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Chapter

Managing Soil Nitrogen under Rain-Fed Lowland Rice Production Systems in the Forest Agroecological Zones in Ghana

Mohammed Moro Buri and Roland Nuhu Issaka

Abstract

Rice is the second most important cereal in Ghana after maize. However, current production levels are about 47% of the country's requirements resulting in huge annual imports of the crop. One major constraint to production has been low soil nutrients and poor nitrogen management. Nitrogen is not only a major nutrient but also 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 rates 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 the total number of tillers per m² 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 1.7 t ha⁻¹ (control) to a maximum of 9.4 t ha⁻¹ (90 kg N ha⁻¹) before declining to 5.8 t ha⁻¹ (150 kg N ha⁻¹) in the order 0 < 30 < 60 < 150 < 120 = 90 kg N 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 90 kg N ha⁻¹, respectively. Nitrogen at 90–120 kg ha⁻¹ was therefore recommended. These rice varieties in addition to other improved ones will also perform well in other environments with similar biophysical characteristics across the country.

Keywords: grain yields, mineral fertilization, "sawah" technology, soil nutrients

1. 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 [1–13]. Another notable and critical factor contributing to low agricultural productivity especially rice in Ghana is the low use of fertilizers [10, 14]. In highly weathered soils with low clay content and low activity clay minerals [13] as those of West Africa including Ghana, technology development for increased and sustainable

nutrient management under improved soil and water management is very paramount. In Ghana where over 80% of rice farmers are poorly resourced, 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 [15] 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 1999 to 24% in 2006. Rice yields in Ghana average about 2 tons per hectare due to inherent poor soils and improper soil management practices [5, 6, 8]. With a potential available lowland area of over 700,000 ha, rice is cultivated across all the agroecological 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 high rain forest and semi-deciduous rain forest agroecological zones have a comparative advantage due to their good rainfall and better water availability throughout a greater part of the year. 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 [3, 16]. Rice is grown within these zones with very little or sometimes 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, rice farmers' yield of at least 4.0 t ha⁻¹ is ensured [4, 7]. However, for higher yields and improved/sustained productivity, mineral fertilization is necessary. Previous studies have shown that rice responds to mineral fertilization in these lowlands [5–7]. 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.

With the increasing use of lowlands in the forest agroecological zones for rice production, this chapter looks at the relevance and how effective nitrogen can be managed for increased rice grain yields and developing a sustainable production system.

2. Forest agro-ecology and rice-growing soils

In Ghana, there are two main forest agroecological zones, namely, the high rain forest and semi-deciduous rain forest (**Figure 1**). These agroecological zones lie between latitude 5°N and 7°N and longitude 0°W and 3°W. The agro-ecology covers a total land area of about 3.45 million hectares representing 18.9% of total land area of country. The agroecological zones cover the whole of the Western, Western North, parts of the Ashanti, Central and Eastern regions. Lowlands (inland valleys, floodplains) are spread across the area where rice cultivation is gradually intensifying due to water availability.

Rice is grown mainly in the valley bottoms, valley fringes, floodplains, colluvial foot slopes, and generally hydromorphic sites. Water is readily available throughout greater portions of the year. Rice is mainly grown under partially irrigated and rain-fed conditions. Within very limited areas, however, rice is also grown under irrigation. The main soils of rice-growing sites include valley bottoms (Gleysols), foot slopes, and valley fringes (Humic Ferralsol and Gleyic Lixisols).

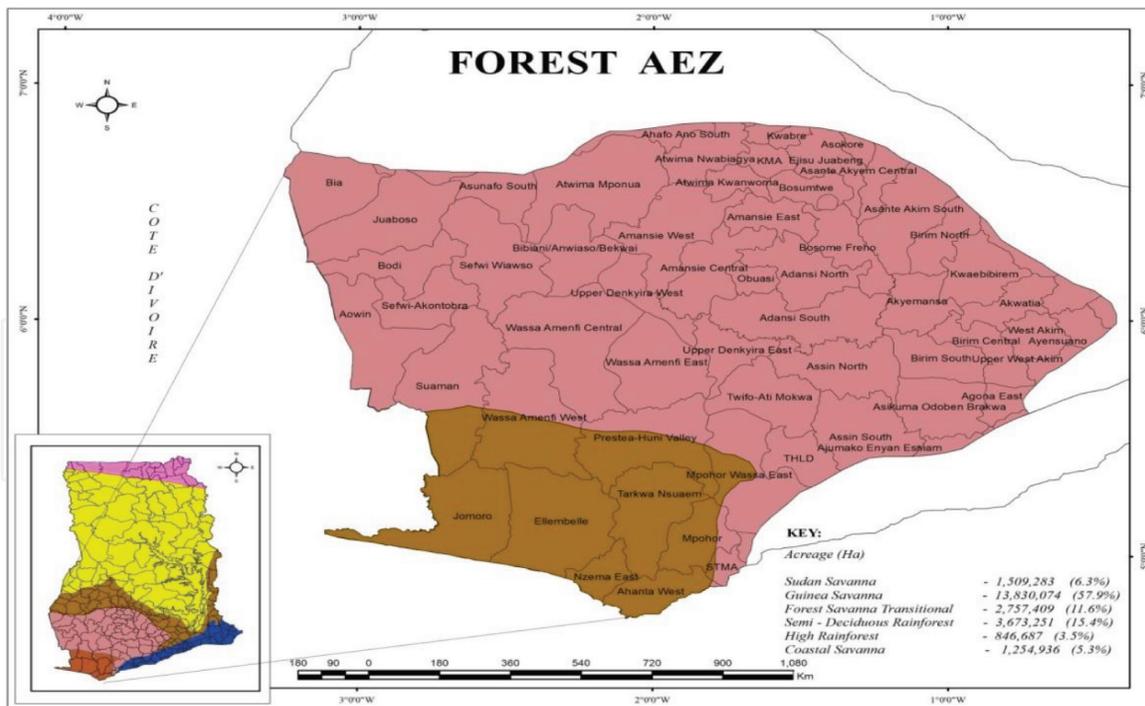


Figure 1.
 Location of the two forest agroecological zones of Ghana.

3. Materials and methods

3.1 Experimental setup

The site was initially slashed and vegetative cover removed. The area was then ploughed using a mini-tractor (power tiller). The plowed site was demarcated into four main blocks through the construction of bunds. Using a split plot design with nitrogen rate (level) as main treatment and rice variety as sub-treatment, each block was divided into six main plots using minor bunds (100 cm wide and 50 cm high) representing six nitrogen rates (0, 30, 60, 90, 120, 150) kg N per ha. Each main plot was again subdivided to three plots, each measuring 2 m × 2 m for the three rice varieties (Sikamo, Jasmine 85, Marshall). The characteristics of these rice varieties are indicated in **Table 1**. Each subplot was then puddled and manually leveled. A composite soil sample (0–30 cm) was initially collected from the site for laboratory analysis before land preparation. Three-week-old rice seedlings were transplanted to their respective plots using the specified varieties at a spacing of 20 cm × 20 cm and at two seedlings per hill. A uniform level of 60 kg P ha⁻¹ as

| Rice variety | Days to maturity | Av. yield (t ha ⁻¹) | Yield potential (t ha ⁻¹) | Comments |
|--------------|------------------|---------------------------------|---------------------------------------|-------------|
| Sikamo | 130–135 | 6.5 | 8.5 | Nonaromatic |
| Jasmine 85 | 120–130 | 6.5 | 8.5 | Aromatic |
| Marshall | 120–130 | 6.0 | 8.0 | Nonaromatic |
| AGRA | 125–130 | 6.0 | 8.0 | Aromatic |
| Amankwatia | 120–125 | 6.0 | 8.0 | Aromatic |
| CRI-Dartey | 120–125 | 6.5 | 9.0 | Aromatic |

Table 1.
 Characteristics of the varieties used and other existing varieties.

P₂O₅ using triple superphosphate as phosphorus source, 60 kg K ha⁻¹ as K₂O using Muriate of Potash as potassium source, and 50% N using urea as nitrogen source was applied to each subplot immediately after transplanting as basal fertilizer. All fertilizer was uniformly broadcasted on the field manually. The remaining 50% N was applied as split, at 25 days after transplanting (maximum tiller formation) and 55 days after transplanting (at panicle initiation) using the same broadcast method. Weed control was manual, mainly by handpicking. Crop growth was then monitored until harvest.

3.2 Soil analysis

Soil sample was air dried at room temperature. Dried sample was then ground and passed through a 2 mm sieve. Soil pH was measured in a soil/water ratio of 1:2.5 [17]. Total carbon was measured by the method of [18] and total nitrogen by the micro Kjeldahl method [17]. Available P was measured by the method of [19]. Exchangeable cations (Ca, Mg, K, Na) were extracted using a 1.0 M ammonium acetate solution and determined by atomic absorption spectrometry [20]. Exchangeable acidity was determined by titration and eCEC calculated as sum of exchangeable cations and acidity.

3.3 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.

3.4 Yield characteristics

At maturity, an area of 1m² excluding border rows was measured out in each subplot 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 (HI) was calculated as ratio of grain yield to total yield (grain + stover).

3.5 Statistical analysis

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

4. Characteristics of growing environment

The agroecological zones have a bimodal rainfall pattern (**Figure 2**) and therefore have two main cropping seasons (major and minor). The major season has its peak rainfall in June to July, while that of the minor is in September to October. The two agroecological zones have a comparative advantage over other agroecological zones due to their good rainfall and higher water availability throughout a greater part of the growing season. The physicochemical properties of the soils of these zones are shown in **Table 2**. The soils are typically low in inherent fertility and poor in plant nutrients particularly total nitrogen (N) and available phosphorus (P). Soil texture ranges from pure sandy soils through loam to clay soils. Under such low levels of fertility, improved/efficient nutrient management is critical if higher rice yields are to be obtained and when increased and sustained total productivity are to be achieved.

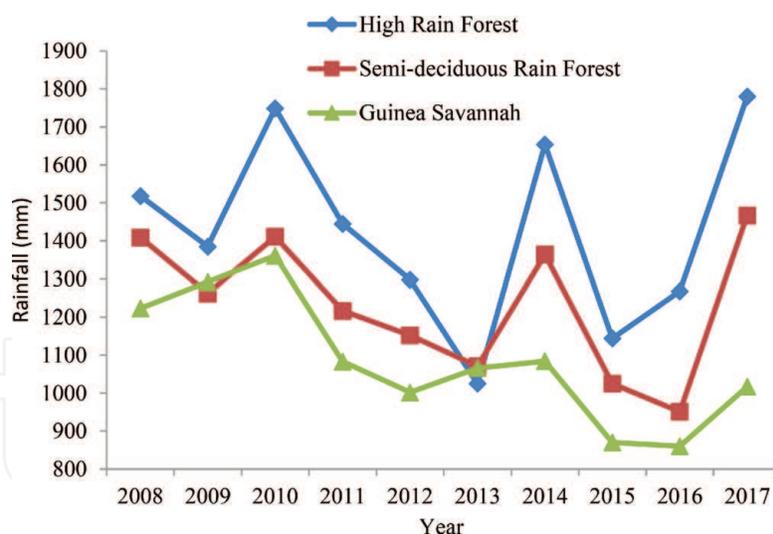


Figure 2.
 Rainfall amounts and distribution in the three main agroecological zones of Ghana.

| Parameter | Units | High rain forest | Semi-deciduous rain forest | Savannah |
|----------------|---------------------------|------------------|----------------------------|----------|
| pH (water) | — | 5.7 | 5.7 | 4.6 |
| Total carbon | g kg ⁻¹ | 10.3 | 12 | 6.1 |
| Total nitrogen | g kg ⁻¹ | 0.90 | 1.10 | 0.65 |
| Av. phosphorus | mg kg ⁻¹ | 1.4 | 4.9 | 1.5 |
| Ex. potassium | cmol (+) kg ⁻¹ | 0.22 | 0.42 | 0.22 |
| Ex. calcium | cmol (+) kg ⁻¹ | 2.25 | 7.50 | 2.10 |
| Ex. magnesium | cmol (+) kg ⁻¹ | 1.12 | 4.10 | 1.00 |
| Ex. sodium | cmol (+) kg ⁻¹ | 0.26 | 0.32 | 0.12 |
| Ex. acidity | cmol (+) kg ⁻¹ | 0.65 | 0.31 | 1.00 |
| Effective CEC | cmol (+) kg ⁻¹ | 4.49 | 12.65 | 4.44 |
| Clay | g kg ⁻¹ | 110 | 127 | 66 |
| Silt | g kg ⁻¹ | 240 | 620 | 607 |
| Sand | g kg ⁻¹ | 650 | 300 | 327 |

Table 2.
 Mean physicochemical properties of soils of the main agroecological zones.

5. Responses to nitrogen fertilizer application

5.1 Effect of nitrogen on growth parameters

5.1.1 Number of tillers m²

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 0 kg N to 30 kg N than from 30 to 60, 60 to 90, 90 to 120, and 120 to 150 kg N ha⁻¹ (**Table 3**). Generally, total number of tillers per m² significantly increased by 53, 70, 72, 77, and 103% over the control for 30, 60, 90, 120, and 150 kgN ha⁻¹, respectively. There was also a corresponding increase in total dry matter production with increasing levels of N. These observations are

| 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 × Variety = 112.

Table 3.

Effect of the interaction of nitrogen levels and rice varieties on the number of tillers m⁻².

similar to other findings. In 2006 [21], working on the effect of N and P fertilizers reported application of N up to 120 kg ha⁻¹ increased the number of panicles per m² significantly apparently by increasing the number of productive tillers. However, the authors also reported that there was a reduction in the number of panicles per m² at the highest N application, attributing this observation to excessive vegetative growth of the rice crop. However, paddy yield did not show a similar trend with increasing levels of N. At higher levels of N (> 90 kg ha⁻¹), more tillers tended to be unproductive resulting in lower paddy yield. There were also no significant differences in the number of effective tillers produced in the variety × N rate interaction in line with an observation earlier made by [22] who noted that interactions between N and variety were not significant for all measured traits for four lowland NERICA varieties in Nigeria and those of [23], who worked on the effect of minerals N and P on the yield and yield components of flooded lowland rice in Ethiopia.

5.1.2 Plant height

Plant height was significantly affected by N application (**Table 4**). Plant height was similar for 0 and 30 kg N ha⁻¹ levels but significantly shorter than for 60, 90, 120, and 150 kg N ha⁻¹. The initial nutrient levels were probably good enough to produce plants of similar height to 30 kg N ha⁻¹. Nitrogen is a major contributor

| 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 × Variety = 16.

Table 4.

Effect of the interaction of nitrogen levels and rice varieties on plant height (cm).

to crop growth, size, and total dry matter production. The increase in height with increasing levels of N could not be explained better. While [23] 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, Metwally [24] also reported that plant height was significantly affected by nitrogen rate of 110 and 165 kg N ha⁻¹ over the control. Ref. [24] further indicated that the interaction between mineral N rates and organic materials had a significant effect on plant height. [25], however, reported that there were no significant differences in N rates × 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 60 kg N ha⁻¹ level and above to give significantly taller plants. Similar taller plants were also observed when Marshall interacted with 60 kg N ha⁻¹ level and above. Generally when N was not applied, plants were significantly shorter.

5.2 Effect of nitrogen on yield parameters

5.2.1 Total biomass

The total biomass (straw + grain) increased with increasing levels of N (**Table 5**). Total biomass increased from 9.9 t ha⁻¹ at 0 kg N ha⁻¹ to a maximum of 18.5 t ha⁻¹ at 150 kg 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. Higher N rates of 120 and 150 kg N ha⁻¹ further significantly produced higher biomass yields. Total biomass increased by 4.0, 5.4, 6.1, 8.4, and 8.6 t ha⁻¹ over the control for 30, 60, 90, 120, and 150 kg N ha⁻¹, respectively. Between varieties, total biomass production for Sikamo was similar to Jasmine 85 but significantly higher than Marshall. The 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 3**), and higher N rates had more tillers than the control (**Table 4**). This largely explains the observed differences in biomass production.

Reference [23] 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

| Nitrogen rate (kg ha ⁻¹) | Rice variety | | | Mean |
|---|--------------|------------|----------|-------|
| | Sikamo | Jasmine 85 | Marshall | |
| 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 × Variety = 3.475.

Table 5.
 Effect of different levels of nitrogen on total biomass (t ha⁻¹) for the three varieties.

80 kg N ha⁻¹. Ref. [24] while investigating the effect of mineral N fertilizer on rice reported that increasing N fertilizer levels resulted in a corresponding increase in straw yields, stating that the highest straw yields were obtained with the highest N rates of 165 and 110 kg N ha⁻¹. Ref. [24] attributed these observations mainly due to the fact that N fertilizer increased dry matter, leaf area index, and number of tillers. In this study, while total biomass increased with increasing levels of N up to 150 kg N ha⁻¹, grain yield declined after 90 kg N ha⁻¹. After 90 kg N ha⁻¹, further N addition seemed to contribute more to vegetative growth (greater straw production) at the expense of reproductive growth (grain production).

5.2.2 Mean panicle weight

The mean weight of individual panicles was determined for each level of N applied (**Figure 3**). Panicle weight was significantly affected by N application. Lowest individual panicle weights (< 3.0 g panicle⁻¹) were obtained under the control where N was not applied. Individual panicle weight increased significantly (> 4.0 g panicle⁻¹) with 30kgN ha⁻¹ additions, rising to above 5.0 g per panicle⁻¹ at 90 and 120 kg N ha⁻¹. Significantly lower panicle weights were recorded at 150 kg N ha⁻¹ than 90 and 120 kg N ha⁻¹. These results are in conformity with other findings. Ref. [23] reported that plant height, grain yield, panicle weight, 1000 grain weight, and grain harvest index (GHI) were significantly influenced by N and genotype treatments. In the same vein, [24] also reported that mineral N and organic material application to rice significantly affected the number of grains per panicle. Treatments that received mineral N fertilizer in addition to organic materials had significantly higher panicle weights over those that did not, and it increased with increasing levels of fertilizer and organic materials. 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 kg N ha⁻¹ (**Figure 3**).

5.2.3 Grain yield

Grain yield produced for the different levels of N applied is presented in **Figure 4**. Grain yield ranged from 1.7 t ha⁻¹ (lowest) to 9.4 t 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 was almost similar at both 60 and 150 kg N ha⁻¹. Generally grain

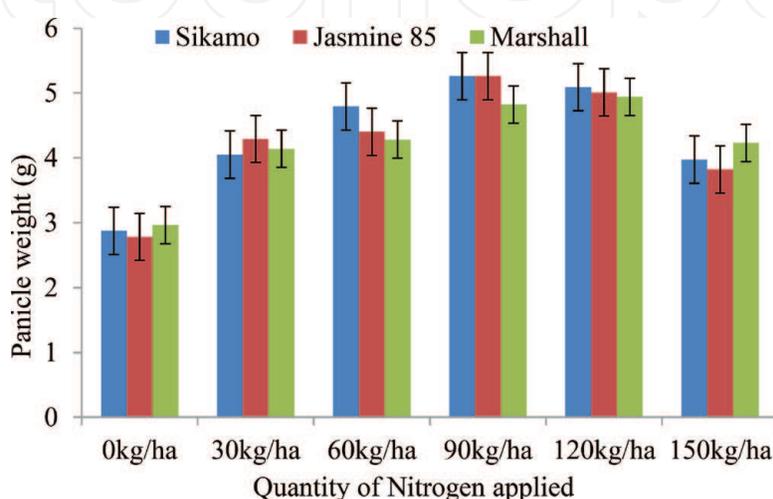


Figure 3. Effect of varying levels of nitrogen on individual panicle weight (g) of rice.

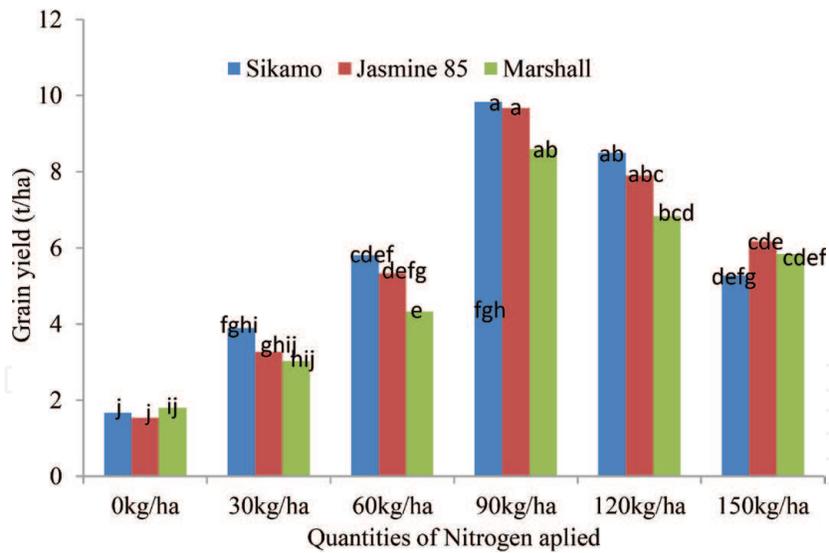


Figure 4.
 Effect of varying levels of nitrogen on rice paddy yield.

yield increased with increasing levels of N from 1.7 t ha^{-1} (0 kg N ha^{-1}) to a maximum of 9.4 t ha^{-1} (90 kg N ha^{-1}) and thereafter declined, indicating that higher levels of N suppressed yield. This is in accordance with the earlier findings of [25] 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. Furthermore, [24] indicated that, filled grain percentage was affected by nitrogen fertilizer and organic materials, adding that plants that did not receive nitrogen produced the lowest number of filled grains while those that received 165 kg N ha^{-1} produced the highest filled grains, followed by those that received 110 kg N ha^{-1} . Ref. [21] working on the effect of N and P fertilizers on yield, and yield components of rice also reported that N had a marked effect on grain yield and that grain yield increased from 3240 to 3962 kg ha^{-1} with an increase in the levels of N from the control (no N) to 60 kg N ha^{-1} and decreased further with increase in applied N fertilizer. Ref. [21] further reported that the magnitude of increase in grain yield over the control due to application of 30 and $60 \text{ kg of N ha}^{-1}$ was 13.5% and 22.3% , respectively. 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 [15]. 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). Ref. [8] reported that lowland rice significantly responded to N, P, and K additions in selected sites in southern Ghana. Ref. [26] also observed that while bunding significantly increased yield across sites in La 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 4 kg of rice grain per kg of N applied in open field. Ref. [26] further indicated that across environments, about 60% of observed variability in rice grain yield was explained 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 [4]. 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, [22] 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 100 kg N ha^{-1} .

With results showing a linear trend and yield increase of 3 tons ha⁻¹ (100 kg N 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, [27] reported that N fertilization significantly increased dry matter and grain yield with maximum yield (6.4 t ha⁻¹) obtained at 120 kg N ha⁻¹ during year 1 and maximum yield (6.3 t ha⁻¹) obtained at 90 kg N ha⁻¹ in year 2. Ref. [27] further observed that other yield components such as panicle length and panicle number per m² were significantly affected by N fertilization with panicle number per m² showing the highest correlation ($r = 0.70$ and 0.78) for 2 years. In this study, however, mean maximum yields were obtained at 90 kg N ha⁻¹ for all three varieties over the period confirming the findings of [9] who recommended 90 kg N ha⁻¹ as the optimum rate.

5.2.4 Weight of 1000 grains

The effect of varying levels of N on 1000 grains is presented in **Table 6**. Lowest 1000 grain weight recorded was 22.04 g, while the highest was 26.91 g, 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 60 kg N ha⁻¹ to produce the highest 1000 grain weight, followed closely by Sikamo at 90 kg N ha⁻¹.

5.2.5 Correlation between grain yield and yield components.

Table 7 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.

5.2.6 Grain harvest index (GHI)

The grain harvest index (GHI) calculated for the different levels of N applied is shown in **Figure 5**. This is a measure 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. The lowest GHI (0.27) was recorded for the control (no N applied), while the highest GHI (0.68) was recorded at 90 kg N ha⁻¹. Harvest index was in

| Nitrogen Rate (kg ha ⁻¹) | Rice variety | | | Mean |
|---|--------------|------------|----------|-------|
| | Sikamo | Jasmine 85 | Marshall | |
| 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.

Table 6.
Effect of different levels of nitrogen on 1000 grain weight (g) for the three varieties.

| Growth parameter | Grain yield |
|-------------------------|-------------|
| Plant height | 0.7474*** |
| Biomass | 0.7533*** |
| Tillers m ⁻² | 0.5881*** |
| Panicle weight | 0.7567*** |
| 1000 seed weight | 0.5718*** |

***indicates significance at 1% probability level.

Table 7.
 Correlation between grain yield and yield components.

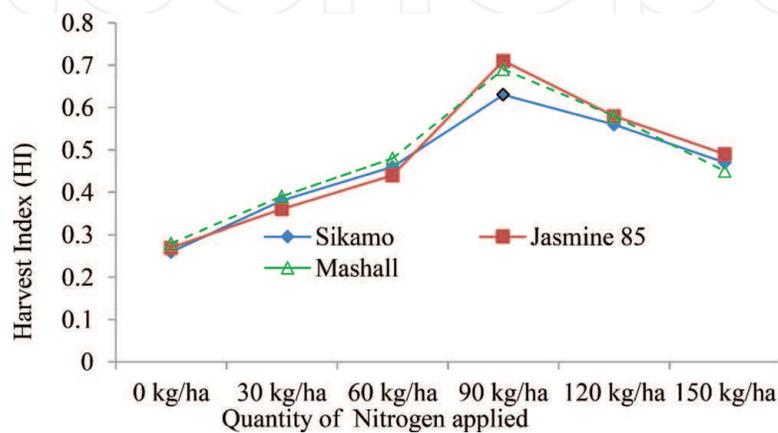


Figure 5.
 Effect of varying levels of nitrogen on grain harvest index (GHI).

the order 0 < 30 < 60 < 150 < 120 < 90 kg N ha⁻¹. GHI showed a similar trend for the three varieties and was significantly and positively correlated with grain yield. A similar observation was also reported by [23]. 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.

6. Conclusion

Results show that fertilizer use significantly affects 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, but this could be increased to 120 kg N ha⁻¹ depending on soil type, rainfall regime, and affordability of individual farmer. In the lowlands therefore appropriate crop, soil and water management practices can result in high rice grain yield of over 9000 kg ha⁻¹. The introduction of such improved technologies can help to significantly improve yields over the current national mean of 2000 kg ha⁻¹ and contribute to enhancing food availability and security in the country. The three rice varieties are highly productive under these nitrogen rates.

6.1 Recommendations

It is therefore recommended that, to sustain rice production and for increased yields, N application is best within 90–120 kg ha⁻¹ based on location, specific rainfall amounts, and soil types. The three tested rice varieties (Sikamo, Jasmine 85, Marshall) are all suitable for cultivation within the high rain forest and

semi-deciduous rain forest agroecological zones of the country. Furthermore these rice varieties, in addition to other improved varieties like AGRA, Amankwatia, and CRI-Dartey, are suitable and recommended for lowlands in the other agroecological zones with similar biophysical and physicochemical characteristics. Land preparation methods and water management remain key and very critical factors, and the adoption of the “sawah” technology (bunding, puddling, and leveling) with easy-to-adapt water control structures is most suitable for these areas.

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