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Response of Selected Rice Genotypes to Nitrogen Fertilizer Application in Taita Taveta County, Kenya

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Efficient nitrogen (N) management is critical for optimizing rice productivity, especially in nutrient-deficient soils of sub-Saharan Africa. A split-plot design with three replications was used, with rice variety as the main plot and nitrogen rate as the subplot. This study evaluated the response of five upland rice genotypes (Nerica 1, CSR36, Komboka, 17KH090014B, and AT058 to seven nitrogen application rates (0, 17, 34, 51, 67.5, 83.4 and 101 kg N ha^{-1}) in two agro-ecological zones Bura and Taveta across two cropping seasons.The Nitrogen (N) treatments were applied as topdressing in 3 equal splits, at 15 Days after Transplanting (DAT), peak tillering (30 DAT) and panicle initiation stage (45 DAT). Data collected was subjected to ANOVA using Statistical Tool for Agricultural Research and means were separated using the Turkey's Test Honest Significant Difference HSD

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test. All statistical analysis was performed at alpha=0.05. Nitrogen significantly ($P < 0.05$) enhanced vegetative and yield traits up to an optimal rate of 67.5 kg N ha^{-1}, beyond which gains were minimal. At this level, plant height, tiller number, leaf length, panicle length, and fertile grains per panicle increased by 12%, 15%, 9%, 8%, and 47%, respectively, over unfertilized plots. Genotype 17KH090014B exhibited superior performance, producing the highest total (142.22) and fertile (99.28) grains per panicle, longest panicles (20.65 cm), and most leaves per plant, while Nerica 1 was tallest (60.63 cm) and Komboka had the most tillers (25.2). The variety–nitrogen interaction peaked with 17KH090014B at 83.4 kg N ha^{-1}, yielding 143.8 grains per panicle. Findings suggest that 67.5 kg N ha^{-1} for 17KH090014B during the long rains could be a variety- and site-specific recommendation for upland rice in Taita Taveta County, provided further validation is conducted using broader sampling across the region.

Keywords: Nitrogen fertilizer; upland rice; leaf; grains; panicle.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is a key strategic staple for improving food and nutritional security in Africa, as highlighted by the African Union's Comprehensive African Agriculture Development Programme (CAADP). In Sub-Saharan Africa, rising urbanization, population growth, higher incomes, and changing diets have driven rapid increases in rice consumption, making the region a net importer (Wudil *et al*.,2022: Rodenburg, J. and Saito, K. 2022). In Kenya, rice annual demand is growing at approximately 12%, outpacing wheat (4%) and maize (1%), resulting in significant import dependency of up to 80%. Despite its growing importance, rice productivity remains low due to degraded soils, poor nutrient management, and climate variability (Gweyi-Onyango *et al*., 2021; Kogo *et al*., 2021). Nitrogen (N) is the most limiting nutrient for rice, playing a vital role in chlorophyll synthesis, amino acid and nucleic acid formation, energy transfer, and biomass production. Adequate and timely N supply promotes leaf development, tillering, panicle formation, and grain filling, while excessive application increases costs and environmental risks. Optimal N rates vary with genotype, growth stage, and site-specific conditions (Zou *et al*., 2023). In Taita Taveta County, previous studies have focused on fertilizer types and general agronomic practices, with limited research on nutrient rate optimization (Akula, 2019: Akula *et al*., 2021: Chawana et al., 2021: Milela et al., 2021; Wekesa et al., 2021). Limited data exist on how different nitrogen rates affect the growth and yield of new rice varieties under local conditions. This study assessed five upland rice genotypes across seasons in Taita Taveta to identify genotype-specific optimal nitrogen rates for efficient, sustainable, and profitable production.

2. MATERIALS AND METHODS

2.1 Description of Study Area

Field experiments were conducted in 2022 and 2023 season, at Taveta (coordinates 3°28'22" S, 37°41'44" E), 794 meters above sea level (m.a.s.l) and Bura (3°29'24.8" S, 38°18'44.8" E), 946 m.a.s.l., located in Taita Taveta County, Kenya (Fig. 1). Taveta's soils are classified as vertic Luvisols, slightly saline and moderately sodic, whereas the soils of Bura soils are Rhodic Ferralsols, with ferralic Arenosols and ferralo-chromic Luvisols, with moderate to high fertility levels (Jaetzold *et al.,* 2012). The region receives bimodal rainfall with long rains March-June and short rains NNovember-December (Nyambariga, 2024).

2.2 Experimental Layout, Design and Crop Husbandry

Five rice varieties; Nerica 1, CSR36, Komboka, 7KH090014B, AT058 and seven Nitrogen doses: 0, 17, 34, 51, 67.5, 84.3, 101 kg N ha^{-1}, were evaluated. The field experiment was organized in a Randomized Complete Block Design with split plot arrangement, with variety as the main plot and nitrogen doses as the subplot (Chawana *et al*., 2021). The total experimental was divided into three replicates (blocks), each separated by 2-meter-wide pathways to minimize inter-block interference. Each block was partitioned into five main plots, corresponding to the five rice varieties tested. Subsequently, each main plot was subdivided into seven subplots**,** representing different nitrogen levels. This resulted in a total of 35 treatment combinations per block (5 varieties × 7 nitrogen rates), and thus 105 subplots across the three replicates. Subplots measured 5 m² and were isolated by 1 m paths

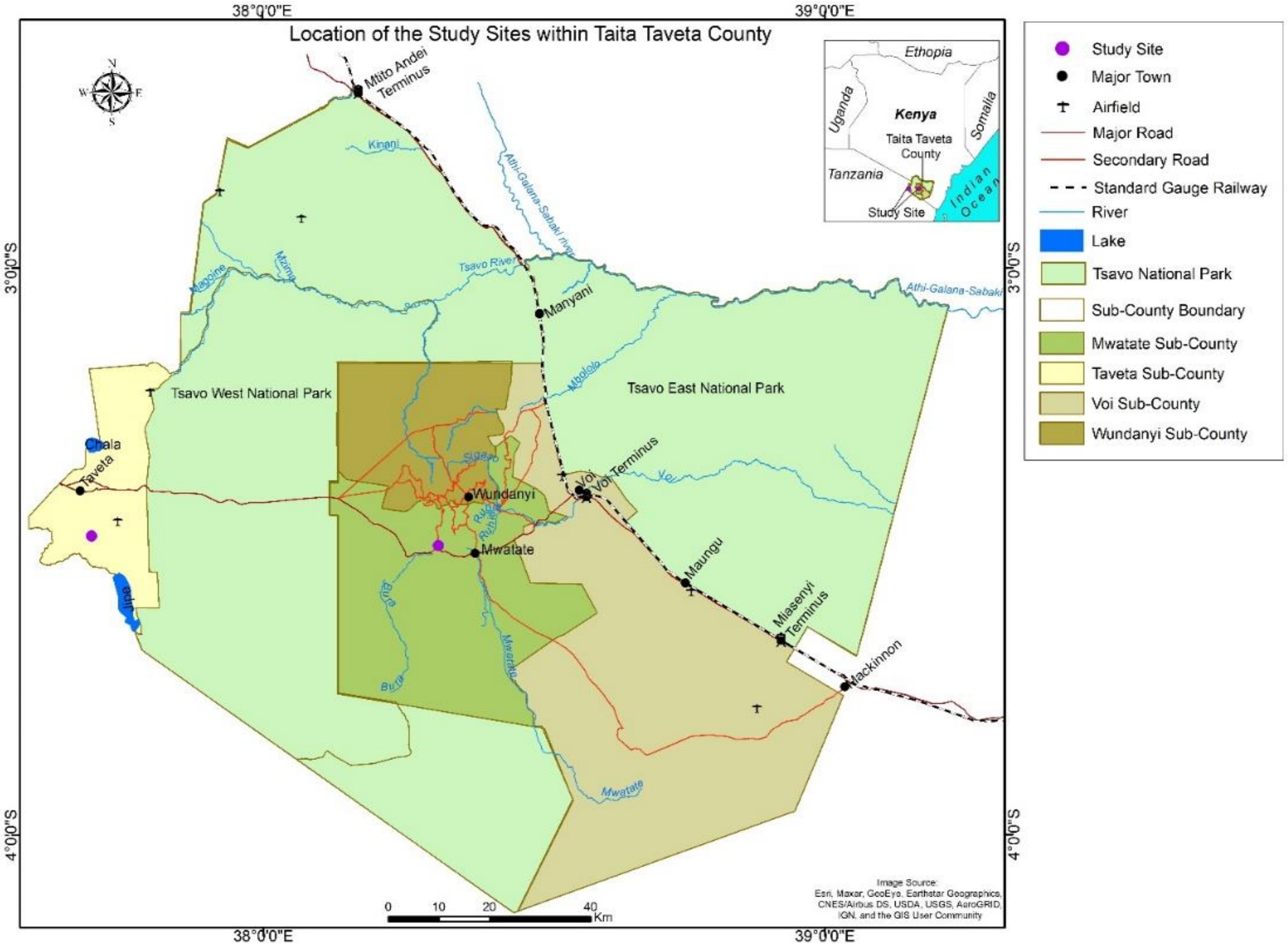

Fig. 1. Map of Taita Taveta County showing the study sites in Bura and Taveta

and polythene barriers 60 cm deep, 10 cm above ground, to prevent N movement between treatments. Four week seedlings were transplanted at 20 × 10 cm spacing (216 plants per subplot) on 15 September 2022 (short rains) and 10 March 2023 (long rains). A uniform basal application of NPK (17:17:17) supplied 11.05 kg P_2O_5 ha^{-1} and 11.05 kg K_2O ha^{-1}. The seven levels of Nitrogen treatment, were applied as ammonium sulfate [$(NH_4)_2SO_4$], as top-dressing in three equal splits at 15, 30, and 45 days after transplanting (DAT). Ammonium sulfate supplies readily available nitrogen and sulfur, enhances nutrient availability in alkaline soils, and reduces nitrogen losses in paddy systems (Sabina *et al*., 2025). Weeding was done manually at 15, 30, 45, and 60 DAT. Supplemental irrigation was provided twice weekly after 70 DAT during dry spells. Bird nets were installed before heading to protect against grain predation by red-billed quelea.

2.3 Data Collection and Analysis

Soil sampling was done at the beginning of the season before land preparation to determine adequacy of soil nutrients. At each site, six soil subsamples (0–30 cm depth) were collected using a zigzag sampling pattern, they were combined into a 1 kg composite sample, and analyzed for physicochemical properties (Results presented in Table 1). Five representative plants were randomly selected from the inner two rows of each subplot excluding the central 1 m². These plants were tagged at 15 DAT and were used collecting data on plant height, leaf length, leaf width, number of leaves per plant, number of tillers per plant, panicle length, number of total and fertile grains per panicle. For each variable studied, data was subjected to Analysis of Variance (ANOVA) using Statistical Tool for Agricultural Research (STAR). Means were ranked using the Turkey's Test Honest Significant Difference HSD test. All statistical analysis was performed at alpha=0.05.

3. RESULT AND DISCUSSION

3.1 Soil Properties Before Land Preparation

Results of the analysis of soil used at Bura and Taveta experimental sites are presented in Table 1. The soil at Taveta experimental plot had a pH of 9.01, with high sodium (3.92 Meq %), high Electric conductivity (4), low Fe (7.33 ppm) and Zn (0.93). Total Nitrogen was low (0.17%), Phosphorus Olsen high (48 ppm) and adequate potassium (1.2 mmol per kg). Macronutrients were generally lower at Taveta compared to Bura where they were adequate. In Bura, pH was 6.27, with adequate sodium (0.74 Meq %), Electric conductivity (1.5) and adequate micronutrients. Total Nitrogen was (0.24%), Phosphorus Olsen (31.2ppm) and potassium (0.54mmol per kg). The soil texture at Taveta was clayey while Bura was sandy clayey loam with percentage particle size distribution of % sand: clay: silt as 36: 52: 12 and 62: 30: 8 respectively.

Table 1. Physico-chemical characteristics of experimental soil (0-30cm depth), before sowing

Chemical property	Taveta		Bura	
	Concentration value	Description	Concentration value	Description
pH (water)	9.01	Extreme alkaline	6.27	Slightly acidic
%Organic Carbon	2.09	Moderate	2.84	Moderate
%Total Nitrogen	0.17	Low	0.24	Adequate
Phosphorus Olsen (ppm)	48	High	31.2	Adequate
Potassium (mmol/kg)	1.2	Adequate	0.54	Adequate
Calcium (meq%)	22.4	High	4	Adequate
Magnesium (meq%)	3.77	High	3.87	High
Manganese (meq%)	0.39	Adequate	0.23	Adequate
Copper (ppm)	1.17	Adequate	8.17	Adequate
Fe(ppm)	7.33	Low	38.7	Adequate
Zn (ppm)	0.93	Low	7.7	Adequate
Sodium (Meq%)	3.92	High	0.74	Adequate
Electric conductivity(mS/cm)	4.0	High	1.5	Adequate
Particle size distribution	36%sand 52% clay 12% silt	Class C:Clay	62%sand 30% clay 8% silt	Class Sandy clay loam

3.2 Plant Height and Tillering as Influenced by Variety and Nitrogen Doses

Plant height and plant tillering ability differed significantly ($p \leq 0.05$) among the rice varieties and nitrogen doses tested during the two cropping seasons (Table 2). Plant height increased from 0 to 67.5 kgN ha^{-1}, beyond which further increments to 84.3 and 101 in kgN ha^{-1} resulted in marginal gains. This N dose produced the tallest plants (57.89 cm), which were 12% taller than those planted without nitrogen. The increase in plant height with rising nitrogen levels is associated with enhanced metabolic activity leading to enhanced development of plants meristematic cells, hence the formation of new shoots greater internode elongation and overall plant height. Nitrogen, being a key constituent of amino acids, proteins, and nucleic acids, supports vigorous shoot elongation and structural development (Pal *et al*., 2020). Similar findings were reported by (Pal *et al*., 2020: Chirchir et al., 2018). In a study in Kenya, (Kagito and Gikonyoi, 2020) reported significantly taller plants (103.87 cm) and more number of tillers (14.29) at higher N fertilizer dose (78 kg Nha^{-1}), across two cropping seasons under local agro-ecological conditions in Mwea, Kirinyaga. They attributed the positive response to improved nitrogen availability and internode expansion. Plants grown without nitrogen were significantly ($p<0.05$) shorter (50.91cm) with fewer tillers (16.67), across all varieties.

Tillering was significantly ($p \leq 0.05$) influenced by N doses with the highest number of tillers (19.66) recorded in 84.3 kgN ha^{-1} representing 15.1% more tillers than non-fertilized plants. The trend was similar to plant height where tillering increased with nitrogen increment peaking at 84.3 kgN ha^{-1}. These results highlight the key role of nitrogen in enhancing vegetative growth, tiller initiation by stimulating axillary bud development and prolonging the vegetative phase (Allahyar, 2011). Among the tested genotypes**,** Nerica 1, recorded taller plants (60.63 cm) which was 15% taller than the shortest (51.39cm) plants recorded in variety AT058, while Komboka had the highest number of tillers (25.15), a 49% higher value compared to Nerica 1 which recorded the least number (12.8) tillers per plant. The results demonstrate that variation in genetic makeup of rice varieties may have been influenced by heredity and environmental factors leading to differences in plant height and tiller number (Allahyar, 2011)**.** A similar study in the same area reported higher number of tillers (19.64) and plant height (111 cm) in rice variety silewa under lowland irrigated conditions (Chawana *et al*., 2021).

The long rain season attained 8% taller plants and 22.7% higher tillering compared to short rain season. This is attributed to increased availability of adequate moisture, enabled better uptake, translocation and use of nutrients over the cropping period. (Allahyar, 2011), reported a positive influence of moisture and Nitrogen on plant height and tiller number among other parameters. This could be due to better distributed rainfall and nutrient synchrony during the vegetative phase, as well as reduced risk of nitrogen leaching due to lighter soils. Plant Height and rice tillering was influence by genotype, Nitrogen and season. Similar observations were made by (Wekesa *et al*., 2021) in their study on effect of Inorganic and organic amendments on agronomic characteristics of rice straw in the hills of Taita Taveta County.

3.3 Leaf Morphological Traits as Influenced by Variety and Nitrogen Levels

Leaf length, leaf width and number of leaves were significantly ($p \leq 0.05$) influenced by treatments with exception on N influence on Leaf length and number of leaves in Taveta. This lack of interaction between Varieties and Nitrogen rates in Taveta implies a non-synergistic influence on N uptake and utilization to incremental N (Table 3). Leaf length, leaf width and number of leaves, increased progressively with nitrogen application up to 101 kgN ha^{-1}, with maximum values 26.1cm, 1.04cm and 26.62 respectively, representing 12.2, 13.2 and 14.3% higher values compared to non-fertilized plots. Nitrogen plays a key role in leaf elongation by stimulating the production of cytokinins, which promote cell division and expansion. These hormonal effects increase tissue formation, thereby expanding the photosynthetic surface area. Enhanced leaf length improves light interception, facilitates higher photosynthetic rates, and ultimately boosts assimilate accumulation (Fathi, 2022). Adequate nitrogen influences the synthesis of chlorophyll and photosynthetic proteins, which aids in robust vegetative growth (Fathi, 2022) wider leaves broaden the canopy's photosynthetic area, hence improving the effectiveness and efficiency of light capture, utilization and dry matter production. Non-fertilized control plots (0 kgN ha^{-1}) recorded

Table 2. Effect of Nitrogen fertilizer Levels and Varieties on Plant Height and Number of tiller per rice plant in Bura and Taveta

	Plant Height (cm)				Number of Tillers per Plant			
Treatment	**Bura**		**Taveta**		**Bura**		**Taveta**	
	Short rain	**Long rain**	**Short rain**	**Long rain**	**Short rain**	**Long rain**	**Short rain**	**Long rain**
V1	59.51a	67.06 a	63.64 a	52.29 d	11.91d	15.17 c	10.52 d	13.60 d
V2	49.16 bc	54.57 c	58.40 b	64.65 b	20.53 b	28.06 a	17.62 b	22.87 b
V3	50.33 b	57.67 b	56.86 b	67.26 a	22.72 a	27.33 a	21.00 a	29.55 a
V4	47.17cd	55.00 c	56.23 b	59.41 c	15.07 c	18.23 b	15.00 c	19.39 c
V5	45.7d	55.49 c	50.88 c	53.47 d	15.25 c	16.31bc	11.62 d	17.95 c
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD (0.05)	2.00	1.81	3.86	2.19	1.33	2.49	1.34	1.89
CV (%)	6.44	5.05	10.92	5.97	12.55	19.1	14.89	14.79
N0	45.77 c	53.21 e	50.39 b	54.25 d	13.81 c	19.19 c	13.60 b	20.15
N1	49.75 b	55.45 de	55.55ab	57.42 c	15.87 bc	19.99 bc	14.93 ab	20.19
N2	50.31ab	56.41 cd	56.74a	58.32 c	16.73 ab	20.61abc	15.20 ab	20.99
N3	50.63 ab	58.45 bc	57.93a	59.35 bc	18.01 a	20.95 ab	14.93 ab	19.26
N4	51.47 ab	59.53 ab	59.32a	61.25 ab	18.04 a	22.09 a	15.80 ab	20.70
N5	51.84 ab	60.95 ab	59.25a	62.61a	18.49 a	22.28 a	16.20 a	21.67
N6	52.87 a	61.71 a	61.23a	62.70 a	18.73 a	22.02 a	15.40 ab	21.73
Mean	50.38	57.96	57.2	59.41	17.1	21.02	15.15	20.67
p value N	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.07
p value NxV	0.970	0.810	1.000	0.610	0.930	0.990	0.910	0.931
HSD (0.05)	2.8	2.78	5.85	2.18	2.12	1.69	2.27	
CV (%)	4.35	3.75	8	2.87	9.71	6.29	11.69	10.15

Means followed by the same letter in each column are not significantly different from each other at α=0.05; CV – Coefficient of Variation; LSD – Least Significant Difference

Table 3. Effects of nitrogen levels and varieties on rice Leaf morphological characteristics in Bura and Taveta in two cropping seasons

	Leaf Length (cm)				Leaf Width (cm)				Number of leaves			
Treatment	**Bura**		**Taveta**		**Bura**		**Taveta**		**Bura**		**Taveta**	
	Short rain	**Long rain**	**Short rain**	**Long rain**	**Short rain**	**Long rain**	**Short rain**	**Long rain**	**Short rain**	**Long rain**	**Short rain**	**Long rain**
V1	26.03 a	31.12 a	22.63 b	21.99 d	1.02 a	1.04a	0.75 b	1.00 c	40.61 a	39.27 a	16.43 b	12.95 c
V2	23.96b	26.38 c	23.02 b	26.84 a	0.95 b	0.99b	0.77 ab	1.30 b	40.17 a	30.47 c	21.46 a	19.29 a
V3	23.60 b	27.51 b	25.71 a	26.32 ab	0.98 ab	0.93c	0.80 a	1.52 a	42.86 a	36.10 b	23.00 a	17.24 b
V4	21.55 c	27.58 b	21.08 c	22.78 cd	0.95 b	0.99b	0.69 c	0.99 c	26.60 b	26.50 d	18.51 b	14.90 c
V5	21.31 c	26.18 c	22.73 b	24.64 bc	0.90 c	0.96 bc	0.78 a	0.99 c	22.24 c	28.14 cd	14.00 c	14.24 c
p value V	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD (0.05)	0.77	1.11	1.12	2.10	0.04	0.04	0.04	0.08	4.32	3.07	2.34	2.04
CV (%)	5.37	6.45	7.85	13.86	7.50	5.98	8.22	11.27	20.25	15.48	20.25	21.00
N0	21.50 c	25.19 e	21.23 b	23.60	0.94 b	0.94b	0.66 c	1.08 b	29.47 b	31.34	15.97 b	14.47
N1	22.61b c	26.27 de	22.58 ab	23.76	0.97 ab	0.97ab	0.71 bc	1.09 b	33.87 ab	32.73	19.29 a	14.60
N2	23.26 ab	26.91 cd	23.55 a	23.62	0.96 ab	0.96ab	0.76 ab	1.12 b	34.17 a	31.12	18.55 a	15.80
N3	23.52 ab	28.12 bc	23.10 ab	23.86	0.98 ab	0.98ab	0.7 7ab	1.15 b	37.87 a	32.20	18.73 a	15.80
N4	23.76 ab	28.67 ab	23.27 ab	24.97	0.99 ab	0.99ab	0.76 ab	1.19 ab	34.53 a	32.67	18.80 a	16.00
N5	24.08 a	29.31 ab	23.46 a	25.74	1.00 ab	1.00ab	0.78 ab	1.19 ab	34.80 a	31.84	19.19 a	16.67
N6	24.30 a	29.81 a	24.07 a	26.02	1.03 a	1.03a	0.82 a	1.29 a	36.77 a	32.77	20.21 a	16.73
Mean	23.29	27.75	23.04	24.51	0.96	0.98	0.76	1.16	34.50	32.10	18.68	15.72
p value N	<0.001	<0.001	0.01	0.08	0.09	0.03	<0.001	<0.001	<0.001	<0.001	<0.001	0.15
p value NxV	0.55	1.00	0.89	0.46	1.00	0.61	0.54	0.31	0.97	0.67	0.98	1.00
HSD (0.05)	1.39	1.33	2.16			0.07	0.09	0.12	4.51		2.23	
CV (%)	4.67	3.76	7.35	10.45	9.28	5.97	9.73	8.10	10.24	15.84	9.34	15.85

Means followed by the same letter in each column are not significantly different from each other at α=0.05; CV – Coefficient of Variation; LSD – Least Significant Difference

the shortest (21.50 cm) and the narrowest (0.66 cm) leaves across both sites and seasons. Nitrogen facilitates protein and nucleic acid synthesis, which are critical for cell division and leaf development. Optimum nitrogen availability is essential for chloroplast formation and meristematic activity, both of which are vital for sustained leaf initiation and expansion. Many leaves contributes to an increased Leaf Area Index (LAI)**,** enhancing light capture and photosynthetic activity, resulting in higher dry matter accumulation and yield formation. Similar findings have been reported. Despite the application of nitrogen doses, leaf length and number of leaves in Taveta did not show significant ($p \leq 0.05$) variation, indicating a lack of synergistic interaction between nitrogen dose and genotype response. This can be attributed to the inherent properties of soils in Taveta experimental site (Table 1), which have insufficient macro and micronutrients, high pH (9.01) and sodium levels (3.92 Meq%), all of which interfered with nutrient uptake, hence the applied nitrogen was rendered ineffective. Rice production requires slightly acidic soils. Sodium ions compete with essential cations, reducing nitrogen absorption and utilization efficiency. High levels of salinity induce osmotic tension, thereby reducing the flow of nutrients to plant roots (Chen *et al*., 2015).

Significant ($p \leq 0.05$) varietal effects were observed, with 17KH090014B producing the longest leaves (25.78 cm), widest leaves (1.06 cm) and highest number of leaves 26.62 representing 9.8%, 14.4% and 34% higher values compared to the lowest leaf parameters CSR36. These genotypic differences reflect the inherent variation in nitrogen uptake, root architecture, and above ground growth potential. Nerica varieties, in particular, are known for greater root plasticity and adaptability under stress conditions such as moderate drought (Menge *et al*., 2016). Such root systems are able to support more effective nutrient acquisition, resulting to greater leaf expansion and tiller formation. Similarly (Allahyar, 2011: Wekesa *et al*, 2021) reported longer leaves in Nerica1 and WDR73 under varying environments, highlighting the adaptability and yield potential of improved upland rice genotypes.

3.4 Panicle Traits as Influenced by Varietal Differences and Nitrogen Levels

Nitrogen application significantly ($p<0.05$) enhanced panicle morphological traits including panicle length, total and filled grain number per panicle (Table 4). Optimal performance was observed at 67.5 kg Nha^{-1}kg N ha^{-1} with longest panicles (18.07cm), total and fertile grains per panicle (120.77) and (79.43) respectively, representing 7.6, 14.2 and 22.9% respectively, above non fertilized plots**.** In contrast, the shortest panicles (16.71cm), lowest total and fertile grains per panicle 103.66 and 61.23 respectively occurred in the control (0 kgN ha^{-1}), confirming nitrogen's key role in reproductive organ improvement. Panicle development is greatly influenced by N up to ideal doses hence, thus Supporting the elongation of panicles by energy supply and reproductive tissue differentiation**,** including improved vascular development and assimilate partitioning. However, nitrogen dose above reproductive limit may stimulate increased vegetative growth, leading to sink competition, increased number of unfilled grains per panicle and reduced panicle size. Adequate nitrogen during tillering and panicle initiation phases ensures that more tillers develop into productive panicles, enhancing yield potential According to (pal, (Chirchir *et al*., 2018). nitrogen stimulates spikelet fertility through enhanced chlorophyll content, photosynthetic rate and cytokinin activity, all of which have (Chirchir *et al*., 2018). a positive influence on floret initiation and grain filling. This is in agreement with findings reported by (Chirchir *et al*., 2018) who reported increased panicle length with increased nitrogen application up to 150 kg N ha^{-1}, after which sterility or unfilled grains tended to increase in number, reducing grain yield. Findings of these studies also contradicts findings by (Allahyar, 2011; Wekesa *et al*., 2021) who reported non-significant effects of nitrogen on panicle length under highland conditions in Taita Taveta. This discrepancy could be attributed to site-specific challenge, including soil pH, salinity, or moisture stress, which may have inhibited nitrogen uptake and utilization.

Maximum values for genotypes influence were observed in rice variety 17KH090014B, which attained a panicle length (20.65 cm), total grains per panicle (142.22) and fertile grains per panicle (99.28), respectively, representing 28%, 39.8% and 47.4% higher than AT058 which obtained lower. Varietal characteristics of rice genotype play a significant role in enhancing panicle traits and grain filling (Parida, et al., 2022). Variation in panicle length was reported by (Milela *et al*., 2022) who attributed it to environmental factors, such as moisture and the genetic traits of a cultivars that may have either many or long roots.

Table 4. Main effect of nitrogen levels and varieties on panicle length, total number grains per panicle, fertile number grains per panicle

Treatment	Panicle Length (cm)				Number total grains per panicle				Number of fertile grains per panicle			
	Bura		Taveta		Bura		Taveta		Bura		Taveta	
	Short rain	Long rain	Short rain	Long rain	Short rain	Long rain	Short rain	Long rain	Short rain	Long rain	Short rain	Long rain
V1	22.95 a	22.61 a	16.23 b	15.67 cd	160.69 a	182.06 a	99.26 c	101.93 c	120.59 a	164.25 a	57.94	50.39 c
V2	17.63 c	16.58 c	19.27 a	19.84 b	115.60 b	114.46c	108.41 b	125.74 b	68.44 b	86.16 c	54.65	81.19 b
V3	20.28 b	21.93 b	18.69 a	21.68 a	118.04 b	149.96 b	127.56 a	173.33 a	72.03 b	126.42 b	71.83	126.82 a
V4	13.26 e	16.27 c	14.66b c	16.14 c	81.22 c	109.44c	89.63 d	96.43 c	45.37 c	77.95 d	48.00	60.55 c
V5	15.21 d	15.13 d	14.08 c	14.99 d	83.97 c	86.99 d	85.62 d	85.78 d	42.53 c	62.49 e	50.92	53.11 c
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD (0.05)	1.93	0.47	1.86	0.98	5.05	5.30	7.65	9.82	7.16	6.12	4.00	2.00
CV (%)	17.45	4.10	18.11	9.00	7.30	6.67	12.13	13.62	16.60	9.56	11.41	25.07
N0	16.55 b	17.96 d	15.63 b	16.69 d	99 d	120.76 d	87.63c	107.24 b	37.98 b	86.44 b	56.19 ab	64.26 b
N1	17.28 ab	18.08 cd	16.34 ab	17.14 cd	106.36 c	125.07 cd	98.93b	113.35 ab	72.93 a	102.28 a	57.38 ab	72.55 ab
N2	17.81 ab	18.28 bcd	16.55 ab	17.37 bcd	110.16 bc	127.82 bc	100.32b	112.47 ab	71.45 a	105.92 a	58.21 ab	74.08 ab
N3	17.35 ab	18.37 bcd	16.14 ab	17.72 abc	113.92 ab	129.58 abc	103.34ab	117.47 ab	77.18 a	106.38 a	59.53 a	73.76 ab
N4	18.57 ab	18.65 abc	17.06 a	18.03 ab	116.83 a	131.72 ab	105.52ab	118.85 ab	74.28 a	105.89 a	59.37 a	76.71 a
N5	18.66 ab	18.93 ab	17.23 a	18.32 a	118.22 a	131.86 ab	109.07a	123.92 a	75.41 a	106.44 a	55.13 b	80.74 a
N6	18.84 a	19.26 a	17.15 a	18.37 a	118.84 a	133.26 a	109.88a	123.19 a	79.31 a	110.85 a	50.86 c	78.80 a
Mean	17.86	18.50	16.58	17.66	111.91	128.58	102.10	116.64	69.79	103.46	56.67	74.41
p value N	0.03	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
p value NxV	0.99	1.00	1.00	<0.001	1.00	1.00	1.00	1.00	0.63	0.39	1.00	<0.001
HSD (0.05)	2.22	4.95	1.20	0.69	5.89	5.18	8.67	11.90	11.96	13.40	4.02	12.14
CV (%)	9.72	**2.82**	**5.67**	**3.05**	**4.12**	**3.15**	**6.64**	**7.98**	**13.41**	**10.14**	**5.55**	**12.76**

Means followed by the same letter in each column are not significantly different from each other at α=0.05; CV – Coefficient of Variation; LSD – Least Significant Difference

Table 5. Tiller and leaf numbers per plant as affected by interaction between rice varieties and Nitrogen levels

	Variety	N kg per ha						
		0	**17**	**34**	**51**	**67.5**	**83.4**	**101**
Tillering	Nerica 1	14.8±0.8a	15.3±0.8a	15±0.8 a	15.4±0.4a	15.4±0.7a	14.9±0.8a	15.3±1.2a
	KOMBOKA	23.7±3.9b	27±4 ab	27.3±3.5ab	27.7±3.1a	29.7±2.1a	30.3±2.3a	30.7±2.1a
	17KH090014B	23±8.7 c	25.3±8.1bc	27±7.8 ab	27.7±6.7ab	29±6.1ab	29.7±4.9a	29.7±4.9a
	CSR36	23±8.7 c	15.9±2.7 a	17.7±1.2 a	18±1.7a	19.7±5 a	19.7±5 a	18±1 a
	AT058	15.7±0.5a	16.4±0.5 a	16±0.1 a	16±0.1 a	16.7±0.5a	16.8±0.7a	16.4±0.5a
	p value	**0.0057**						
Number of Leaves	Nerica 1	33±10.6b	40.7±13.7ab	23.3±5.8a	42.9±13.3a	43±15.9 a	39.7±15ab	43.7±16.3a
	Komboka	31.7±5.8b	38±1.7 ab	38±2ab	42.7±0.6a	42±3a	43.7±2.3a	45.2±5.3a
	17KH090014B	35.3±0.6c	41±1.7 bc	41.7±1.5bc	53.3±8.1a	40.7±2.5bc	42.3±4 bc	45.7±1.2ab
	CSR36	24.7±5.1a	26.3±6.4 a	27.2±7.1 a	27.1±6.1 a	26.7±5.8 a	26.7±5.8 a	27.7±6.8 a
	AT058	22.7±6.4a	23.3±5.8 a	22.7±4.6 a	23.3±5.8 a	20.3±0.6 a	21.7±2.9 a	21.7±2.9 a
	p value	**0.0194**						

Means followed by the same letter in each column are not significantly different from each other at α=0.05; CV – Coefficient of Variation; LSD – Least Significant Difference

Table 6. Total and fertile grains per panicle as affected by interaction between rice varieties and Nitrogen levels

	Variety	KgN ha^{-1}						
		0	**17**	**34**	**51**	**67.5**	**83.4**	**101**
Total grains per panicle	Nerica 1	89.4±11.2b	98.4±11.9ab	99.3±12.1ab	100.0±12.5ab	100.7±12.6ab	104.2±16.1a	102.4±14.5a
	Komboka	97.6±28.5c	103.6±23.1bc	107.1±24.6abc	107.1±24.3bc	112.5±28.3ab	113.2±28.9ab	117.6±24.6a
	17KH090014B	103.3±27.8c	122.8±20.3 b	124.1±19.6 b	125.6±18.5 b	132.6±26.4 b	143.8±33.7 a	140.4±30.8
	CSR36	77.2±5.2 b	85.0±7.2 ab	86.2±8.3 ab	93.9±11.2 a	93.5±12.5 a	95.1±14.8 a	96.6±14.0 a
	AT058	70.7±10.3 b	84.8±10.0 a	85.0±10.8 a	89.9±7.5 a	88.0±11.8 a	88.6±11.2 a	92.4±12.9 a
	p value	**0.0183**						
Fertile grains per panicle	Nerica 1	70.3±17.9b	130.5±13.6a	128.7±10.8a	130.5±5.9a	127.1±7.2a	126.5±2.8a	130.5±9.1a
	Komboka	36.3±9.1 b	66.9±14.5 a	67.1±16.7 a	80.5±22.3a	70.3±16.7a	74.4±6.5 a	83.6±7.1 a
	17KH090014B	36.8±10.8b	78.7±18.7a	75.4±13.7a	74.2±10.4a	77.1±13.4a	77.2±20.2a	84.7±26.1a
	CSR36	23.6±0.9 b	46.9±4.5 a	45.3±12.9 a	52.5±7.6 a	50.6±14.8a	51.1±9.2a	47.1±8.1a
	AT058	22.9±4.8 b	41.7±11.6 a	40.8±14.2ab	48.2±15.5a	46.2±15.0a	47.8±8.5 a	50.1±6.1 a
	P Value	**0.0112**						

Means followed by the same letter in each column are not significantly different from each other at α=0.05; CV – Coefficient of Variation; LSD – Least Significant Difference

The good performance of Bura in panicle characteristics, leaf morphological parameters and rice tillering ability was due to adequate initial inherent soil fertility at the beginning of experiment, with optimum soil pH for rice growth, together with applied Nitrogen which enhanced the availability of nutrients for rice varieties during growth and grain filling period (Table 1). Taveta soils had high pH, high sodium levels, with inadequate macro and micronutrients, which may have rendered applied Nitrogen ineffective. A study by (Jewel *et al.,* 2019), reported that nitrogen influence on productivity of rice growth and yield attributes depend on agro ecological zones and fertility status of the soil.

3.5 Effects of Variety-Nitrogen Interaction on Rice Number of Leaves and Number of Tillers

A significant interaction ($p \leq 0.05$) between nitrogen levels and rice varieties was observed on the number of tillers and number of leaves per plant in Bura during long rains season (Table 5). These interactions suggest that nitrogen responsiveness was more pronounced at 51 to 83.4 kg N ha^{-1}. Higher number of leaves per plant (53.3), were obtained in 17KH090014B at 51 kgN ha^{-1}, followed by Komboka (45.2) at 101 kg N ha^{-1}. Rice varieties CSR and AT058 were not influenced by N level (Table 5).

The interaction effect of Nitrogen and variety was statistically significant on tillering with higher tiller number (30.7), obtained in Komboka at 101 kgN ha^{-1}, which was significantly ($p \leq 0.05$) similar to 83.4, 67.5 and 51 kgN ha^{-1}. This was followed by 17KH090014B at 83.4 kgN ha^{-1} (29.7). However, Nerica1**,** CSR36, and AT058 did not exhibit significant tillering responses to increasing nitrogen, indicating that either their tillering potential is genetically fixed or they are less efficient in nitrogen uptake and utilization during the vegetative phase. This is in agreement with (Chawana *et al*., 2021) who reported that rice genotype MWIR2, R 1081, and SARO had a positive response of inorganic fertilizer application, resulted in significantly higher values in grains per panicle compared to non-fertilized control plots.

A significant interaction ($p \leq 0.05$) between nitrogen levels and rice varieties was observed on total and fertile grains per plant (Table 6). These interactions suggest that nitrogen responsiveness was more pronounced at 51 to 83.4 kgN ha^{-1}. Higher values 143.8 grains per panicle were obtained in 17KH090014B per ha at 83.4 kgN ha^{-1}, which was not different from 101 kgN ha^{-1}. Komboka attained 117.6 grains per panicle at the same level. Nerica 1 at 83.4 kgN ha^{-1} (104.2 grains), while CSR at 67.5 kgN ha^{-1}. Rice variety AT058 was not influenced by N level.

4. CONCLUSIONS AND RECOMMENDATIONS

The study found that 67.5 kgN ha^{-1} was the optimum nitrogen rate, as higher rates (83.4 and 101 kgN ha^{-1}) did not yield significant additional benefits. Variety 17KH090014B outperformed others by producing the highest total (142.22) and fertile (99.28) grains per panicle, longest panicles (20.65cm), and most leaves per plant. The interaction of genotype and nitrogen maximized number of tillers (30.7) in rice variety kwamboka at 67.5 kgN ha^{-1}, with further N increase yielding minimum benefits. Nerica 1 obtained the lowest tillering despite yielding higher fertile grains per panicles compared to other varieties. Similarly 17KH090014B interacted with 83.4 kgN $ha^{-1}$to produce the highest (143.8) grains per panicle. It is recommended to apply 67.5 kgN ha^{-1} for 17KH090014B during the long rains in Taita Taveta County, with further validation needed using wider regional trials.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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