 grain weight and grain harvest index (GHI) were significantly influenced by N and genotype treatments. In this study, the significantly higher panicle weights of 90 and 120 kg N ha^{-1} significantly contributed to higher grain yields recorded for those treatments, particularly at 90 kgN ha^{-1} (Fig. 3).

Grain yield: Grain yield produced for the different levels of N applied is presented in Fig. 3. Grain yield ranged from 1.7t ha^{-1}(lowest) to 9.4t ha^{-1} (highest) across N levels and varieties. Grain yield was significantly higher for Sikamo and Jasmine 85 fertilized at 90 kg N ha^{-1}than all the other N x Variety interactions except Marshall x 90 kg N ha^{-1}and both Sikamo and Jasmine fertilized at 120 kg N ha^{-1}. Grain yield for all the varieties were almost similar at both 60 and 150 kg N ha$^{-1.}$ Generally grain yield increased with increasing levels of N from 1.7 t ha^{-1} (0kgN ha^{-1}) to a maximum of 9.4 t ha^{-1}(90kgN ha^{-1}) and thereafter declined, indicating that higher levels of N suppressed yield. This is in accordance with the earlier findings of Shaobing et al (2010), who reported that excessive nitrogen application to rice in China caused environmental pollution, increased cost of farming, reduced grain yield and contributed to global warming. Grain yield was generally very high compared to the mean grain yield of 2.0 t ha^{-1} reported by the Ministry of Food and Agriculture, Ghana (MoFA, 2010). Such high levels of grain yield for the rain-fed lowlands could be attributed to the use of good varieties, fertilizer additions and improved soil and water management under the "Sawah" system (bunded and leveled fields). Buri et al (2008) reported that lowland rice significantly responded to N, P, and K additions in selected sites in southern Ghana. Becker and John (2001) also observed that while bunding significantly increased yield across sites in La

Figure 2. Effect of varying levels of nitrogen onindividual panicle weight (g) of rice.



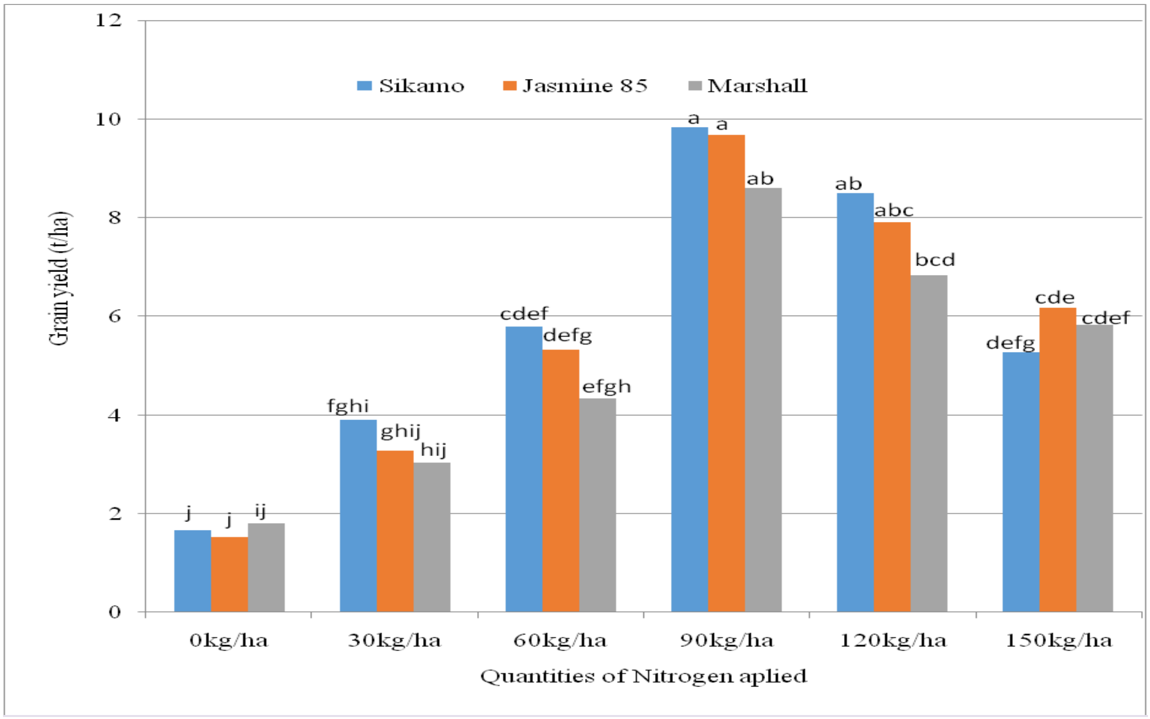
Error bars represent Standard Errors.

Cote d'Ivoire by almost 40% and controlled weeds, mineral fertilizer N application significantly increased yield by 18% with N use efficiency being 12 kg compared to 4kg of rice grain per kg of N applied in open field by water control and agronomic management (N application, weed control). With improved soil and water management under the" Sawah" system, N use efficiency is increased and higher grain yields are obtained when compared to open fields with poor soil management and no water control (Issaka et al, 2008). Under this study, N utilization was improved due to improved water management. Hence moderate levels of N recorded higher grain yields. Evaluating the response of four rain-fed NERICA varieties to N fertilization, Kamara et al (2011), also reported that even though the interactions between N and variety were not significant for all measured traits, yield response to N was linear and significantly increased with increasing levels of N up to 100kgN ha^{-1}. With results showing a linear trend and yield increase of 3tonnes ha^{-1} (100kgN ha^{-1}) over the control, the authors recommended further studies to establish optimum levels for the rain-fed lowlands of the northern Guinea savanna zone of Nigeria. In a similar study, Fegeria and Baligar (2001) reported that N fertilization significantly increased dry matter and grain yield with maximum yield (6.4t ha^{-1}) obtained at 120kgN ha^{-1} during year 1 and maximum yield (6.3t ha^{-1}) obtained at 90kgN ha^{-1} in year 2. The authors further observed that other yield components such as panicle length and panicle number per m^2 were significantly affected by N fertilization with panicle number per m^2 showing the highest correlation (r = 0.70 and 0.78) for two years, In this study, however, mean maximum yields were obtained at 90 kgN ha^{-1} for all three varieties over the period confirming the findings of Buri et al (2008) who recommended 90 kgN ha^{-1}as the optimum rate.

Weight of 1000 grains:

The effect of varying levels of N on 1000 grains is presented in Table 5. Lowest 1000 grain weight recorded was 22.04g while the highest was 26.91g both under Jasmine 85. The application of N significantly affected the weight of 1000 grains over the control. However, there were no significant differences in 1000 grain weight between 30, 60, 120 and 150 kg N ha^{-1} application. Jasmine 85 interacted with 60kg N ha^{-1} to produce the highest 1000grain weight, followed closely by Sikamo at

Figure 3. Effect of varying levels of Nitrogen on rice paddy yield.



In the histogram, figures followed by similar letters are not significantly different at LSD 5%.

Table 5. Effect of different levels of Nitrogen on 1000grain weight (g) for the three varieties.

Nitrogen rate (kg ha^{-1})	Rice Variety			
	Sikamo	Jasmine 85	Marshall	Mean
0	22.32	22.04	22.20	22.19
30	24.17	25.46	26.65	25.42
60	26.46	26.91	26.66	26.68
90	26.88	26.74	26.66	26.76
120	26.51	26.42	26.69	26.54
150	25.44	25.58	25.86	26.17
Mean	16.29	15.42	14.37	

LSD (0.05) Fertilizer = 1.35
LSD (0.05) Variety = 0.66
LSD (0.05) Fertilizer x Variety = 1.89

90kg N ha^{-1}.

Correlation between grain yield and yield components

Table 6 shows the relationships between grain yield and yield components. All the yield components strongly correlated with grain yield with plant height, biomass and panicle weight giving the highest correlations. This signifies that changes in these components will affect grain yield, as was observed.

Grain Harvest Index (GHI)

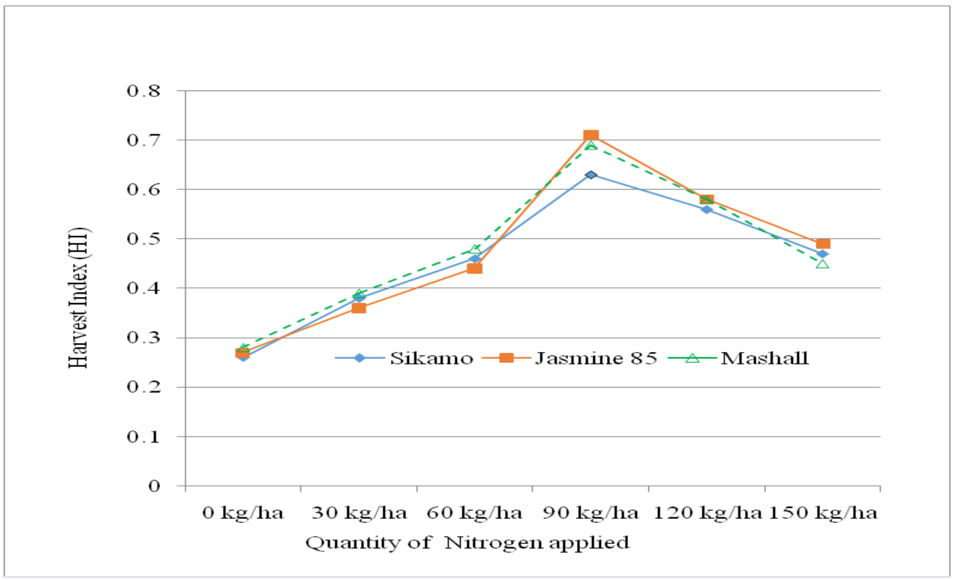
The Grain Harvest Index (GHI) calculated for the different levels of N applied is shown in Fig. 4. This is a measure

Table 6. Correlation between Grain Yield and Yield Components.

Growth Parameter	Grain Yield
Plant height	0.7474***
Biomass	0.7533***
Tillersm^{-2}	0.5881***
Panicle weight	0.7567***
1000 seed weight	0.5718***

*** indicate significance at 1% probability level.

Figure 4. Effect of varying levels of nitrogen on grain harvest index (GHI).



of the ratio of economic yield (grain) to total yield (grain + straw).The higher the value, the better or higher the returns/gain from any fertilizer additions. GHI was significantly affected by N application for all the three varieties. Lowest GHI (0.27) was recorded for the control (no N applied) while the highest GHI (0.68) was recorded at 90kgN ha-1. Harvest Index was in the order: 0 kg N ha-1 < 30 kg N ha-1 < 60 kg N ha-1 < 150 kg N ha-1 < 120 kg N ha-1< 90 kg N ha-1. GHI showed a similar trend for the three varieties and was significantly and positively correlated to grain yield. A similar observation was also reported by Fageria and Santos (2015). The above observations clearly show that higher doses of nitrogen for rice production in these lowlands do not only result in significant yield reductions but also lead to higher cost of production for the mostly resource poor farmers as cost of mineral fertilizer is high.

CONCLUSION

Results show that fertilizer use significantly affect rice yield. However, higher rates of N tended to suppress grain yield but promote straw production. The optimum rate was observed to be 90 kg N ha-1 after which grain yield decreased. In the lowlands therefore appropriate crop, soil and water management practices can result in high rice grain yield of over 9000kg ha-1. The introduction of such improved technologies can help to significantly improve yields over the current national mean of 2000kg ha-1 and contribute to enhancing food availability and security in the country.

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