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Response of Paddy Rice (*Oryza sativa* L.) Morphological Characteristics to Nitrogen Fertilizers in Taveta, Kenya

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Authors' contributions

This work was carried out in collaboration among all authors. Author IRC wrote the methodology, conducted the experiment, and collected the data. Author JG supervised the study and participated in manuscript preparation. Author JK provided expert technical support during the study and participated in manuscript preparation. Authors AKK, MM and JM participated in manuscript preparation. Author MM provided technical support in study design, supervised the study, performed the statistical analysis, wrote the first draft of the manuscript and prepared the final copy. All authors read and approved the final manuscript.

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ABSTRACT

This study investigated the effect of applying nitrogenous fertilizers on the morphological traits in six paddy rice varieties in Taveta, Kenya. The six paddy rice varieties, including local control, were tested during the 2018 and 2019 seasons. The experiments were laid out in a split-plot design with three replications. The main plot was the fertilizer treatment while the subplot was the varieties tested including NIBAM-11, K2-9, MWIR-2, R-1081, Silewa, and a local control Saro. The fertilizer

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treatments were no fertilizer, farm yard manure (FYM) alone, FYM+Urea fertilizer, and FYM+CAN fertilizer. Significant differences (P < 0.05) among varieties were observed for all the morphological traits that were assessed. Silewa was the tallest plant (111 cm), had the highest number of grains per panicle (163), and also the highest 1000-grain weight (29.2 g). Fertilizer treatments had significant effects on plant height, leaf length, number of tillers, panicle length, and number of grains per panicle. FYM+Urea resulted in the highest number of grains per panicle while FYM alone resulted in the highest 1000- grain weight (25.56 g). Varieties significantly interacted with fertilizers for the number of grains per panicle. Leaf length had significant direct association with 1000-grain weight (r = 0.427) and grains per panicle (r = 0.874). It can be recommended that there is an opportunity to use farm yard manure alone or in combination with an inorganic fertilizer to improve yield traits while reducing dependence on inorganic fertilizers.

Keywords: Rice; fertilizer; grain; variety; correlation.

1. INTRODUCTION

Global paddy rice production totaled 755.47 million tons in 2019 [1] underscoring it as one of the most important cereals for food. At the same time, the average world yield of paddy rice was 4.66 tons ha^{-1} while that in Kenya was 6.84 tons ha^{-1} [1]. Several factors that influence production include the genotypes produced, cultural practices, environmental conditions, and pest and disease attack. While the production environment can be made more favourable for enhanced productivity [2], breeding for improved yield is seen to be the most sustainable option [3]. Yield is also influenced by various yield-related traits which may have a direct or inverse relationship. For example, [4] found that full-grain number per plant had the greatest influence on yield (r=0.96). Other variables that had a positive correlation with yield were the number of panicles per plant and grain length. Associations among yield-related traits have also been reported by several researchers. [5] reported that the number of tillers per plant was positively correlated with plant height and the panicle length. On the other hand, they reported that plant height was negatively correlated with 100-seed weight. [6] reported negative but non-significant correlations between 1000-grain weight and biomass.

Management practices have been known to have a significant effect on rice yield [2]. These management practices include watering regimes, spacing, and soil fertility management. [7] reported significant differences in yield and uptake of nitrogen by paddy rice varieties when they subjected the varieties to different levels of nitrogen fertilizer. Correlations between yield and yield-related traits were shown to vary under different nutrient conditions [8]. Notably, they found that the absence of phosphorous tended to strengthen the positive relationship between grain yield and biomass. [9], in their study on japonica soft super rice, also recorded increasing rice grain yield with increasing nitrogen application levels up to 300 kg ha^{-1} of nitrogen before yields decreased with higher levels of nitrogen applied. However, they concluded that 270 kg $ha^{–1}$ of nitrogen was the most suitable level for both high yields and high cooking quality. [10] tested lodging resistance for three super rice varieties under three nitrogen levels (0, 150, and 300 kg ha^{-1}). They found that increased nitrogen application increased the tendency to lodge. They also reported that higher nitrogen levels tended to increase the values of morphological traits of the varieties thus increasing their lodging tendency.

Nitrogen fertilizer has, therefore, been shown to have a positive effect on the morphological characteristics of rice. However, the effect depends on the variety and also on the level of nitrogen used. To ensure that farmers use available fertilizers optimally and under good management practices, it is important to provide appropriate recommendations. So far, the effect of nitrogen on morphological characteristics of the new varieties being tested has not been assessed in Taveta. The objective of this study was, therefore, to test the effect of different types of nitrogenous fertilizers on yield-related traits of rice.

2. MATERIALS AND METHODS

2.1 Plant Materials

Six rice varieties, including Silewa, K2–9, MWIR 2, NIBAM-11, R 1081, and Saro, were used in the experiment based on their desirable characteristics (Table 1). Saro was included as a local control because of its popularity among Taveta farmers.

2.2 Study Area Description

The experiment was conducted in Taveta Sub-county, Taita-Taveta County, Kenya, on latitude 3°28'22"S and longitude 37°41'44"E with an elevation of 794 MAMSL. The soils in the experimental site are majorly deep vertisols/montmorillonite clay that often shrink and crack when dry while they expand and swell when wet. They are very sticky in the wet season, very hard in the dry season, and have an aridic moisture regime. The soil chemical properties at the beginning of the two planting seasons are presented in Table 2. This is a lowland irrigated site where farmers plant paddy rice under flood irrigation during the January to June cropping season while they plant beans from June to October during the off-season. The experiments were laid out in November 2018 to February 2019 and April to July 2019, respectively.

2.3 Experimental Design

The experiment was laid out in a split-plot design with three replications. The main plots consisted of the fertilizer treatments while the sub-plots were made up of the six rice varieties with the main interest being varietal response. Each subplot measured 2.5 m by 2 m, and the subplots were separated by 1m wide paths. Each replicate was made up of four main plots and within each main plot were six sub-plots. Within each sub-plot, the plants were spaced 0.3 m between rows and 0.2 m within rows. The seedlings were transplanted at the rate of one seedling per hill giving a population of 83 plants per plot (166,000 plants ha^{-1}).

2.4 Experimental Treatments and Procedures

The land was ploughed, raked, and pulverized to level the field and remove any trash. Before transplanting commenced, farm yard manure (FYM) was applied at the rate of 10 tons ha^{-1} to the three main plots except the control main plots. Among the three main plots treated with FYM, one of them was top-dressed with urea (46% N) at the rate of 240kg ha^{-1}, the one was not top-dressed, while the third one was top-dressed with CAN (26% N) at the rate of 160kg ha^{-1}. This top-dressing was done14 days after transplanting. The main-plot fertilizer treatments were, therefore: (i) Farm yard manure (FYM), (ii) Farm yard manure (FYM) + urea, (iii) Farm yard manure (FYM) + CAN, (iv) Control (natural fertility, that is, no fertilizer applied). The seedlings of the six rice varieties were raised in a nursery for three weeks before they were randomly allocated to the sub-plots and transplanted. During both seasons, the crop was flood irrigated until physiological maturity. Water availability to the crop, therefore, was not considered as a factor to affect crop growth and development.

2.5 Data Collection

Six plants within the middle area (1 m^2) of each plot were randomly selected from each plot and tagged at 14 days after transplanting while avoiding the border rows. Data were collected from the six plants at harvest. These variables included plant height, leaf length, number of tillers per plant, panicle length, number of grains per panicle, 1000-grain weight. Fresh straw weight per plant was obtained by cutting the plant at ground level and weighed immediately after harvest. Samples of soil were collected before planting in each season, and the nutrient content was analyzed.

2.6 Data Analysis

Data were subjected to analysis of variance (ANOVA) at α=0.05, using the Statistical Tool for Agricultural Research (Version 2.0.1) software. The LSD test was used to identify any significant differences among the means. Associations among the variables were assessed using the Pearson linear correlation coefficient.

Table 1. Paddy rice varieties evaluated in the study

Variety		Characteristics
1.	NIBAM-11	Highly aromatic, thin slender grains
2.	K2-9	High yielding, early maturity (60-70 days)
3.	MWIR-2	High yielding, tolerant to rice blast and Rice Yellow Mottle Virus
4.	R-1081	High yielding
5.	Silewa	Japonica cold tolerant
6.	Saro	High yielding local variety with dense grains

2.7 Limitation

This study did not consider grain yield but sought to limit itself to yield-related traits that tend to have significant effects on grain yield.

3. RESULTS AND DISCUSSION

3.1 Soil Analysis

The soil pH in both seasons was neutral the pH of the FYM-treated soil tended to be alkaline. Rice requires slightly acidic conditions (Table 2). Soil K was higher in season 2 while Fe and Mn were higher in season 1 but were lower than the optimum values required. In both seasons, the organic carbon was three times higher, Ca was almost three times higher, Fe over 100% higher, and P content 6 times more in the farm yard manure than in the soil.

3.2 Morphological Variations among the Varieties

Varieties were significantly different for all traits while fertilizer had significant effects on all traits except 1000-grain weight. The seasons had significant effects only on plant height, leaf length, and panicle length (Table 3). Season, fertilizer, and variety interactions were significant only for plant height and fresh weight.

The means for the various traits from the experiments are presented in Table 4. Significant differences among varieties were observed for all the morphological traits that were assessed. Variation in traits could be due to the rice ecotype, the availability of nutrients, or a combination of both [13,14,15]. [16] also obtained significant variation for plant height, panicle length, and 1000-grain weight in a trial involving 14 upland rice genotypes. Three varieties in this study were taller than the mean, whereby the tallest variety was Silewa (111.08cm), almost three times taller than K2-9 which was the shortest (48.37cm). Silewa had significantly longer leaves than the other varieties. On the other hand, Silewa had the least number of tillers per plant (19.64) while the rest of the varieties were not significantly different from one another. [14] suggest that it is not just tillers *per se* that increase yield, but the number of productive tillers. In addition, Silewa had the longest panicles, highest number of grains per panicle, highest and 1000-grain weight. Some of these variables were found to be directly associated with yield by [16] and [17]. Only Saro and Silewa had higher grain weight than the mean. K2-9, on the other hand, performed consistently the lowest for all the parameters assessed except the number of tillers per plant. Fresh straw weight per plant was highest in MWIR-2 (47.28g), probably as a result of many tillers, followed by Saro (44.77g). These two varieties had 50% higher fresh weight compared to K2-9 and 19% more fresh weight than the third variety (NIBAM-11).

3.3 Effect of Fertilizer Treatment on Plant Morphology

Fertilizer treatments had significantly different effects on plant height, leaf length, number of tillers per plant, panicle length, and number of grains per panicle (Table 5). Other studies showed significant differences among varieties in grain weight [18,19]. The FYM+urea fertilizer combination consistently resulted in the highest values for most variables except in some instances where the FYM+CAN combination outperformed it. Urea has almost twice the amount of nitrogen compared to CAN hence this nitrogen is likely to have contributed to more morphological growth. [20] noted that higher

Table 2. Nutrient content of soil and farm yard manure

Property	Guideline value[1,2]	Season 1		Season 2	
		Soil	FYM	Soil	FYM
pH (H_20)	5.0-6.5	7.10	8.14	7.27	7.90
% OC	2.0-3.5	2.68	8.50	2.20	9.90
% N	>0.2	0.28	0.98	0.31	1.03
K (mmol/kg)	>2	16.50	39.40	25.70	39.50
Zn (ppm)	>1	2.70	8.90	2.08	5.28
Fe (ppm)	>5000	53.20	120.20	45.90	110.30
Mn (ppm)	>500	95.70	80.20	87.00	65.20
P (ppm)	>10	118.00	828.00	129.00	816.00
Ca (mmol/kg)	>38.46	82.50	266.00	97.50	257.00

Sources: 1. [11]; 2. [12]

Table 3. Analysis of variance for the morphological variables

Source	Degrees of freedom	Plant height (cm)	Leaf length	Number of tillers per plant	Panicle length	Number of grains per panicle	1000-grain weight (g)	Fresh straw weight per plant (g)
Season	1	13154.94**	120.56*	2.30	3103.05*	15.87	132.25	1849.00
Replication within Season	4	32.30	6.46**	164.08**	17.77**	81.63**	21.89	1579.77
Fertilizer	3	1163.05**	135.40**	387.12**	18.87**	4218.47**	7.43	3242.18*
Season*Fertilizer	3	945.95**	1.57	14.73	6.57	11.39	9.75	975.11
Pooled Error(a)	12	79.91	0.79	17.21	2.49	14.59	6.85	549.34
Variety	5	10804.06**	500.98**	106.40**	182.13**	61385.25**	255.18**	907.39**
Fertilizer*Variety	15	150.34	3.27**	14.36	2.97	160.60**	3.63	161.77
Season*Variety	5	1036.07**	1.37	19.84	12.03**	9.08	8.98	1835.52**
Season*Fertilizer*Variety	15	223.71**	0.89	14.96	4.27	10.29	5.04	267.69**
Pooled Error(b)	80	91.94	0.81	10.63	3.45	45.31	4.44	116.96
Total	143							

Table 4. Means of morphological traits during the short rains season 2018 and long rains season 2019

Variety	Plant height (cm)	Leaf length (cm)	Number of tillers per plant	Panicle length (cm)	Number of grains per panicle	1000-grain weight (g)	Fresh straw weight per plant (g)
NIBAM-11	84.03b	31.11b	25.21a	15.24a	155.61a	22.71b	37.56ab
K2-9	48.37d	22.02c	22.36ab	10.45b	34.99b	21.88b	30.04b
MWIR-2	67.01c	31.59b	25.29a	15.64a	159.36a	23.42b	47.28a
R-1081	84.65b	31.17b	22.41ab	14.55ab	159.09a	23.88b	40.73ab
Saro	69.10c	31.49b	22.97a	14.93ab	155.22a	29.13a	44.77a
Silewa	111.08a	35.92a	19.64b	19.07a	163.89a	29.17a	37.05ab
Mean	77.37	30.55	22.98	14.98	138.03	25.03	39.57
CV(%)	22.01	4.77	15.62	37.85	4.35	10.34	42.41
LSD	14.25	1.22	3.00	4.75	10.06	2.17	14.05
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.009

**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. Response of morphological parameters to fertilizer treatment during the short rains season 2018 and long rains season 2019

Fertilizer treatment	Plant height (cm)	Leaf length (cm)	Number of tillers per plant	Panicle length (cm)	Number of grains per panicle	1000-grain weight (g)	Fresh straw weight per plant (g)
Control	71.66b	28.00c	19.19c	13.92b	122.50c	24.72	37.05
FYM	73.33b	30.10b	22.38b	15.16a	139.44ab	25.56	42.97
FYM + CAN	82.59a	31.90a	23.18b	15.51a	142.97a	24.58	40.65
FYM + urea	81.92a	32.20a	27.17a	15.35a	147.19a	25.25	38.98
CV(%)	10.99	2.8	22.38	10.97	3.23	10.84	68.56
LSD	4.90	0.49	2.97	0.95	6.61	ns	ns
P value	<0.001	<0.001	<0.001	0.0042	<0.001	0.3931	0.0103

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

Table 6. Correlations among plant morphological characteristics

	Leaf length	Number of tillers	Panicle length	Grains per panicle	1000-grain weight	Fresh straw weight
Plant height	0.7059 (<0.0001)	-0.0512 (0.5423)	0.085 (0.3111)	0.5578 (<0.0001)	0.2748 (0.0009)	0.0218 (0.7956)
Leaf length		0.0811 (0.3338)	0.2379 (0.0041)	0.8742 (<0.0001)	0.427 (<0.0001)	0.2337 (0.0048)
Number of tillers			0.0068 (0.9353)	0.1341 (0.109)	-0.2433 (0.0033)	0.5224 (<0.0001)
Panicle length				0.376 (<0.0001)	0.4413 (<0.0001)	0.3163 (0.0001)
Grains per panicle					0.3626 (<0.0001)	0.2999 (0.0003)
1000-grain weight						0.1215 (0.147)

nitrogen levels increased the yields of both upland and paddy rice, but with a greater effect on upland rice. The FYM+CAN combination resulted in the greatest effect on five out of the eight parameters examined. The FYM+urea treatment had a significantly greater effect than the FYM+CAN treatment only in the number of tillers per plant. The FYM+CAN and FYM+urea treatments did not have significantly different effects on plant height. The two treatments, however, resulted in taller plants compared to FYM alone and control because of the higher nitrogen added to the soil. The effect of fertilizers on leaf length followed similar trends to those of plant height, although the control treatment had significantly shorter leaves. There was a wide disparity in the number of tillers per plant. The FYM+urea treatment resulted on average in 42% more tillers per plant than the control treatment. The study by [21] found that the application of urea resulted in a significant decrease in 1000-grain weight for late-harvested rice. Further, all fertilizer treatments resulted in significantly longer panicles than the control. When the number of grains per panicle was assessed, only the plants under control treatment had significantly fewer grains (up to 25% fewer grains than plants under FYM+urea) compared to other treatments. The results of this study suggest that FYM alone can achieve significant improvement in yield traits compared to the control, thus reducing reliance on inorganic fertilizers, which is in agreement with [22]. [23] also found that a combination of cattle manure and chemical fertilizer had the potential to sustainably provide nutrients for an increase in rice yield and enhance soil health.

Varieties interacted with fertilizers in a significant manner (P<0.001) only for leaf length and the number of grains per panicle (Table 3). It has been noted that although variety and fertilizer rates combined with other management practices may significantly affect crop response, there may not necessarily be any interactions between these two main effects [19]. An interaction between two *japonica* varieties and increasing Nitrogen fertilizer rates was also noted in China [18]. In all the varieties, except Saro, the FYM+Urea combination resulted in the highest number of grains per panicle. The genotype and fertilizer nutrient content, therefore, affected how a variety responded to the fertilizer applied. This is evident in the case of varieties MWIR-2, R-1081, and Saro, respectively, where the response of inorganic fertilizer application (CAN and urea) resulted in significantly more grains per panicle compared to control and FYM alone. When [13] studied the effect of three rates of fertilizer on yield, they found that the *indica japonica* hybrid varieties had significantly higher yields than hybrid *indica* varieties and inbred *japonica* varieties.

3.4 Association among Agronomic Parameters

Plant height had significant and positive correlations with leaf length, grains per panicle, and 1000-grain weight (Table 6). [16] also reported a positive correlation between plant height and 1000-grain weight. Leaf length in our research had significant positive correlations with 1000-grain weight (r = 0.427) and number of grains per panicle (r = 0.874), an indication that more photosynthesis contributed to a higher level of reproduction. [24] suggested that higher leaf photosynthesis and other traits that contribute to higher photosynthetic rate are critical for higher grain filling and hence higher yields. On the other hand, [6] did not find any significant correlations between 1000-grain weight and other agronomic traits. In the current study, the number of tillers per plant had a negative and significant correlation with 1000-grain weight. So, although more tillers are desirable to produce a higher seed yield, the size of the seed decreases. Our results show that number of tillers was negatively correlated (r = -0.051) with plant height, which is contrary to the positive correlation that [8] obtained. While a positive correlation (r = 0.376) was obtained between the panicle length and grains per panicle, a result supported by [25]. A study by [26] goes further to suggest that correlations between agronomic traits and yield depended on the ecotype when they investigated four rice ecotypes: indica hybrid, indica inbred, japonica hybrid, and japonica inbred. This could indicate the reason for the diversity of correlation analysis results.

4. CONCLUSION

Silewa and Saro were the most promising varieties in terms of desired yield traits. Fertilizer treatments suggest that the use of farm yard manure alone or in combination with an inorganic fertilizer, such as urea, has promising prospects to improve yield-related traits and ultimately yield, while reducing dependence on inorganic fertilizers. This has the potential of reducing the cost of on-farm rice production among resource-poor farmers. It is recommended that future studies consider a more comprehensive approach incorporating time to maturity, plant yield, and yield per unit area.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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