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Rice Yield and Yield Components as Influenced by Phosphorus and Nitrogen Application Rates in the Moist Savanna of West Africa

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Abstract: A two-year field experiment was conducted to evaluate the influence of nitrogen (0, 30, 60, and 120 kg N ha^{-1}) and phosphorus (0, 30, and 60 kg P_2O_5 ha^{-1}) application on grain yield and yield components of five New Rice for Africa (NERICA) cultivars, their parents, and a check on a degraded soil in the moist savanna of Nigeria. Nerica 14 recorded the highest grain yield of 1.3 mg ha^{-1}compared to the other NERICA cultivars. It also produced significantly ($P < 0.05$) longer panicles (19.24 cm), higher sink capacity as determined by thousand-kernel weight (30.3 g), and a higher potential for partitioning photosynthates (45.15%) into grains than the other cultivars. N × P interaction effect on grain yield was significant ($P < 0.05$) with moderate P (60 kg P_2O_5 ha^{-1}) and moderate N (60 kg N ha^{-1}) resulting in optimum grain yield (1.7 mg ha^{-1}). Thus, moderate N and P were recommended for the production of NERICA varieties in low-input smallholder upland rice production systems of the moist savanna of Nigeria.

Key words: Moist savanna, NERICA© rice, nitrogen, *Oryza sativa*, phosphorus, upland.

1. Introduction

The demand for rice far exceeds the production which in the last 30 years in Sub-Saharan Africa (SSA) has increased by 70% due mainly to land expansion and only 30% due to increase in productivity [1]. Although Nigeria is the largest rice producer in West Africa and produces about 50% of the rice grown in the sub region, Nigeria still spends a large proportion of its foreign exchange on the importation of rice because of the high demand and consumption rate.

In Nigeria, it is estimated that 4.6 million hectares of land area could be put into rice cultivation, but only 40% are currently being utilized. However, there has been some increase in rice production from 0.7 million tonnes in 1978 to 3.3 million tonnes in 1998 [2]. This increase in production, not withstanding, rice production has not kept pace with the demand as a result of rapid population growth. The short fall in supply is partly due to the low productivity of rice in the country. Grain yield as in most developing countries is as low as 0.5 mg ha^{-1} [3]. The low productivity arises from the use of low yielding varieties, pest and disease problems, inherently low soil fertility, and poor nutrient supply.

In the early 1990s, interspecific lines of rice named New Rice for Africa (NERICA®) were developed from crosses between high yielding *Oryza sativa* (Asian rice) and low-yielding resilient *Oryza glaberrima* (African rice) [4]. NERICA varieties are

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low-management rice plant types for resource-limited, smallholder production systems [5]. Their characteristics and importance in smallholder production systems has earlier been documented [6].

However, most of these NERICA varieties and their parents can not be successfully grown without applying adequate nutrients. The recommendations for the *Oryza sativa* grown in the Southern Guinea savanna are 40 kg N, 15 kg P_2O_5, 15 kg K_2O_5 ha^{-1} for short varieties, and 20 kg N, 15 kg P_2O_5, 15 kg K_2O_5 ha^{-1} for tall varieties, while in the Northern Guinea savanna, 70 kg N, 30 kg P_2O_5, and 30 kg K_2O_5 ha^{-1} (short varieties) and 40 kg N, 30 kg P_2O_5, 30 kg K_2O_5 ha^{-1} (tall varieties) have been recommended [7]. Recently, Oikeh et al. [6] recommended 60 kg N, 26 kg P, and 25 kg K ha^{-1} for the production of some NERICA varieties for smallholder low-input production systems in the forest agro-ecologies of Nigeria and 30 kg N, 26 kg P, and 25 kg K ha^{-1} for the coastal savanna of Benin Republic prone to frequent drought. But the responses of NERICA varieties to applied nutrients in the moist savanna of Nigeria have not been fully investigated. Such information will be useful to guide upland rice farmers avoid injudicious fertilizer application as they intensify NERICA rice production.

Therefore, the objective of the study was to determine the N and P requirements of some upland NERICA varieties and their parents in the highly degraded soil of the moist savanna agro-ecosystem of Nigeria.

2. Materials and Methods

2.1 Location and Time of Study

An on-farm experiment was conducted in Kasuwan Magani village in the Northern Guinea savanna of Nigeria (10°24′ N, 7°42′ E) in 2006 and 2007. The field had in the past been intensively cropped by the farmers with low levels of fertilizers, resulting in degraded soil conditions as reflected by the soil chemical properties (Table 1).

Table 1 Pre-planting soil characteristics of the experimental sites.

Soil characteristics	Farmers field		Soil fertility rating
	2006	2007	
pH (H_2O)	5.6	4.4	Acidic
Organic C (g/kg)	5.7	8.6	Low at < 20 g/kg
Total N (g/kg)	0.6	0.6	Low at < 1.5 g/kg
Mehlich P (ug/g)	4.8	3.28	Low at < 8 ug/g
Exch. K ($cmol^+$/kg)	0.36	0.22	Medium at 0.20 $cmol^+$/kg
Exch. Mg ($cmol^+$/kg)	1.02	1.24	
Exch. Ca ($cmol^+$/kg)	2.67	2.14	
Sand (%)	79	47	
Silt (%)	6	19	
Clay (%)	15	34	
Soil textural classification	Loamy-sand	Clay-loam	

2.2 Experimental Design and Treatments

Eight rice cultivars NERICA 1, NERICA 2, NERICA 3, NERICA 8, NERICA 14, CG 14, WAB 56-104, and Yar China (check) were used in the trial. These varieties were obtained from the West Africa Rice Development Association (WARDA) now Africa Rice Center (Africa Rice). The farmers' rice variety used (Yar China, introduced from China) was obtained from the farmers. The crossing of the *O. sativa* and *O. glaberrima* produced the New Rice for Africa (NERICA). The genetic names of the interspecific crosses used were: WAB 450-1-B-P-38-HB (NERICA 1), WAB 450-11-1-P31-1-HB (NERICA 2), WAB 450-1-B-P-28-HB (NERICA 3), WAB 450-1-BL-136-HB (NERICA 8) and WAB 880-32-1-2-P1-HB (NERICA 14). The trial was laid out in a randomized complete block design in a split-split-plot arrangement and replicated three times. The main plot was 22 m × 26.1 m consisting of three levels of P: 0 (Zero-P), 30 (30P), and 60 (60P) kg P_2O_5 ha^{-1}; the subplots was 5 × 26.1 m consisting of four levels of N: 0 (Zero-N), 30 (30N), 60 (60N) and 120 (120N) kg N ha^{-1}. The sub-subplot was 5 m × 3 m comprising the eight rice varieties. The N source was urea (46% N), while the P was single super phosphate (18% P_2O_5). The net plot size was 3 m × 2 m (6 m^2). The application of nitrogen fertilizer was done by drilling along the side of the rice plant and this was done in two splits of one-third at 21-25 days after sowing and two-thirds at panicle initiation (PI); phosphorus was applied by broadcasting on the field and K (30 kg K_2O_5 ha^{-1} equivalent of 24.9 kg K ha^{-1}) was applied to all the plots. Bunds were done on each of the plots so as to ensure that the fertilizer applied to the plots did not drift to other plots. Weeding was done three times before harvesting and the bunds were raised after each weeding to maintain good bund height.

2.3 Plant Sampling and Measurements

Ten randomly selected plant hills were tagged on plot basis for data collection.

Number of panicles per meter square: the number of panicles within one-meter quadrant was counted 2-3 days before harvesting.

Number of grains per panicle: average number of grains on 10 panicles from plant hills.

Panicle length: average length of 10 randomly selected panicles.

1,000-grain weight: weight of 1,000 randomly selected grains.

Harvest index: ratio of the weight of grains to the above-ground plant weight expressed in percentage.

Grain yield: grains obtained from each net plot were weighed and converted to mg ha^{-1}.

2.4 Statistical Analyses

Data collected were subjected to analysis of variance using the mixed model procedure with the restricted maximum likelihood method (REML) for variance estimates over years [8]. Fixed effects were year, cultivars and levels of phosphorus and nitrogen, while replications (blocks) were random effects. Where three-way interactions were significant (P < 0.05) between main effects, simple effect differences were evaluated among treatments. The statistical significance of a given factor at different levels of the other factor (s) (simple main effects) was obtained using the least square means (LSMEANS) slice option in PROC MIXED [8]. Mean separation was performed using the SAS LSMEANS test (probability of difference (PDIFF)) at P < 0.05. LSMEANS and standard error of means (SE) are presented. The pair-wise difference (PDIFF) was used in separating the means, while the slice option was also used to best explain the significant interaction among the treatments used.

3. Results

3.1 Rainfall Distribution

There was slightly more rain in 2007 (1,293.11 mm) than in 2006 (1,246.07 mm) during the growing seasons of June to October. In 2006, 1,004.75 mm rain fell during the cropping cycle from late June to end of October (Fig. 1). In 2007, the amount of rainfall was slightly higher (1,017.74 mm) during the crop life cycle from early June to end of October. In 2007, rainfall distribution was more even during the grain filling period than the same period in 2006.

3.2 Seasonal Effect on Grain Yield and Yield Components of Rice Cultivars

The performance of yield and yield components was better in 2007 than in 2006 except for number of panicles per square meter in 2006 which was significantly (P < 0.05) higher by 12% (Table 2). Number of seeds per panicle, panicle length, and grain yield of rice were significantly higher in 2007 than in 2006 (Table 2).

3.3 Influence of Phosphorus and Nitrogen on Yield Components of Rice Cultivars

Year had a significant (P < 0.05) influence on grain yield and yield components measured, except harvest index and 1,000-grain weight. The main effects of phosphorus was also significant (P < 0.05) on yield and yield components measured, except number of

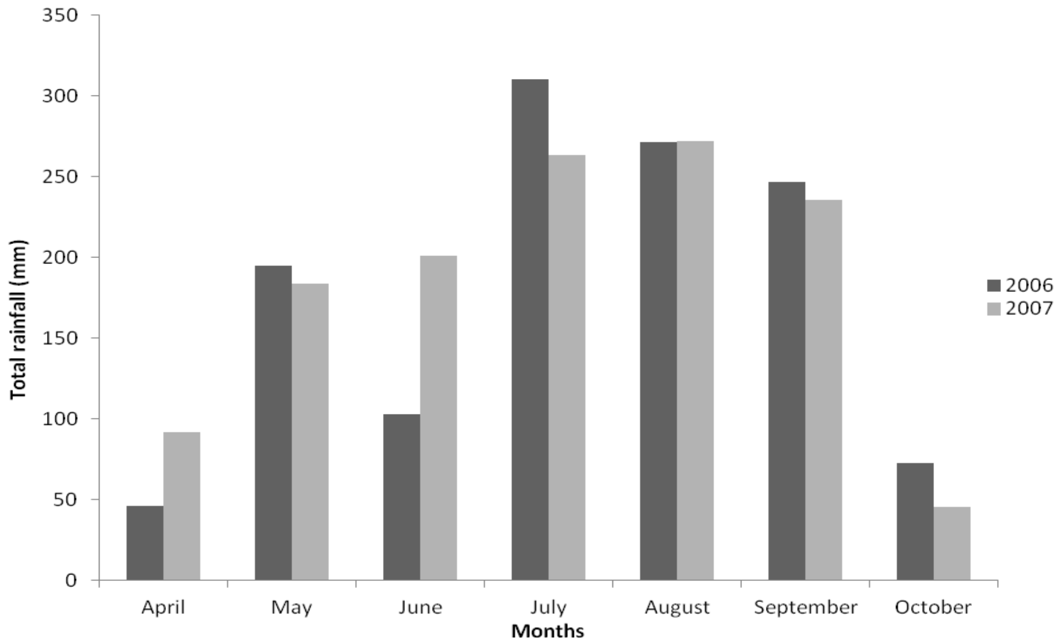

Fig. 1 Total rainfall during the growing seasons in 2006 and 2007.

Table 2 Yield of rice as influenced by year, phosphorus and nitrogen rates, and cultivars, 2006 and 2007.

Source	Number of seeds per panicle	Panicle length (cm)	Panicles per meter square	Harvest index (%)	1,000-grain weight (g)	Grain yield (mg ha^{-1})
Year						
2006	62b	17.3b	120.1a	27.4	37.1	0.9b
2007	106a	20.6a	94.3b	25.9	46.6	1.5a
SE ± (4 df)	2.5	0.3	5.9	NS	NS	0.1
Phosphorus (P_2O_5 kg ha^{-1})						
0	85	19.0	98.1b	25.6b	38.3b	0.9b
30	85	18.9	108.9ab	26.8a	42.9ab	1.2ab
60	82	18.9	114.5a	27.7a	44.3a	1.4a
SE ± (8 df)	NS	NS	4.9	0.4	2.0	0.1
Nitrogen (kg N ha^{-1})						
0	84	18.6b	88.3c	26.0b	38.9	0.9c
30	83	18.8ab	103.2bc	27.6a	43.3	1.2b
60	84	18.9ab	118.1ab	27.0ab	43.7	1.3ab
120	86	19.4a	119.1a	26.1b	41.4	1.4a
SE ± (36 df)	NS	0.2	5.2	0.4	NS	0.1
Cultivars						
NERICA 1	88b	18.6bc	107.9b	27.2bc	40.8ab	1.0b
NERICA 2	80b	19.1b	95.0b	25.7c	43.1a	1.1ab
NERICA 3	90ab	19.1b	96.1b	27.7b	42.7a	1.2ab
NERICA 8	89b	18.5bc	97.7b	26.5bbc	42.1ab	1.1ab
NERICA 14	83b	19.2ab	97.1b	30.3a	45.2a	1.3ab
CG 14	64c	19.9a	140.5a	23.6d	36.2b	1.3ab
WAB 56-104	98a	18.9bc	97.2b	28.2b	40.8ab	1.2ab
Yar China (local check)	80b	18.2c	125.8a	24.1d	44.0a	1.4a
SE ± (336 df)	2.9	0.3	5.4	0.5	2.1	0.1

Means with the same alphabets in the same column are not significantly different from one another at $P < 0.05$ using the pair-wise difference (PDIFF);
NS = not significant.

seeds per panicle and panicle length. Nitrogen had significant ($P < 0.05$) effects on all parameters measured, except number of seeds per panicle and 1,000-grain weight. Rice cultivars were significantly ($P < 0.05$) different for grain yield and yield components measured (Table 2).

N and P had no significant influence on number of seeds per panicle, but there were significant ($P < 0.05$) differences among rice varieties. Cultivar WAB 56-104 had the highest number of seeds per panicle (98), while CG 14 had the lowest (64). All NERICA varieties had similar number of seeds per panicle ranging from 80 to 90 (Table 2).

Year had a significant influence on cultivar as there was a significant year × rice cultivar interaction on number of seeds per panicle (Table 3). WAB 54-104 and NERICA 8 significantly ($P < 0.05$) produced the highest number of seeds per panicle (130 and 119) in 2007, while CG 14 had the lowest number of seeds per panicle (77). Among the NERICAs, NERICA 8 had the highest number of seeds per panicle (119) in 2007, while NERICA 2 produced the least seeds per panicle in 2007 (Table 3).

Nitrogen rates significantly ($P < 0.05$) influenced panicle length with the highest influence (19.4 cm) obtained with 120 kg N ha^{-1} compared with no N (18.6 cm) application (Table 2). Among the rice cultivars evaluated, the longest panicle was obtained from CG 14 (19.9 cm) while NERICA 8 (18.5 cm) and the local check (18.2 cm) ranked among the shortest in panicle length. No significant ($P < 0.05$) differences in panicle length were observed among the NERICAs (Table 2). The significant ($P < 0.05$) year × nitrogen rate interaction on panicle length showed that rice had longer panicle length in 2007 than in 2006 (Fig. 2). Also, the significant ($P < 0.05$) influence of year × rice cultivar interaction on panicle length showed that longer panicles were observed in 2007, the highest panicle length was obtained from NERICA 14 (21.6 cm), while in 2006, CG 14 produced the longest panicle (18.6 cm) (Table 3).

Low to moderate P (30 to 60 kg P_2O_5 ha^{-1}) significantly ($P < 0.05$) increased the number of panicles per square meter by 11% to 17% over zero-P.

Table 3 Year × rice cultivars interaction on yield and yield components of rice, 2006 and 2007.

Cultivars	Seeds per panicle	Panicle length (cm)	1,000-grain weight	Harvest index (%)	Yield (mg ha^{-1})
2006					
NERICA 1	67.1de	17.4efg	27.7b	33.1d	0.8c
NERICA 2	59.1e	17.0efg	26.3b	36.3d	0.7c
NERICA 3	71.3de	17.9ef	28.0b	37.7cd	0.8c
NERICA 8	58.6e	16.6g	27.3b	35.2d	0.8c
NERICA 14	59.5e	16.9fg	29.3a	35.5d	0.8c
CG 14	51.1e	18.6de	26.1b	43.3ab	1.4b
WAB 54-104	66.3de	17.3efg	29.7a	33.5d	0.9c
Yar China (local check)	62.7e	16.4g	24.9bc	42.5ab	1.0bc
2007					
NERICA 1	108.1bc	19.9bc	26.7b	48.5ab	1.3b
NERICA 2	101.6c	21.2a	25.1b	49.8ab	1.5a
NERICA 3	108.5bc	20.3bc	27.5b	47.7ab	1.5a
NERICA 8	119.4ab	20.3bc	25.6b	48.9ab	1.5a
NERICA 14	106.8c	21.6a	31.4a	54.8a	1.7a
CG 14	77.2d	21.4a	21.2d	29.1d	1.2b
WAB 54-104	129.6a	20.5a	26.7b	48.1ab	1.5a
Yar China (local check)	97.6c	19.3cd	23.4c	45.6bc	1.8a
SE ± (336 df)	4.1	0.4	0.7	3.0	0.1

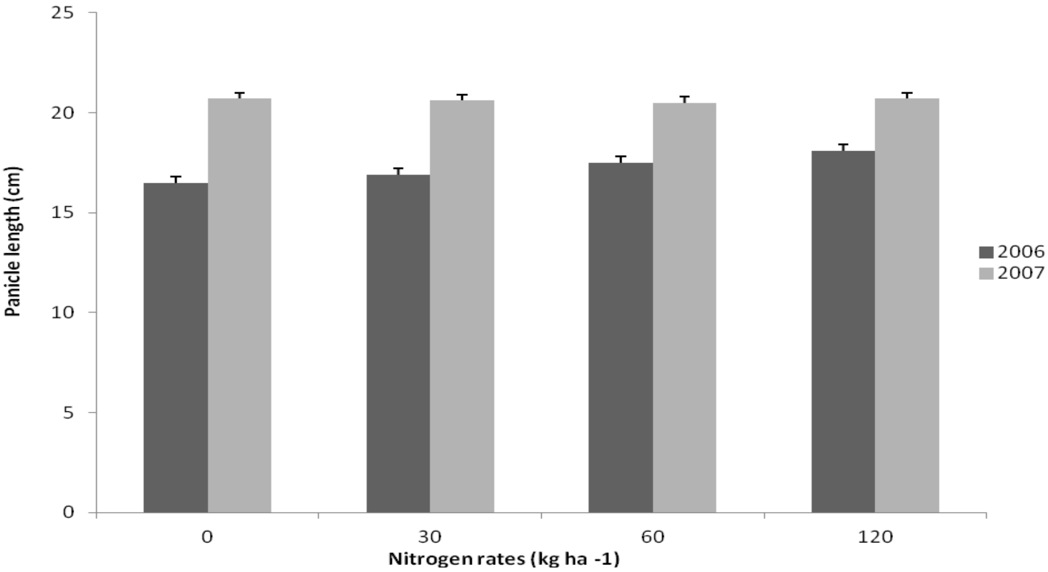

Fig. 2 Influence of year × nitrogen rates interaction on panicle length.

Nitrogen application rates also significantly (P < 0.05) enhanced the number of panicles per square meter by 19% to 35% over zero-N, but there was no significant (P < 0.05) difference in panicle production observed between 30 versus 0 kg N ha^{-1}, 30 versus 60 kg N ha^{-1}, and 60 versus 120 kg N ha^{-1} (Table 2). The local check and CG 14 produced the highest number of panicles (126 and 141 m^{-2}), while among the NERICAs, no significant (P < 0.05) differences were observed in panicle production (Table 3).

The application of 30-60 kg P_2O_5 ha^{-1} increased harvest index by 5% to 8% over when no P was applied. However, no significant (P < 0.05) difference in harvest index was observed between 30 and 60 kg P_2O_5 ha^{-1} (Table 2). Harvest index was significantly (P < 0.05) increased by 4% to 6% with the application of 30 and 60 kg N ha^{-1} compared with zero-N. There was no significant (P < 0.05) difference in harvest index between 60 and 120 kg N ha^{-1}(Table 2).

Among the rice varieties evaluated, NERICA 14 significantly (P < 0.05) had the highest harvest index (HI) (30.3%), while CG 14 had the least HI of 23.6% (Table 2). The significant (P < 0.05) year × nitrogen rate interaction showed that the cultivars produced higher HI at all nitrogen rates in 2007 than 2006. Harvest index was the lowest in 2006 when N fertilizer was not applied (Fig. 3).

Rice cultivar × N rate interaction showed a significant response on HI, where CG 14 had the lowest HI value (28.4%) when N fertilizer was not applied. Also, among the cultivars evaluated NERICA 14 had the highest HI (47.9%-49.3%) with the application of 60 to 120 kg N ha^{-1}. While among the NERICAs, NERICA 8 and NERICA 1 had the lowest harvest index (36.9% and 37.8%) at zero N and 120 kg N ha^{-1} (Fig. 4).

There was a significant (P < 0.05) interaction of year × N × P rates on harvest index. When averaged over cultivars, there were seasonal differences in harvest index in response to N and P fertilizers (Table 4). The slice option indicated that in 2006, 30 kg P_2O_5 ha^{-1} gave the lowest harvest indices (30.1%-36.9%) when zero-N or 30 kg N ha^{-1} was applied, but P application had no influence on harvest index at moderate to high N rates. In 2007, P application did not significantly influence harvest index at each of the N rates (Table 4). In both years, when P was not applied, low N of 30 kg ha^{-1} gave the highest harvest index, while in 2006, when 30 kg P_2O_5 ha^{-1} was applied, harvest index increased to a maximum of 43.8% with increments in N rates up to 60 kg ha^{-1}. There was no further benefit of higher rates of N and

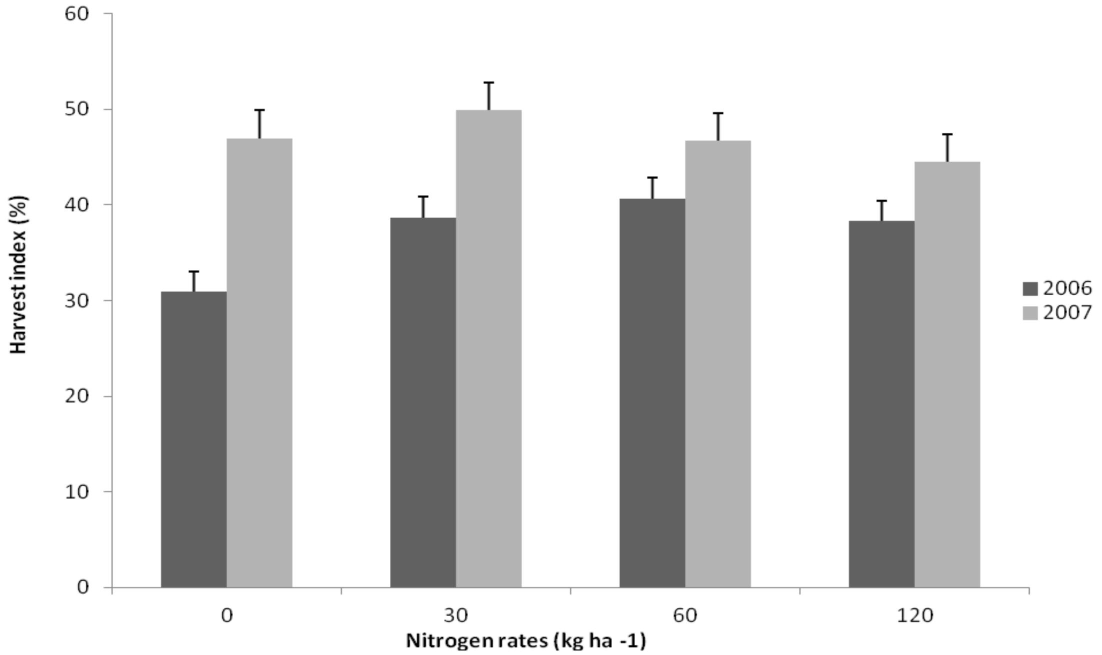

Fig. 3 Influence of year × nitrogen rates interaction on harvest index of rice.

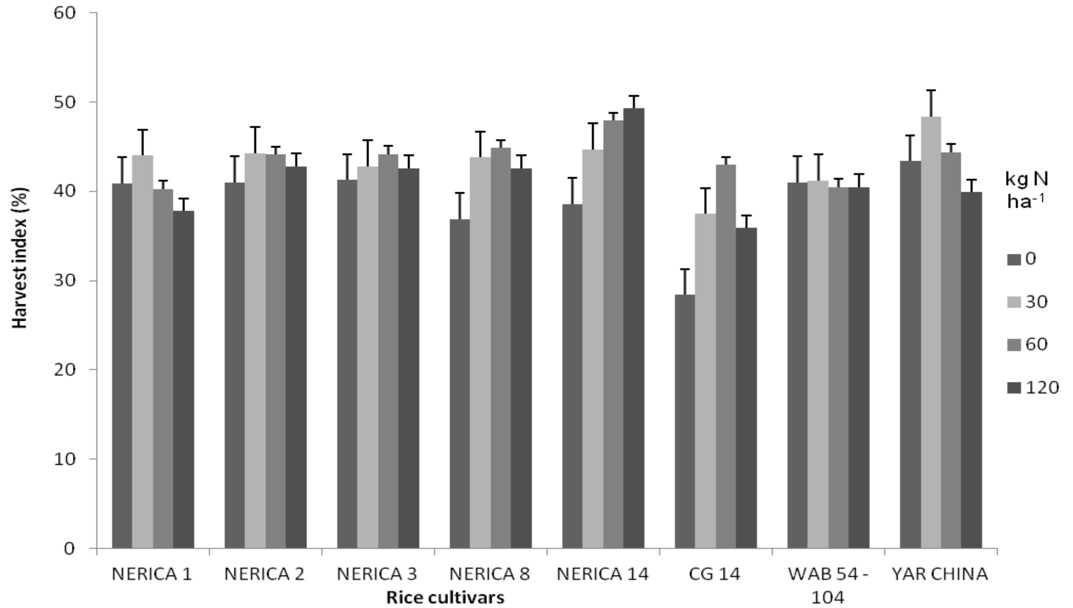

Fig. 4 Influence of nitrogen application rates × rice cultivars interaction on harvest index (%).

P on harvest index. In 2007, the application of 60 kg P_2O_5 ha^{-1} without N or with low N gave the highest indices of 51% to 53%, while further increments in N slightly depressed the index.

There was a significant year × rice cultivar × P rate effect on harvest index. In 2006, there were no significant differences among the cultivars at zero-P and 30 kg P_2O_5 ha^{-1}; but at 60 kg P_2O_5 ha^{-1}, the harvest index of CG 14 and the local check were similar (46.2%-50.4%) and significantly higher than the harvest index of the other cultivars (32.1%-40.7%) (Table 5). In 2006, the harvest index of NERICA 2 and CG 14 responded to P application, with NERICA 2 attaining the highest index of 42.9% at 30 kg P_2O_5 ha^{-1}, while CG 14 had 50.4% harvest index at 60 kg P_2O_5 ha^{-1}. In 2007, the harvest index of only WAB

Table 4 Year × nitrogen × phosphorus rates interaction on harvest index of rice.

Year	Phosphorus ($kg\ P_2O_5\ ha^{-1}$)	Nitrogen ($kg\ N\ ha^{-1}$)			
		0	30	60	120
2006	0	30.2A[1]a[2]	38.8Aa	36.6Aa	30.4Ba
	30	30.1Ab	36.9Aab	43.8Aa	43.4Aa
	60	32.2Aa	40.3Aa	41.7Aa	41.1Aa
2007	0	39.8Ba	44.2Aa	43.3Aa	43.13Aa
	30	48.4ABa	48.7Aa	47.3Aa	44.69Aa
	60	52.9Aa	51.0Aa	49.4Aa	45.78Aa
	SE ± (0.05)	3.5			

[1]Means within a column in a given year × nitrogen level followed by the same upper cased letter are not significantly different at $P < 0.05$. Test effects of slicing by year × nitrogen levels;
[2]Means within a row followed by the same lowercased letter are not significantly different at $P < 0.05$. Test effects of slicing by year × varieties.

Table 5 Year × rice cultivars × phosphorus rates interaction on harvest index (%) of rice 2006 and 2007.

Year	Cultivars	Phosphorus rates ($kg\ P_2O_5\ ha^{-1}$)		
		0	30	60
2006	NERICA 1	28.6A[1]a[2]	35.4Aa	35.2Ba
	NERICA 2	31.9Ab	42.9Aa	34.2Bab
	NERICA 3	33.9Aa	38.5Aa	40.7ABa
	NERICA 8	34.2Aa	36.5Aa	34.9Ba
	NERICA 14	33.0Aa	36.6Aa	36.9Ba
	CG 14	37.1Ab	42.5Aab	50.4Aa
	WAB 56-104	35.1Aa	33.3Aa	32.1Ba
	YAR CHINA (Local check)	38.3Aa	42.9Aa	46.2ABa
2007	NERICA 1	43.3Ba	47.1Aa	55.1Aa
	NERICA 2	46.5Aa	52.2Aa	50.6Aa
	NERICA 3	42.0Bab	44.9Ab	56.1Aa
	NERICA 8	44.3Ba	50.3Aa	52.1Aa
	NERICA 14	52.7Aa	57.7Aa	53.9Aa
	CG 14	30.5Ca	27.0Ba	29.8Ba
	WAB 56-104	39.4Bb	52.4Aa	52.6Aa
	YAR CHINA (Local check)	42.0Ba	46.7Aa	48.1Aa
	SE ± (336 df)	3.7		

[1]Means within a column in a given year and phosphorus level followed by the same uppercase letter are not significantly different at $P < 0.05$. Test effects of slicing by year and phosphorus level;
[2]Means within a row followed by the same lowercase letter are not significantly different at $P < 0.05$. Test effects of slicing by year and variety.

56-104 was significantly enhanced by 33% with application of 30 kg P_2O_5 ha^{-1}, while the harvest index of the other cultivars did not respond to P application. In the same year, NERICA 14 gave the highest harvest index with zero-P or 30 kg P_2O_5 ha^{-1}, while CG 14 ranked the lowest (Table 5).

Low to moderate P rates (30-60 kg P_2O_5 ha^{-1}) significantly ($P < 0.05$) enhanced 1,000-grain weight (grain size) of rice by 12% to 16% over zero-P rate (Table 2). However, no significant ($P < 0.05$) difference in grain size was observed between 30 and 60 kg P_2O_5 ha^{-1}. All rice cultivars except NERICAs 1 and 8 and WAB 56-104 had significantly higher 1,000-grain weight than CG 14 (Table 2). There was significant year × cultivar effect on 1,000-grain weight. The grain weight of NERICA 14 was the highest (31.4 g) in 2007, and also ranked among the highest (29.3 g) in 2006 (Table 3).

3.4 Influence of Phosphorus and Nitrogen on Grain Yield of Rice Cultivars

Mean grain yield was significantly ($P < 0.05$) enhanced by 55% with the application of 30 kg P_2O_5 ha^{-1} and 56% with the application of 60 kg P_2O_5 ha^{-1} over zero-P (Table 2). There was no significant difference observed between 30 and 60 kg P_2O_5 ha^{-1} (Table 2).

Also, the yield of rice was significantly ($P < 0.05$) influenced by N rates. High N at 120 kg ha^{-1} significantly ($P < 0.05$) increased the yield of rice by 56%, while 60 kg N ha^{-1} increased it by 44%, and 30 kg N ha^{-1} increased the yield by 33% compared to 0 kg N ha^{-1} (Table 2). There was no significant difference in grain yield between 60 and 120 kg N ha^{-1}. Averaging across years, N and P rates, grain yield was similar among the cultivars evaluated, ranging from 1.1 to 1.4 Mg ha^{-1}, except NERICA 1 that had about 30% significantly lower grain yield than the farmers' variety, Yar China (Table 2).

The effect of the interaction of nitrogen × phosphorus rates on the yield of rice showed that mean yield increased with increments in N and P rates. The response also showed that moderate P (60 kg P_2O_5 ha^{-1}) and N (60 kg N ha^{-1}) gave the highest yield of 1.7 mg ha^{-1} (Fig. 5). A combination of 120 kg N ha^{-1} and 30 kg P_2O_5 ha^{-1} increased grain yield (1.4 mg ha^{-1}) compared to when both nutrients were not applied. But, a combination of 120 kg N ha^{-1} and 60 kg P_2O_5 ha^{-1} depressed grain yield by 21% (Fig. 5).

4. Discussion

This study has shown the response of the rice cultivars to the main and simple effects of P and N application rates in a two-year study carried out in a highly degraded moist savanna soil of Nigeria. The better responses of the cultivars to both nitrogen and phosphorus in 2007 than in 2006 might have been due to the better rainfall distribution in 2007. It has been estimated that about 25% of fields used for upland rice production are prone to yield reduction caused by frequent drought events [9]. Thus, adequate soil moisture is an important determinant of grain yield in upland rice production, particularly in the savannas [3].

The native soil status showed that the total soil N and available soil P were far below the critical level considered as low for N and P for upland rice production. These could have been responsible for the significant responses of the NERICAs to P and N application in this study, as previously reported for upland NERICA rice production in the humid forest agro-ecosystem [6], and for lowland NERICA rice production in the Sudan savanna [10].

Yield components including grain size, harvest index, and number and length of panicles were significantly influenced by N and P application as previously reported for some upland NERICAs [6, 11]. However, other studies had reported a lack of significant influence of P on tillers and panicles of lowland NERICA rice grown for two years in the Sudan savanna of Nigeria [10].

Although the local check (Yar China) had a higher number of panicles, 1,000-grain weight, higher yield, it is known to be highly susceptible to biotic stresses such as blast, and the variety is too short, thus farmers, particularly women complain of back pains during harvesting. Farmers seldom use this rice cultivar on their fields because of the problems associated with it.

One of the NERICA parents (CG 14) also had the highest yield in 2006, but it is highly susceptible to lodging and shattering [5] which will not be favored by the farmers because a lot of the seeds will be lost before harvesting or during the harvesting process. NERICA 14, which had a comparable yield to the local check in both years and better yield components including filled grains per panicle, panicle length and

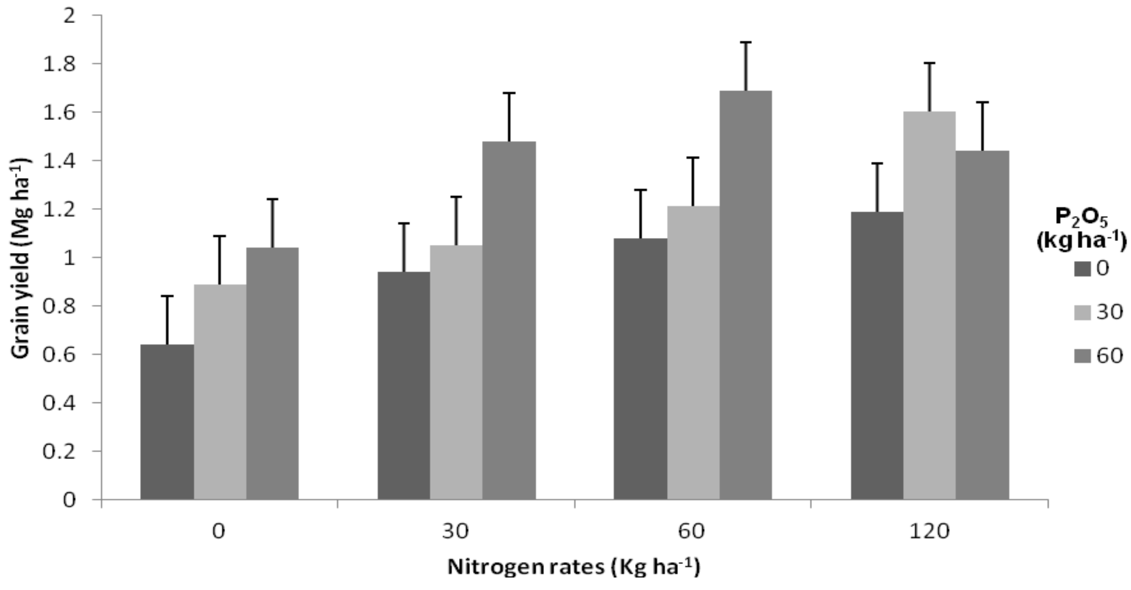

Fig. 5 Nitrogen × phosphorus application rates interaction on grain yield of rice cultivars.

harvest index in both years compared to the local check, will be the most attractive to the farmers.

The significant positive response of the cultivars to N and P might have been due to the very low N and P contents of the highly degraded soil of the study site. Our results showed that moderate levels of N (60 kg N ha^{-1}) and P (60 kg P_2O_5 ha^{-1}) were optimum for NERICA rice production in the moist savanna similar to the previous recommendation for some upland NERICA cultivars in the humid forest agro-ecosystems of Nigeria [6]. However, the optimum N rate in our study was twice the amount (30 kg N ha^{-1}) recommended for some upland NERICAs in the highly degraded *Terre de barre* soils of the coastal savanna of Benin Republic that is prone to frequent drought [11].

The lack of significant difference between 60 and 120 kg N ha^{-1} corroborates the study on responses of upland NERICAs to N and P carried out in the humid forest agro-ecosystems of Nigeria that reported no significant difference between these rates [6], possibly because the NERICAs were developed as low-management plant types, and thus are more adapted to low to moderate input systems [5, 6].

5. Conclusions

Phosphorus and nitrogen application played a significant role in the yield and yield components of upland rice cultivars in the moist savanna. The yield of rice was found to be promising when moderate P rate (60 kg P_2O_5 ha^{-1}) and moderate N rate (60 kg N ha^{-1}) were used, which suggests that both rates were sufficient for the optimum yield of rice in the moist savanna agro-ecosystem. Therefore, for resource-limited smallholder farmers growing upland NERICA varieties in the moist savanna agro-ecosystem, moderate levels of P and moderate N are recommended. NERICAs 14, 8 and 3 performed well in respect of grain yield, but NERICA 14 was the best for the moist savanna agro-ecosystem at moderate P (60 kg P_2O_5 ha^{-1}) and moderate N (60 kg N ha^{-1}).

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