



## Evaluation of Different Improved Upland Rice Varieties for Low Soil Nitrogen Adaptability

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### Authors' contributions

*This work was carried out in collaboration between all authors. Authors PAS and JKM designed the study, wrote the protocol, managed the experimental process, analyzed the data and wrote the first draft of the manuscript. Authors JWK and SN managed the experimental process and literature searches. All authors read and approved the final manuscript.*

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### ABSTRACT

Scarcity of nitrogen fertilizer is a major constraint to rice production particularly in developing countries. Low soil fertility prevalent in farmer's fields has led to low rice yields and the ever escalating fertilizer prices have made this important input unaffordable to most smallholder farmers who have limited resources for purchasing the required inputs. The Mwea Upland rice (MWUR) varieties were bred under low fertilizer input environment while other authors have indicated that the New Rice for Africa (NERICA) gives high yields under low input conditions. There is therefore need to identify the superior rice varieties that are adaptable to low nitrogen levels. Thus, the objective of this study was to investigate the effects of different rates of nitrogen fertilizer on improved upland rice varieties and identify the low input adaptable varieties. Field studies were conducted at Alupe in Western Kenya under rainfed upland conditions between August 2012 and April 2013. The experiment layout was split plot factorial in a Randomized Complete Block Design with three replicates. The main plot treatments were four rates of nitrogen fertilizer levels which were; 0 (control), 40, 80 and 120 kg ha<sup>-1</sup> applied as calcium ammonium nitrate (26% N) in two equal splits; 21 days after sowing (DAS) and at panicle initiation (46 DAS). Sub-plots consisted of

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four MWUR varieties namely MWUR 1, MWUR 2, MWUR 3, MWUR 4; and four NERICA varieties namely NERICA 1, NERICA 4, NERICA 10 and NERICA 11. The parameters measured included plant height, tiller number, filled grain ratio percentage and yield components. In the study, nitrogen treatment showed significant effect on plant growth and the measured parameters increased significantly with increase in nitrogen level. MWUR varieties studied were more adaptable to low nitrogen conditions as compared to NERICA varieties. The NERICA varieties recorded higher yield at high nitrogen levels as compared to MWUR varieties. However, NERICA 4 gave higher yield as compared to other NERICA varieties regardless of the nitrogen level. Results from our study suggest that MWUR 1 and 2 and NERICA 4 were more tolerant to low nitrogen as compared to MWUR 3 and 4 and NERICA 1, 10 and 11, because of higher height, more tiller number, higher filled grain ratio percentage and higher yield component as compared to the other studied varieties and may be suitable for soils low in nitrogen.

*Keywords: Nitrogen; height; tiller; filled grain ratio percentage; yield components.*

## 1. INTRODUCTION

Rice (*Oryza sativa*) is a principal staple food in Kenya [1]. However, its production in Kenya is still low due to low and declining soil fertility. This has resulted into food and nutritional insecurity and low living standards in the region. In Kenya, rice is grown mainly by small scale farmers majority of whom are resource poor for commercial and as food crop [2]. Rice requires essential macro and micro nutrients that are typically deficient in the soil to meet the crop's demand. Optimal application of fertilizers would enable farmers achieve rice yields matched to their local climatic and agro-ecological conditions [3]. The consequent declining soil fertility in Alupe, Western Kenya, makes it necessary to add supplementary fertilizers to achieve a high productivity. According to [4] scarcity of water and nitrogen (N) fertilizer are major constraints to rice production particularly in developing countries where rainfed upland conditions dominate.

Nitrogen is one of the major essential plant nutrients and a key input for increasing crop yield [5]. It contributes to carbohydrate accumulation in culms and leaf sheaths during the pre-heading stage and in the grain during the ripening stage of rice [6]. Optimum dose of nitrogen fertilization plays a vital role in growth and development of the rice plant. Its growth is seriously hampered when lower dose of nitrogen is applied which drastically reduces yield [7]. However, it has remained one of the most expensive inputs and most essential in sustainable rice production. In Kenya, low soil fertility prevalent in farmers fields have led to low rice yields [8]. The ever escalating fertilizer prices have made this important input unaffordable to most smallholder farmers who have limited resources for

purchasing the required inputs. As a result, rice farmers are unable to harness the potential of rainfed rice to meet their food demand despite having two seasons of rainfall that could be utilized for production [9]. There is growing need for the development of sustainable production systems that would enable rice productivity to be maintained with less N fertilizer. According to [10] selection and breeding should be tailored towards nitrate management to reduce N loss. Efforts should be focused on identifying varieties which are adaptable to low N inputs and so reduce cost. Breeders could aim at breeding for traits associated with high grain yield. Selection criteria in the breeding programmes should aim at developing N-efficient varieties without sacrificing rice yield potential [11].

According to [12] the improved upland rice varieties may require different nutrient amounts' when compared to traditional upland rice varieties to optimize production under rainfed conditions. Varietal improvement plays an important role in increasing rice yields. Furthermore, increases in rice production depend on the availability of high yielding varieties [2]. Varieties differ in their ability to impact productivity and some varieties can perform well under low nitrogen input [8]. Some studies have shown that mineral N is commonly found in the top soil at the beginning of cropping season; therefore, split application of 60 kg ha<sup>-1</sup> is sufficient for the production of some upland varieties [12]. Other studies have recommended more than 90 kg ha<sup>-1</sup> [5]. However, some rice varieties may do reasonably well under low nitrogen conditions. These varieties need to be identified and the mechanisms which confer their low soil fertility traits studied and identified [13].

The main objective of this study was to investigate the effects of different rates of nitrogen fertilizer on improved uplands rice varieties. The specific objective was to compare the performance of improved upland lines with the NERICAs. These objectives were set against the hypothesis that the improved upland rice in Kenya were as good or even could out perform the popular NERICA lines in low fertile soils. The research will thus contribute to the nutritional well-being and food security of the communities in Kenya. Recommendations could then be given to farmers who may be less endowed with high fertilizer inputs but must grow rice for food security. Farmers more endowed with high fertilizer inputs could use the high yielding but high fertilizer required varieties to derive maximum commercial benefits

## 2. MATERIALS AND METHODS

### 2.1 Site Description

Field studies were conducted to assess the response of eight improved rice varieties to different N levels under rainfed upland conditions between August 2012 and April 2013 at Alupe farm of Lake Basin Development Authority (LBDA). The experimental area was located on latitude 0° 30' 0 N; longitude 34° 7' 50 E and at elevation of 1170 metres above sea level. Precipitation ranged between 680.5 - 860 mm and temperature ranged from 16 - 34°C during the growing period. The soils at Alupe have been characterized as Ferralo-orthic Acrisol with pH of 5.0 [14]. Specific soil chemical characteristics of the location were determined according to the analytical procedures of [15] and are presented in Table 1. Soil samples were collected at depth of 20 cm from all corners of the plot, the middle and along the diagonals. This was done at the beginning of the experiment to assess the initial chemical status of soil in each of the plots. The soil was thoroughly mixed together to form a composite sample which was then air dried and passed through a 2.0mm sieve for soil texture and 0.5mm sieve for chemical analyses. Land was ploughed and harrowed to a suitable tilth before sowing.

### 2.2 Experimental Design and Treatments

The experiment layout was split plot factorial arrangement in a Randomized Complete Block Design (RCBD) with three replicates. The main plot was fertilizer N source and different rice

varieties as sub-plots. The main plot treatments were four rates of nitrogen fertilizer which were; 0 (control), 40, 80 and 120 kg ha<sup>-1</sup> applied as calcium ammonium nitrate (26% N) in two equal splits, 21 days after sowing (DAS) and at panicle initiation (46 DAS) following the recommendation by [12]. Sub-plots consisted of eight rice varieties; four MWUR rice varieties coded as MWUR 1 (M-1), MWUR 2 (M-2), MWUR 3 (M-3), MWUR 4 (M-4). These were bred and selected by KARI-Mwea under low N fertilizer input environment and four New Rice for Africa (NERICA) varieties namely NERICA 1 (N-1) NERICA 4 (N-4), NERICA 10 (N-10) and NERICA 11 (N-11) that have been released to farmers in Kenya. Drill sowing was done in 5 m x 1.2 m plots, 20 cm between rows and within rows at a depth of 3 cm and four seeds per hill. The seedlings were thinned to 1 plant per hill 15 days after sowing. In between the plots, trenches of 0.5 m depth and 1 m in width were constructed, to avoid seepage between plots. A basal dose of 30 kg P ha<sup>-1</sup> triple super phosphate (TSP) was applied as P source. The fertilizer granules were worked into the bottom of the hole and covered with about 1 cm of soil to avoid fertilizer burn to the rice seeds during dissolution. The rice seeds were placed and covered with roughly 2 cm of soil. The sowing date coincided with onset of the long rainy season. Bird scaring was done to protect the trial from bird damage.

### 2.3 Sampling and Measurements

#### 2.3.1 Plant height

Five hills in each plot were randomly selected discarding the border hills and tagged for recording plant height. Measurements were made using a metre rule from the stem base to shoot apex in cm. This was done at 85 DAS.

**Table 1. Chemical characteristics of soils at LBDA Alupe farm (0 - 20 cm depth)**

Soil chemical properties	Value
pH <sub>1:1</sub>	4.69
EC (Electrical conductivity)	0.18
Total N g kg <sup>-1</sup>	0.73
Available P (ppm)	0.14
Extractable-Zn (ppm)	1.75
Extractable-Cu (ppm)	5.66
Extractable-Mn (ppm)	48
Extractable-Fe (ppm)	479

### **2.3.2 Tiller number**

Number of tillers for all the varieties and treatments were counted and recorded for all emerging shoots in the hills from the time of planting to the flowering stage. The counting of the number of tillers started when the first tillers were noticed, and counting was done every other day until three consecutive counts maintained the same number of tillers. A wooden quadrat (1 m x 1 m) was used in the middle of the plot by ignoring the border plants. All hills within quadrat were counted for total number of tillers.

### **2.3.3 Yield components**

At physiological maturity, a 1 m<sup>2</sup> quadrat was placed in each plot leaving out the border rows and border plants. The quadrats were harvested to determine yield components and rice yield per square meter. The grain yield was determined at harvesting from an area of 1 m<sup>2</sup> in each plot. Filled grains per panicle were determined and yield calculated according to [16]. The yield was extrapolated in kilograms per hectare as follows:

$$\text{Yield (Kg ha}^{-1}\text{)} = \text{Number of panicles m}^{-2} \times \text{Number of grains panicle}^{-1} \times \% \text{ filled grains} \times (\text{Weight of 1,000 grains} \div 1,000) \times 10,000$$

### **2.3.4 Filled grain ratio percentage**

Grains harvested from 1 m<sup>2</sup> in all the plots were put in different buckets of water and the poorly filled grains together with empty grains floated while the well filled grains settled at the bottom. Filled grains were then separated from empty and poorly filled grains. The grains were dried and later weighed but each was handled separately. The percentage of filled grains was calculated according to [16].

## **2.4 Statistical Data Analysis**

Factorial analysis of variance (ANOVA) was carried out on the data for the variables measured to determine the significance of the effects of nitrogen fertilizer levels on the rice varieties using a statistical computer package (SAS software version 9.2) [17]. Significant means were separated using least significance difference test (LSD) at 5% level for comparing the treatment means. Linear regression curve was used to show and define the nature and strength of the relationships between nitrogen levels, rice varieties and grain yield.

## **3. RESULTS**

### **3.1 Plant Height**

Application of nitrogen fertilizer significantly affected plant height over control for all the tested varieties. Plant height of the tested rice varieties significantly ( $P \leq 0.05$ ) increased with increasing level of nitrogen (Fig. 1). There was a marked difference in height between the NERICAs and MWUR rice varieties at 0 N and 40 N with MWUR 1 having statistically higher height at 0 N as compared to all the other varieties. At 80 N and 120 N kg ha<sup>-1</sup>, there was no significant difference between the varieties although NERICA 4 recorded slightly higher height than the other varieties. There was no significant ( $P > 0.05$ ) variety x treatment interactions.

### **3.2 Tiller Number**

Nitrogen application exhibited a significant ( $P \leq 0.05$ ) impact on fertile tiller number with maximum tiller number per hill at 120 N and minimum number of tillers hill<sup>-1</sup> at 0 N (Fig. 2). Significant difference ( $P \leq 0.05$ ) in tiller production per hill was observed among the varieties with MWUR 1, 2 and 3 exhibiting significantly ( $P \leq 0.05$ ) higher number of tiller hill<sup>-1</sup> at 0 N and 40 N as compared with the other rice varieties. NERICA 4 and MWUR 1 recorded statistically significant higher tiller numbers at 80 N as compared to NERICA 1, 4, and MWUR 2, 3 and 4. There was a significant ( $P \leq 0.05$ ) interaction between varieties and treatments.

### **3.3 Filled Grain Ratio (%)**

There was a highly significant ( $P \leq 0.05$ ) increase in filled grain ratio percentage in each successive level of fertilizer application with 120 N recording the highest values while 0 N recorded the least filled grain ratio (Fig. 3). The varietal difference was also highly significant ( $P \leq 0.05$ ) with MWUR 1 and 2 recording significantly ( $P \leq 0.05$ ) higher filled grain ratio percentage as compared to MWUR 4 and the NERICAs at 0 N and 40 N. NERICA 4 registered statistically significant higher filled grain ratio percentage as compared to the other NERICA varieties at 0 N and 40 N. The MWUR varieties recorded significantly higher filled grain ratio percentage as compared to the NERICA varieties at 0 N and 40 N while the NERICAs registered higher values at 80 N and 120 N. However; the difference was not significant ( $P > 0.05$ ).

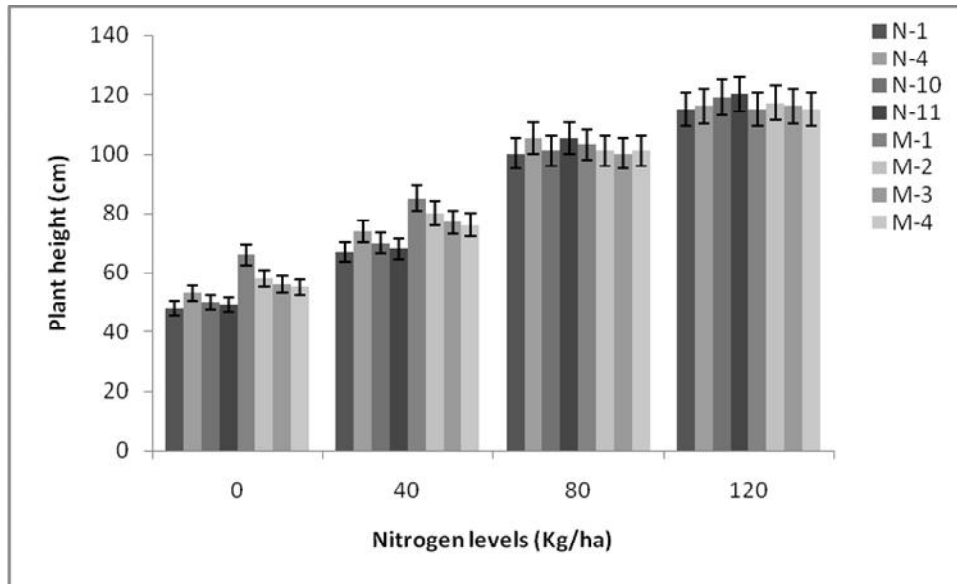


Fig. 1. Effect of N rate on plant height of eight rice varieties grown at four levels of nitrogen treatment (Means of three replicates  $\pm$  SE). LSD (0.05) V = 2.28, T = 1.61

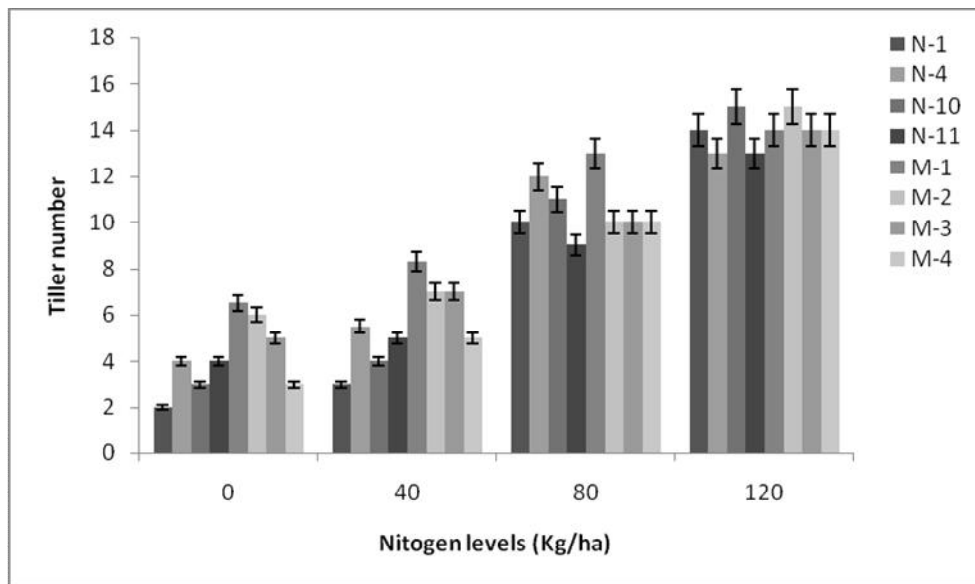


Fig. 2. Effect of N rate on tiller number hill<sup>-1</sup> of eight rice varieties grown at four levels of nitrogen treatment (Means of three replicates  $\pm$  SE). LSD (0.05) V = 1.20, T = 0.85

### 3.4 Yield Component

Nitrogen application significantly increased yield components and there was a significant ( $P \leq 0.05$ ) difference among the treatments with the highest yield recorded at 120 N and lowest at 0 N. MWUR 1 had significantly ( $P \leq 0.05$ ) higher yield component at 0 N and 40 N as compared to MWUR 3, 4 and the NERICAs (Fig. 4). Among

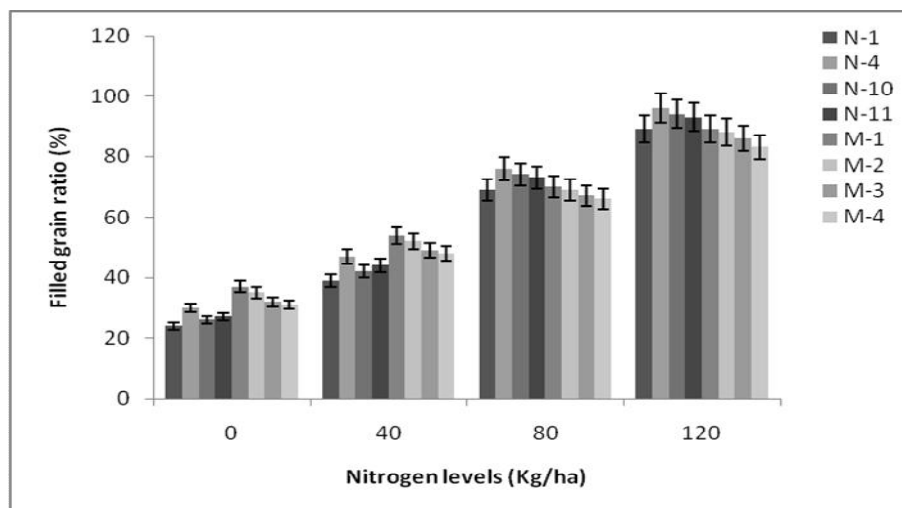
the NERICA varieties, NERICA 4 exhibited the greatest yield regardless of N level. Interactions between the varieties and treatments were also significant ( $P \leq 0.05$ ). There was a positive and significant correlation between yield component and tiller number (Fig. 5). Yield component and filled grain ratio percentage also recorded a positive and significant correlation (Fig. 6).

#### 4. DISCUSSION

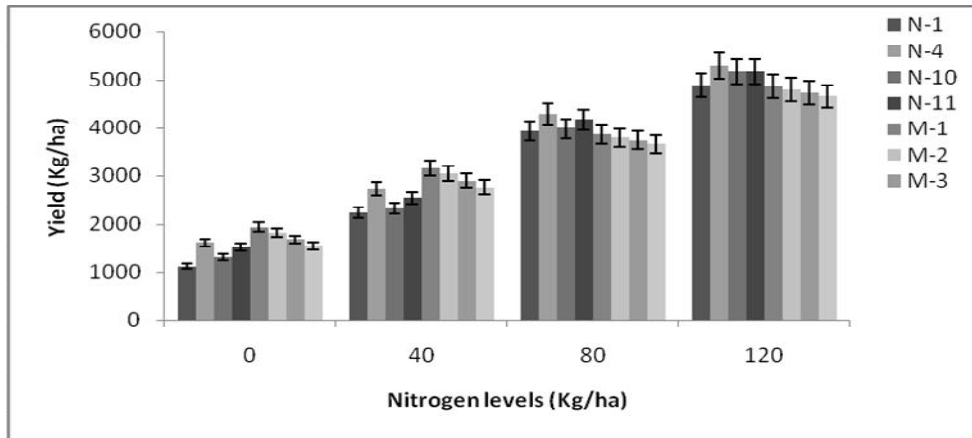
In the study, nitrogen treatment had significant effect on plant growth and plant height increased significantly with increase in nitrogen level. These results are consistent with the findings of [18] on super Basmati rice and [19] on hybrid rice. According to [20], N-deficiency stress delays shoot elongation and leaf growth, but increases root growth. The increase in plant height with increased N application might be primarily due to enhanced cell division and cell elongation leading to vigorous vegetative growth with more nitrogen supply to plant hence increased nodes and inter nodal distance or probably due to enhanced availability of nitrogen which enhanced more leaf area resulting in higher photosynthesis hence more assimilates and thereby increased translocation of carbohydrates from source to growing points in well-fertilized plots. Nitrogen increases the vigor and enhances the growth of the rice plant. When absorbed during vegetative phase, nitrogen helps synthesize the chlorophyll necessary for photosynthesis, promotes rapid leaf, stem, and root growth as evidenced by an increase in the height, size, and number of tillers [21]. [22] Also reported that the main effect of N fertilizer is to increase the rate of leaf expansion, leading to increased interception of daily solar radiation by the canopy vegetative growth resulting to higher photosynthetic activities. According to [23], plant height reveals the overall vegetative growth of the crop in response to nitrogen while plant height of N stressed plants has been shown to be a good indicator of biomass at anthesis [24]. Generally, the MWUR

varieties exhibited higher heights at lower nitrogen levels (0 N and 40 N) while at higher nitrogen levels (80 N and 120 N) the NERICA varieties recorded higher plant heights. This variation might be due to MWUR varieties tolerance to low nitrogen level as compared to NERICA rice varieties. MWUR 1 recorded higher height among the MWUR varieties while among the NERICA varieties, NERICA 4 recorded higher height regardless of the nitrogen level. The vigorous or slow growth of varieties may be due to varietal differences and their inherited characteristics.

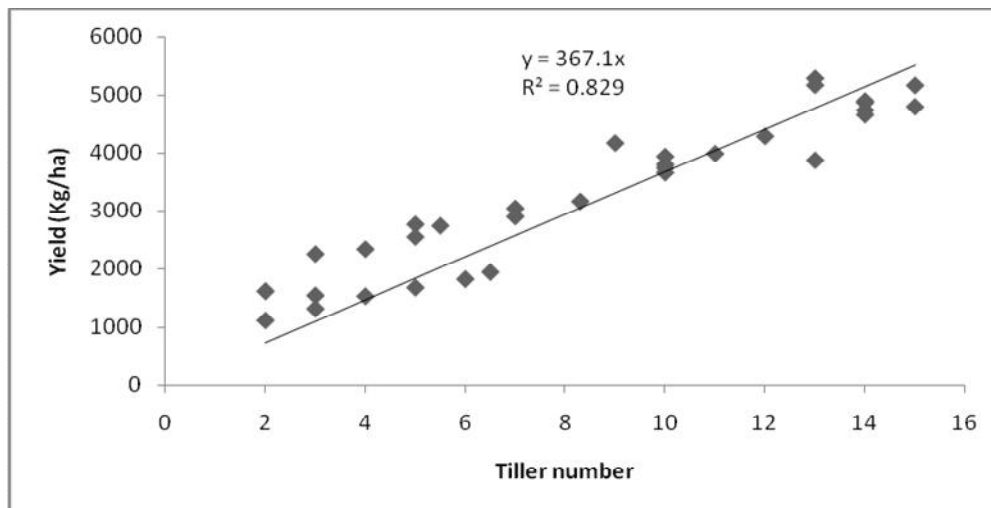
Fertile tillers per hill significantly increased with increase in nitrogen level and the highest number of tillers were recorded at the highest nitrogen application (120 N) and the lowest at control treatment receiving no nitrogen application (N 0). Similar results have been reported in hybrid rice [25], in water seeded rice [26] and on wheat [27,28]. Enhanced tillering by increased nitrogen application might be attributed to more nitrogen supply to plant at active tillering stage that played a vital role in cell division hence enhanced vegetative growth [29,30]. According to [7] the number of tillers per unit area is the most important component of yield and the more the number of tillers, especially fertile tillers, the more will be the yield. The MWUR varieties recorded higher number of tillers at low nitrogen level and NERICA 4 also registered the highest among the NERICAs at low nitrogen levels. This result is probably due to difference of varietal performance.



**Fig. 3. Effect of N rate on filled grain ratio (%) of eight rice varieties grown at four levels of nitrogen treatment (Means of three replicates  $\pm$  SE). LSD (0.05) V = 1.2, T = 0.86**



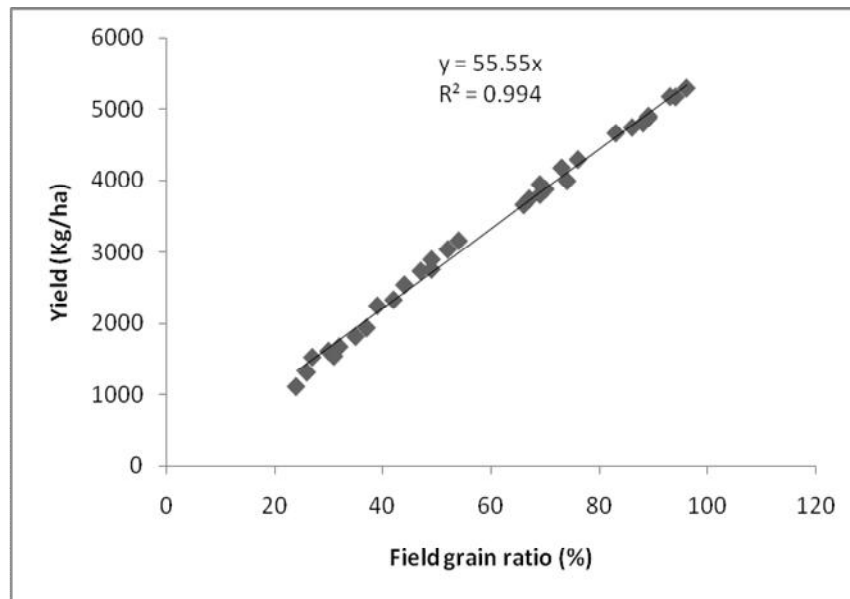
**Fig. 4. Effect of N rate on yield component of eight rice varieties grown at four levels of nitrogen treatment (Means of three replicates  $\pm$  SE). LSD (0.05) V = 99.68, T = 70.48**



**Fig. 5. Relationship between yield component and tiller number of rice as affected by different varieties and nitrogen levels**

Yield components including field grain ratio percentage increased with increase in nitrogen level. Minimum yield was recorded from plants of the control treatment where nitrogen was withheld. These results are in conformity with the findings of [31,32]. There was a positive correlation between yield components and tiller number. Positive correlation between these attributes indicates that increasing nitrogen level led to the increase of tiller number which impacted on yield. As observed by [33], the rice plant's ability to tiller is an important characteristic because tillering impacts panicle production which is highly correlated with grain yield. The improved growth attributes, viz plant height and tiller at higher nitrogen levels might be

responsible for improved yield attributes. According to [34], increasing the amount of nitrogen fertilizer leads to increase of leaf photosynthesis and consequently, increase of the grain effective filling rate because partitioning of assimilates to the grain is influenced by the source and sink. MWUR 1 and 2 had remarkably higher yield at low nitrogen levels as compared to MWUR 3 and 4 and the NERICAs. NERICA 4 on the other hand registered higher yield among the NERICAs regardless of the nitrogen level. MWUR 1 and 2 and NERICA 4 might have performed better due to high height, more tillers and higher filled grain ratio at low nitrogen conditions.



**Fig. 6. Relationship between yield component and field grain ratio (%) of rice as affected by different varieties and nitrogen levels**

## 5. CONCLUSION

The current study has shown that increase in nitrogen level leads to a significant increase in plant height, tiller number, filled grain ratio percentage and yield components. The MWUR varieties registered higher height, more tiller number, higher filled grain ratio and higher yield components at low nitrogen level while at high N levels the NERICA varieties performed better. However, NERICA 4 was superior to the other NERICA varieties and recorded higher values of the parameters measured both at low and at high N levels. It may therefore be concluded that MWUR 1 and 2 and NERICA 4 were more tolerant to low nitrogen as compared to MWUR 3 and 4 and NERICA 1, 10 and 11 because of higher height, more tiller number, higher filled grain ratio percentage and higher yield under low N levels as compared to MWUR 3 and 4 and NERICA 1, 10 and 11. The hypothesis that the improved MWUR varieties outperform the NERICAs at lower N inputs may be accepted. NERICA 4 may be good for both low input and also potentially good for high input N levels.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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