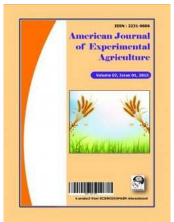

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Influence of Nitrogen Supply on Photosynthesis, Chlorophyll Content and Yield of Improved Rice Varieties under Upland Conditions in Western Kenya

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Authors' contributions

This work was carried out in collaboration between all authors. Authors PAS and JMK designed the study, 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

Rice (*Oryza sativa*) is a principal staple food crop in Kenya. However, its production is still low due to inherently low and declining soil fertility. This has resulted into food and nutritional insecurity and low living standards. The situation has been compounded by the ever escalating fertilizer prices which has made it unaffordable to most small holder farmers. Although some studies have been done on fertilizer application on some rice varieties, 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) varieties give high yields under low input conditions. The objective of the research was to establish photosynthetic and yield performance of eight promising improved rice varieties

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under four nitrogen (N) levels and identify the variety that gives high yields at relatively low N fertilizer rates. Field experiments were carried out at Alupe in western Kenya under rainfed upland condition. 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 which were; 0 (control), 40, 80 and 120 kg ha^{-1} applied as urea in two equal splits, sub-plots consisted of four MWUR and four NERICA varieties. The parameters measured included chlorophyll content (SPAD Units), photosynthesis, panicle length, yield at 14% moisture content, filled grain ratio percentage and yield components. The measured parameters increased significantly with increase in the level of nitrogen fertilizer. Varietal difference was significant and MWUR varieties recorded higher chlorophyll content, photosynthetic rates and panicle length and yield component at low nitrogen levels (0 and 40 N) as compared to the NERICAs with MWUR 1 and 2 recording higher values. The NERICAs out-yielded the MWUR varieties at higher nitrogen levels. NERICA 4 recorded highest yield among the NERICA varieties regardless of the N level. Results from our study suggested that MWUR 1 and 2 and NERICA 4 were more tolerant to low nitrogen soil as compared to MWUR 3 and 4 and NERICA 1, 10 and 11, because of higher chlorophyll content, higher photosynthetic rate, higher panicle length, higher filled grain ratio percentage and higher yield component and may be suitable for soils deficient in nitrogen.

Keywords: Oryza sativa; nitrogen; chlorophyll content; photosynthesis; yield components.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is the most important food crop, being the primary food source for more than one third of the world's population and is grown in 11% of the world's cultivated area. Upland rice has high production potential in Kenya and can be grown by most farmers at low input level [1]. Kenya has a potential to bring 1,000,000 ha under upland rice production [2]. However, currently the area under rainfed rice is 13,000ha [3] hence the national rice development strategy (NRDS) focus is expanding and increasing yields by exploiting existing opportunities on a sustainable basis [4]. Nitrogen (N) is one of the most important nutrients for plant growth and a major factor that limits agricultural yields [5,6]. It is an important component of numerous organic compounds such as amino acids, nucleic acids, chlorophyll, enzymes, hormones and proteins [7]. According to [8], the beneficial effects of nitrogen occur by influencing yield components which are controlled by genetic factors of the plant and environmental factors. Nitrogen functions to establish yield capacity and maintenance of photosynthetic activity during grain filling. Nutrient deficiency symptoms result from impaired metabolism within plant and decreased growth [9]. [10] observed that nitrogen deficiency causes premature senescence and reduced yields.

Nitrogen is required in adequate amount at early, mid tillering, panicle initiation and at ripening stage for better grain development. It has played a major role in the global food production over the past 60 years [11]. According to [12], the sensitivity of plant growth to nitrogen fertilization is of great importance in agriculture. Nitrogen (N) requirements of rice crop are met from both the soil and fertilizers. Usually due to acute N deficiency in most rice soils, fertilizer N must be applied to meet the crop demand [13] and yet excessive N application would lead to increased production cost and negative physiological effects due to excessive growth. This might block agricultural sustainability and cause environmental pollution.

The amount of N required and management of the N varies depending on variety, soil conditions, cultural practices, crop rotations, and other factors. The majority of smallholder farmers who form the bulk of agriculture in Kenya are faced with low soil fertility problems. Rice yields decline due to low input system, for example, rice yields of less than 2.0 tons/ha against a potential of 5.0 tons/ha [3] has been reported. The yield gap is attributed mainly to effects of drought and low soil fertility, the most prominent of which is nitrogen deficiency. As a result, rice farmers are unable to harness the potential of rainfed rice to meet their food and nutritional demand. Lack of identification of improved varieties adaptable to low fertility soils in rainfed conditions and the ever escalating fertilizer prices have made this important input unaffordable to most small-holder farmers who are resource poor hence low rice production [14]. However, some varieties can perform well under low nitrogen input [15]. There is therefore need to evaluate the response of the

MWUR viz a viz the NERICA varieties to identify the superior rice varieties that are adaptable to low nitrogen levels. Identification of low nitrogen adaptable rice varieties is thus crucial in sustaining production in areas where low soil fertility prevails.

Liu and Shi [16] reported that nitrogen is the most important nutrient that limit crop production. They argued that this loss can be mitigated by exploiting varieties well adapted to low soil N conditions in order to increase farm yields. In rice, there are frequent variations within species, regarding the use and accumulation of nitrogen and its genetic control [7]. Genotypes of the same species have different nutritional requirements and tolerances to mineral nutrients [17]. These genotypic differences help in the adaptation of species and cultivars to various environmental stress conditions and form the basis for genetic improvement programs. The cultivation of rice genotypes with efficient N use in combination with correct nitrogen fertilization is a promising strategy for increasing the yield of upland rice, reducing production costs and environmental impacts.

According to [18], selection of the most appropriate level of nitrogen fertilization is a major concern of economic viability in crop production and the impact of agriculture. Given the importance of nitrogen fertilization on the yield in grain from the rice plant, it is necessary to know what the best dose is for each variety as well as its influence on components of yield. Yield studies that will help in identifying varieties that have either specific or general adaptation to low nitrogen which can be exploited for varietal recommendation can greatly help address the soil fertility problem in the region. The identified low nitrogen adaptable varieties would have a substantial impact on rice productivity in terms of soil nutrient supply, nutrient use efficiency, improved food and nutritional security and livelihood/income of rural households in the region. Therefore, advanced farming systems research can contribute to the nutritional well-being and food security of the communities. Incorporating a high yielding variety, which is tolerant to low soil nitrogen is important. Studies have shown that application of N fertilizer to rice leads to increase in panicle length, spikelet number, and grain yield [15,19]. However, the response of rice varieties to increasing N levels has not been studied or documented in Kenya currently. This information is of importance in any rice breeding programme in Kenya as there is little knowledge on the response of improved rice varieties to increasing levels of N fertilizer [14]. The main objective of this study was to establish and document data on the yield performance of eight promising high-yielding improved rice varieties to various nitrogen levels as well as to identify the variety that gives high yields at relatively low N rates. These objectives were set against the hypotheses that improved rice varieties in Kenya are not responsive to increasing N rates as the existing NERICA varieties and that they are not low nitrogen use efficient.

2. MATERIALS AND METHODS

2.1 Site Description

Field studies were conducted to assess the effect of nitrogen fertilizer rates on panicle length and yield component of eight improved rice varieties under rainfed upland conditions between August 2012 and April 2013 at Alupe farm of Lake Basin Development Authority (LBDA) in Western Kenya. Geographically, the experimental area is located at latitude 0°30' 0 N; longitude 34°7' 50 E and at the elevation of the 1170 m 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 as determined in H_2O (1:1) [20]. Specific soil chemical characteristics of the location were determined according to the analytical procedures of [21] and are presented in Table 1. Soil samples were collected at depth of 30 cm using a soil auger from all corners of the plot and between diagonals and the middle part. This was done at the start 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 2.0 mm sieve for soil texture and sub samples ground through 0.5 mm sieve for chemical analyses. The field 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 kg ha^{-1}, 80 kg ha^{-1} and 120 kg ha^{-1} applied as urea in two equal splits i.e. 14 days after sowing (DAS) and at panicle initiation (46 DAS) as recommended by [22]. Sub-plots consisted of eight rice varieties i.e. four MWUR rice varieties namely Mwea upland rice 1, 2, 3 and 4 (MWUR1-4) that were bred and selected by KALRO-Mwea under low fertilizer input environment and four New Rice for Africa (NERICA) varieties namely 1, 4, 10 and 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 three 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 triple super phosphate (TSP) was used as the source of phosphorus, applied at the rate of 30 kg P ha^{-1}. The fertilizer granules were placed at the bottom of the hole and covered with about 1 cm of soil before sowing the seeds to avoid fertilizer burn to the rice seeds during dissolution of triple superphosphate. The rice seeds were covered with roughly 2 cm of soil. The sowing date coincided with onset of the long rainy season. Normal cultural trial practices such as weeding and bird scaring were carried out.

Table 1. Chemical characteristics of soils at LBDA Alupe farm (0 - 30 cm depth)

Soil chemical properties	
pH$_{1:1 \text{ soil:water}}$	4.69
ECe (Electrical conductivity)	0.18
Total N g kg^{-1}	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 Sampling and Measurements

2.3.1 Total chlorophyll content

Chlorophyll content (SPAD Index) of flag leaf of 72 plants per treatment was estimated non destructively using a portable chlorophyll meter (SPAD-502 Minolta Co. Japan). This index was used preferentially because the strong relationship between readings of portable chlorophyll meter and leaf chlorophyll content has been demonstrated by several authors [23-25]. The measurements were carried out between 0930 and 1300 hrs at 28, 42, 56 and 72 days after sowing.

2.3.2 Net photosynthesis

Net photosynthesis were determined on day 28, 42, 56 and 72 after sowing by use of a portable infrared gas analyser system connected to a plant leaf (CIRAS-1, PP Systems Ltd., Herts, U.K.) on 0.7 cm^2 of leaf surface. The measurements were carried out between 0930 and 1300 hours on fully sun exposed top leaf of 72 plants per treatment. The photosynthetically active radiation ranged from 600 – 800 µmol photons m^{-2}s^{-1}, leaf temperature varied from 24℃ to 30℃, relative humidity varied from 35% to 40% and vapour pressure deficit was between 1.6 -1.9 kPa.

2.3.3 Panicle lengths

This was determined using a metre rule at physiological maturity. Measurements were done from the panicle base to the tip of five hills in each plot.

2.3.4 Yield components

At physiological maturity, a 1 m^{-2} quadrat was placed in each plot leaving out the border rows and border plants. The plants within the quadrats were harvested to determine yield components and rice grain yield. The number of grains per 5 g, and filled grains per panicle were determined and yield calculated according to [1]. The yield was extrapolated in kilograms per hectare as follows:

> Yield (Kg ha^{-1}) = Number of panicles m^{-2} x Number of grains/panicle x % filled grains x (Weight of 1,000 grains ÷ 1,000) x 10,000.

2.3.5 Yield at 14% moisture content

This was determined from an area of 1 m^{-2} by measuring the moisture content of the grains immediately after harvesting using a grain moisture tester (model number AF 34086, Japan) and converting the yield of the grains to 14% moisture content and extrapolating to Kg ha^{-1} as described by [1].

2.3.6 Filled grain ratio percentage

Grains harvested from the 1 m^{-2} in all the plots were put in different buckets of water where 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 [1].

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) [26]. 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 Total Chlorophyll (SPAD Units)

Nitrogen treatments caused a marked difference in total chlorophyll content as shown in Fig. 1 with 0 and 40 N recording significantly ($P \leq 0.05$) lower total chlorophyll compared to 80 and 120 N. Varieties had a significant effect ($P \leq 0.05$) in total chlorophyll content at 0 and 40 N with MWUR 1 and MWUR 2 having significantly higher total chlorophyll at 0 as compared to the other rice varieties. There was no significant varietal difference in total chlorophyll at 80 N and 120 N although the NERICA varieties had slightly higher values than MWUR varieties.

3.2 Net Photosynthesis (Pn)

Results indicate that nitrogen deficiency had a significant ($P \leq 0.05$) inhibitory effect on photosynthetic rate of all the rice varieties under study. The highest photosynthetic rates were recorded at 120 N and lowest at 0 N in all the varieties (Fig. 2). The varietal difference was also significant ($P \leq 0.05$) with MWUR 1 recording significantly higher net photosynthetic rates at 0 and 40 N as compared to MWUR 3, MWUR 4 and the NERICA varieties. NERICA 4 recorded significantly ($P \leq 0.05$) higher net photosynthesis among the NERICA varieties.

3.3 Panicle Length

Nitrogen levels had a highly significant effect on panicle length. Increase in nitrogen level caused a significant increase in panicle length ($P \leq 0.05$). The plants subjected to 0 N had the shortest panicle lengths (Fig. 3). Varietal differences were also significant ($P \leq 0.05$). At 40 N, MWUR 1 had significantly higher panicle length than MWUR 2, 3 and 4 and the NERICAs ($P \leq 0.05$). NERICA 4 recorded significantly higher panicle length at 0N as compared to NERICA 1, 10 and 11. At 80 N, MWUR 1 and NERICA 4 recorded slightly higher panicle length as compared to NERICA 1, 10, 11, MWUR 2 and 4. However, there was significant difference in panicle length between MWUR 3 and NERICA 1, 10, 11, MWUR 2 and 4. There was no significant interaction between the varieties and treatments ($P > 0.05$).

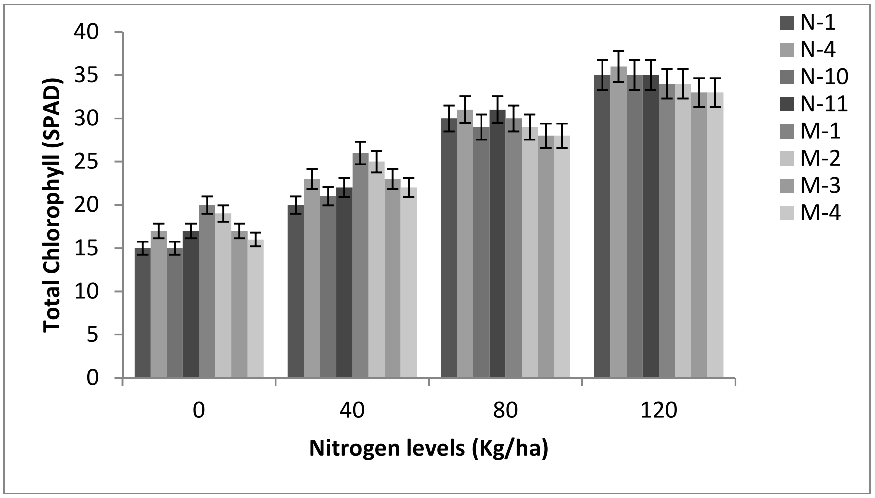

Fig. 1. Effect of N rate on total chlorophyll (SPAD units) at DAS 72 of eight rice varieties grown at four levels of nitrogen treatment (Means of three replicates±SE)

LSD (0.05) V = 0.85, T = 0.53

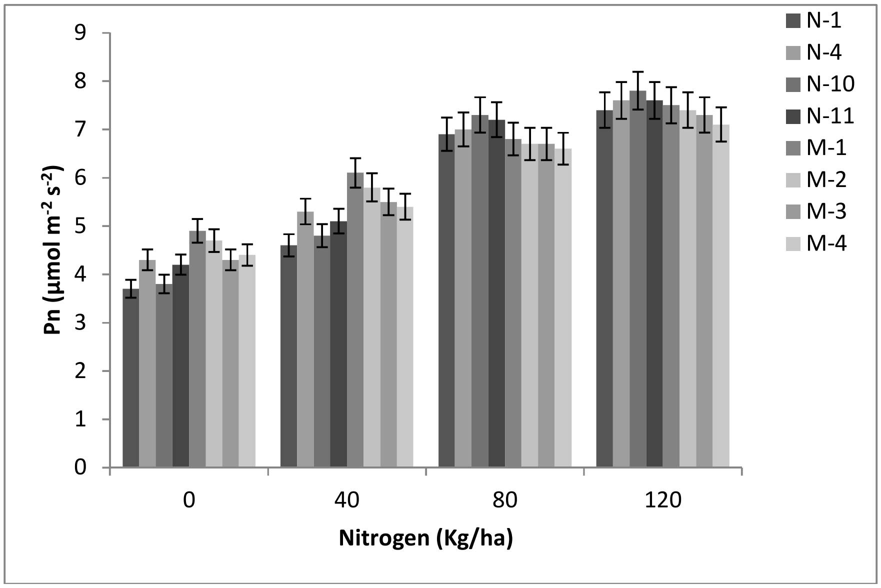

Fig. 2. Effect of N rate on net photosynthesis (Pn) at DAS 72 of eight rice varieties grown at four levels of nitrogen treatment (Means of three replicates±SE)

LSD (0.05) V = 0.23, T = 0.12

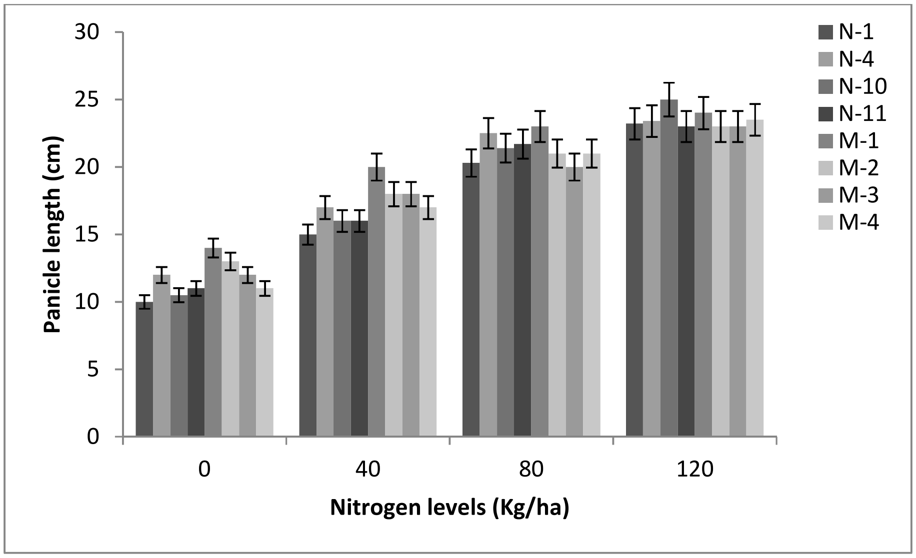

Fig. 3. Effect of N rate on panicle length of eight rice varieties grown at four levels of nitrogen treatment (Means of three replicates±SE)

LSD (0.05) V = 1.06, T = 0.75

3.4 Yield at 14% Moisture Content

Nitrogen application showed a highly significant ($P \leq 0.05$) effect on yield at 14% moisture content. Plants treated with 120 N and 80 N recorded significantly ($P \leq 0.05$) higher yield at 14% moisture content than plants treated with 40 N and 0 N. The varietal difference was also significant ($P \leq 0.05$) with MWUR 1 and 2 registering significantly higher values at 0N as compared to MWUR 3, 4 and the NERICAs (Fig. 4). At 40 N, MWUR 1 and 2 recorded significantly higher yield at 14% moisture content compared to the NERICAs however, the difference in yield was not statistically significant in MWUR 3 and 4. The results also revealed a significant variety and treatment interaction.

3.5 Filled Grain Ratio (%)

Generally nitrogen application caused an increase in filled grain ratio percentage in all the NERICAs and MWURs rice varieties (Fig. 5). Plants fertilized with 120 N and 80 N had significantly higher filled grain ratio percentage than plants treated with 0 and 40 N (P ≤ 0.05). The varietal difference was highly significant (P ≤ 0.05). MWUR 1 and 2 recorded significantly (P ≤ 0.05) higher filled grain ratio percentage at 0 and 40 N compared to MWUR 4 and the NERICAs. At 80 N and 120 N, NERICA 4, 10 and 11 had slightly higher filled grain ratio percentage compared to MWUR varieties. There was a significant (P ≤ 0.05) interaction between variety and nitrogen level.

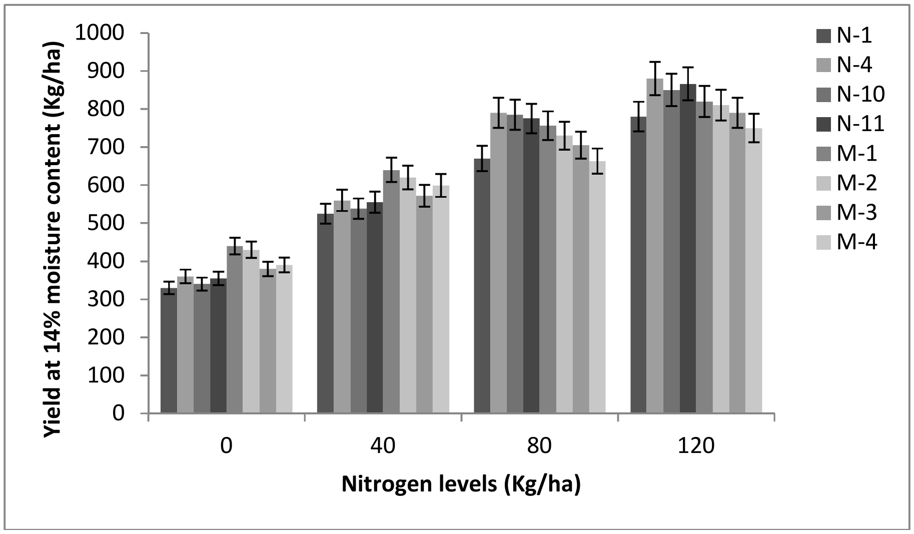

Fig. 4. Effect of N rate on yield at 14% moisture content of eight rice varieties grown at four levels of nitrogen treatment (Means of three replicates±SE)

LSD (0.05) V = 15.67, T = 11.07

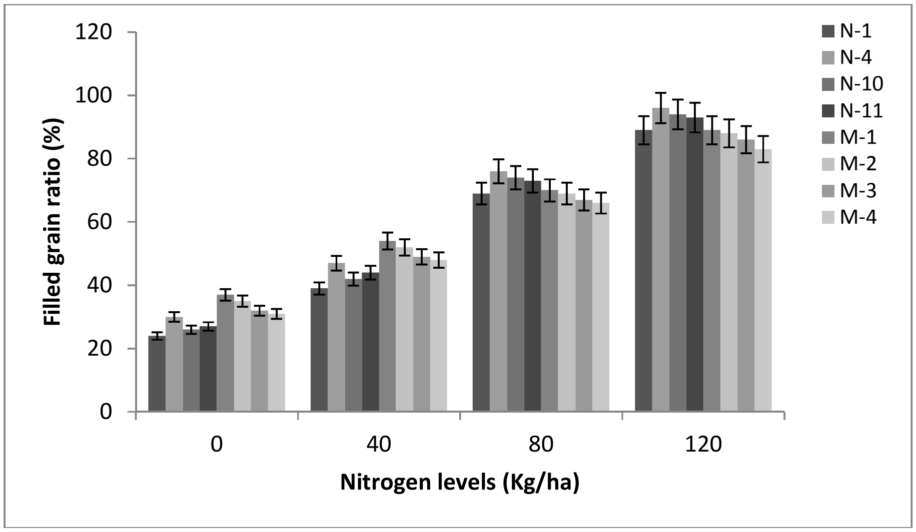

Fig. 5. Effect of N rate on filled grain ratio (%) of eight rice varieties grown at four levels of nitrogen treatment (Means of three replicates±SE)

LSD (0.05) V = 1.2, T = 0.86

3.6 Yield Component

Yield component significantly ($P \leq 0.05$) increased with the increase in nitrogen rate in all the NERICAs and MWURs rice varieties with plants subjected to 120 N recording the highest yield while plants subjected to 0 N recorded the lowest yield (Fig. 6). The varietal difference was significant ($P \leq 0.05$) with MWUR 1 having significantly higher yield component at 0 and 40 N compared to MWUR 3, 4 and NERICA 1, 4, 10 and 11. Generally MWUR varieties registered higher yield components at 0 and 40 N, while NERICAs varieties recorded higher yields at 80 N and 120 N. NERICA 4 had significantly ($P \leq 0.05$) higher yield component at 0 N in comparison to NERICA1, 10 and 11. There was a positive and significant correlation between yield component and panicle length (Fig. 7).

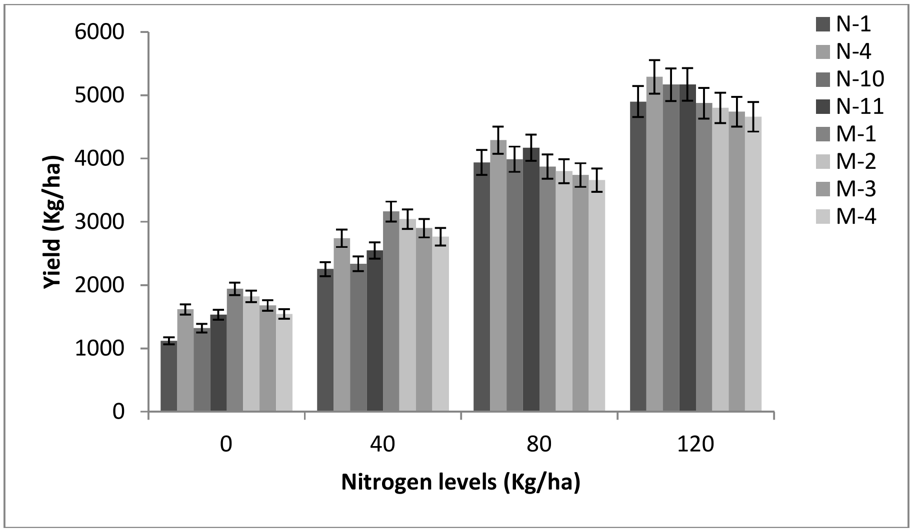

Fig. 6. Effect of N rate on yield component of eight rice varieties grown at four levels of nitrogen treatment (Means of three replicates±SE)

LSD (0.05) V = 99.68, T = 70.48

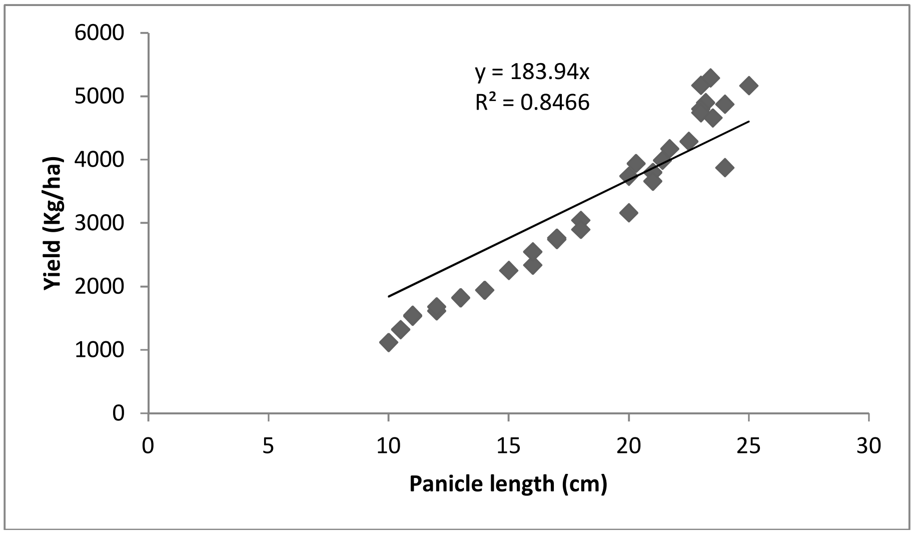

Fig. 7. Relationship between yield component and panicle length of rice as affected by different varieties and nitrogen levels

4. DISCUSSION

The total chloropyll content of the rice varieties increased significantly with increase in nitrogen level. Similar resultes have been reported in rice [27] and in three cultivars of Maize [28]. The increase in chlorophyll content in the varieties studied may be attributed to the fact that nitrogen is part of the enzymes associated with chlorophyll synthesis and the chlorophyll concentration reflects relative crop N status and yield level [29]. There were significant varietal differences in chlorophyll content among the rice varieties at low N levels. These results are in agreement with those obtained by [30] in maize. Data also indicated that MWUR 1 and 2 gave the highest values of chlorophyll content at low N levels as compared to MWUR 3 and 4 and the NERICA varieties. This was attributed to differences in the genetic constitution of the tested varieties.

Net photosynthesis increased significantly with increase in nitrogen levels. Similar results have been reported in Sunflower leaves by [31] and in wheat [32]. According to [33], there is a close relationship between maximum leaf photosynthetic rate and leaf N content in many plant species. In the present study, an increase in nitrogen availability may have resulted in higher leaf nitrogen content which in turn resulted in higher photosynthesis. [34] observed that an increase in nitrogen availability results in higher leaf nitrogen content. This results in strong positive correlation between photosynthesis and leaf nitrogen content for many C4 and C3 species. Up to 75% of leaf nitrogen is found in the chloroplasts and consequently, lower rates of photosynthesis under conditions of nitrogen limitation are often attributed to reduction in chlorophyll content and Rubisco activity [12]. Although leaf nitrogen was not determined in this study, it seems that in rice plants lower rates of photosynthesis are related to reduced mesophyll capacity for net assimilation rates at the cellular level as a consequence of lower nitrogen availability for investment into photosynthetic apparatus. The low rates of photosynthesis under low nitrogen conditions may have resulted due to low chlorophyll content since net photosynthesis rate had a significant positive correlation with chlorophyll content (r =0.82). It has also been reported that photosynthetic capacity of a plant is determined by several factors including photosynthetic pigment composition (chlorophyll content) and the efficiency of light captured to drive photosynthesis is directly correlated to the chlorophyll concentration in the leaf [35]. There was a significant difference in net photosynthesis among the rice varieties at low N levels. Similar results have been reported in Maize by [36] who reported that new maize hybrids were more tolerant than earlier hybrids to limited N supply during the early vegetative phase with respect to photosynthesis and chlorophyll content. The photosynthetic apparatus of MWUR 1 and MWUR 2 seems to be the least affected by low nitrogen level as compared to MWUR 3, 4 and the NERICA varieties as indicated by the high photosynthetic values even under soil nitrogen deficit.

The results showed that panicle length was significantly influenced by different nitrogen application treatments. Plants fertilized with higher nitrogen levels recorded significantly higher panicle lengths than plants fertilized with lower N levels. These results are in line with those reported by [37-39]. The longer panicles obtained in treatments receiving higher nitrogen rates were probably due to better nitrogen status of plant during panicle growth period because nitrogen takes part in panicle formation as well as panicle elongation and for this reason, panicle length increases with the increase of N-fertilization. When absorbed during the reproductive and ripening phases, nitrogen promotes development of the panicle and stimulates nutrient absorption and assimilation as evidenced by an increase in size and number of filled grain ratio percentage [40]. According to [41], the increase in panicle length due to adequate N nutrition is explainable in terms of possible increase in nutrient mining capacity of plant as a result of better root development and increased translocation of carbohydrates from source to growing points in well-fertilized plots. The varietal difference was also significant with MWUR 1 recording higher panicle length at low nitrogen levels compared to other rice varieties. This may imply that MWUR 1 is tolerant to low nitrogen and its cell division and elongation is not greatly affected by nitrogen deficit as compared to MWUR 2, 3, 4 and NERICA 1,4,10 and 11. NERICA 4 registered higher panicle length regardless of the nitrogen level as compared to NERICA 1, 10 and 11. This might imply that among the NERICA varieties under study, NERICA 4 is tolerant to low nitrogen conditions in the soil but can also thrive under adequate nitrogen levels.

Application of N fertilizers significantly increased filled grain ratio percentage and yield at 14% moisture content. Field grain ratio percentage and yield at 14% moisture content increased in all the rice varieties with an increase in nitrogen level. These results are in accordance with those of [19,42,43]. The increase in yield at 14% moisture content with increasing N rates may be due to the high number of panicles per square meter, which is significantly associated with high grain yield in rice [42]. This may also be attributed to the fact that N functions to establish yield capacity and maintenance of photosynthetic activity during grain filling [7]. According to [19], the improvement in yield owing to the application of N-fertilizers might be brought about by the beneficial effect of nitrogen on nutrient uptake and physiological growth. Nitrogen nutrition influences the content of photosynthetic pigments, the synthesis of the enzymes involved in the carbon reduction and the formation of the membrane system of chloroplasts, thus the increase in growth and yield owing to the application of N-fertilizers may be attributed to the fact that these nutrients being important constituents of nucleotides, proteins, chlorophyll and enzymes, are involved in various metabolic processes which have direct impact on vegetative and reproductive phases. Varietal difference was significant with MWUR rice varieties having higher filled grain ratio percentage and higher yield at 14% moisture content at low nitrogen levels as compared to NERICA varieties, while the NERICA varieties registered higher values at higher nitrogen levels. This may imply that the MWUR rice varieties are tolerant to low nitrogen and may out-yield the NERICAs under low nitrogen soils while the NERICAs might perform better than the MWUR varieties under optimal nitrogen levels. This shows MWUR varieties are responsive to N rates and thus can be described as efficient and responsive (ER) genotypes. Genotypes that produced above the average yield compared to all the genotypes tested in the experiment at low N level and had higher N-use efficiency than the average of all the genotypes [14,44].

Nitrogen fertilizer application had a statistically significant effect on the yield component of the studied rice varieties. There was an increase in yield component with increase in each successive level of nitrogen fertilizers. Similar results were also reported by [18,45,46]. The higher yield component under high nitrogen levels might be attributed to the vigorous and healthy growth and development of more productive tillers and leaves ensuring greater resource utilization as compared to plants that were deficient in N. Furthermore, nitrogen nutrition influences the content of photosynthetic pigments, the synthesis of the enzymes taking part in the carbon reduction, the formation of the membrane system of chloroplasts. Thus the increase in yield owing to the application of N-fertilizers may also be attributed to the fact that these nutrients being important constituents of nucleotides, proteins, chlorophyll and enzymes, involve in various metabolic processes which have direct impact on vegetative and reproductive phases of plants [47].

Increases in yield components are associated with better nutrition, plant growth and increased nutrient uptake [48]. The crop at no nitrogen level produced the lowest grain yield which was significantly lower than all other nitrogen levels tested. This might be due to lack of supply of nitrogen into the soil to meet the required nutrients for physiological processes, which in turn lowered the yield. According to [49], the application of nitrogen improves various crop parameters like panicle length, more productive tillers and grain yield thus resulting in higher yields. There was a significant positive relationship of yield component with panicle length and filled grain ratio percentage in all the varieties. This implies that panicle length is a significant yield component for rice yield. This high capacity for sink formation was associated with their higher capacity for N acquisition and biomass production. Panicle length contributes to increment of rice grain yield indirectly by increasing the number of panicles per m^2 and number of spikelets per panicle.

Varietal difference was significant and MWUR varieties recording superior yield components at low nitrogen levels (0 and 40N) as compared to the NERICAs with MWUR 1 and 2 recording higher values while the NERICAs out-yielded the MWUR varieties at higher nitrogen (80 and 120N). NERICA 4 and 11 recorded higher yield components at low nitrogen level as compared to the other NERICA varieties. The results may imply that the MWUR varieties are tolerant to low nitrogen as compared to the NERICAs and that MWUR 1 and 2 are more adaptable to low nitrogen as compared to MWUR 3, 4 and the NERICA varieties. NERICA 4 may be more adaptable to low nitrogen as compared to the other NERICA varieties that were under study. MWUR varieties were bred as low-management rice plant types targeted for resource-limited, smallholder production systems and their performance at 0 and 40 N thus confirms the significant role they may play in African smallholder systems. The observed greater yield in NERICA 4 compared to NERICA 1, 10 and 11 at 0 and 40N could be attributed to its higher chlorophyll content since chlorophyll content determines light energy harvest and yield formation because it is the key pigment converting solar energy into active chemical energy in the plants. It may also be attributed to higher potential for panicle production and greater ability to partition photosynthates more efficiently to the grain as indicated by higher photosynthesis and higher filled grain ratio percentage compared to the other varieties. According to results by [15,19] NERICA 4 was tolerant to low N because of the greater yield observed especially at zero and low N. This was attributed to its high potential for panicle production and ability to partition photosynthates more efficiently to the grain as indicated by a higher harvest index compared with the other cultivars. [50] reported that NERICA 4 produced significantly higher yield and was better weed competitor than CG 14, ITA 150, WAB 56-104, and the other NERICA cultivars (NERICA 1, 10, and 11) in the dry savannas of Nigeria.

5. CONCLUSION

This study indicates that nitrogen levels affected chlorophyll content, photosynthetic rate, panicle length and yield components of all the MWURs and NERICAs varieties studied. The results have shown the vital role of N in plant life and its contribution in increasing the grain yield. Such results clarifies that N is essential for cell division and elongation as well as chlorophyll formation. There was appreciable varietal difference in response to low soil nitrogen conditions. Generally MWUR varieties studied were more adaptable to low nitrogen conditions as compared to NERICA varieties. The study therefore accepts the hypothesis that MWUR varieties which had been bred to low-N management are well responsive to low N environments and are good for resource-limited, smallholder production systems. They exhibit superior yielding capacity under low nitrogen fertilized soils. They may be important in the small-holder farming systems. The NERICA varieties recorded higher yield at high nitrogen levels as compared to MWUR varieties, though, NERICA 4 gave higher yield as compared to other NERICA varieties regardless of the nitrogen level. The decision on the appropriate N rates would depend on economic conditions of the farmer. NERICA 4 would fit in both low and high input fertilizer farming systems. The 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 panicle length, higher filled grain ratio percentage and higher yield component and may be suitable for soils deficient in nitrogen.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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