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Research Article

Nitrogen and Phosphorus Fertilizer Rates Influence on Growth and Yield of NERICA 4 Rice Variety in Upland Conditions at JICA Tsukuba Center Japan

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Abstract

The level of fertilizer application is among the factors prioritized for rice production constraints in Ethiopia, Sierra Leone, and Angola. Therefore, a field experiment was conducted to determine the influence of Nitrogen and Phosphorous fertilizer on growth, yield and yield components of NERICA 4 rice variety under upland condition at Tsukuba International Center, Japan during 2025 cropping season. The experiment involved factorial combinations of three rates of Nitrogen (0, 60 and 120 kg N ha^{-1}) and three rates of Phosphorous (0, 50 and 100 kg P_2O_5 ha^{-1}) laid out in 3×3 factorial arrangements in RCBD with three replications. Growth and yield of rice were significantly affected by nitrogen levels and the treatment difference, but not by phosphorus fertilizer levels. Due to the sufficient phosphorus in the experimental field, the application of high phosphorus did not have a significant effect. The significant highest grain yield (3.49 t ha^{-1}), number of panicles per m^2 (281.7), N uptake (103.8 kg ha^{-1}) and P uptake (21.8 kg ha^{-1}) were obtained from application of 120 kg N ha^{-1}. Applying 60 kg N ha^{-1} and no phosphorus application produced the highest agronomic efficiency and statistically equivalent to the highest application of nitrogen (120 kg N ha^{-1}) and phosphorus (100 kg P_2O_5 ha^{-1}), making it an economical treatment. However, this one season and one location study must be reconfirmed in different seasons and over locations to make a sound conclusion.

Keywords

Fertilizer Rate, Grain Yield, Inorganic Fertilizer, Soil Analysis, Upland Rice

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1. Introduction

Rice is one of the most important food crop and a major food grain for more than a third of the world population [1]. With the recent breakthrough in the development of the New Rice for Africa (NERICA) for upland production system and the high demand for rice, farmers' interest in growing upland rice has increased.

Rice yield in Africa is generally low about 1 t ha^{-1} in uplands, 1 to 2 t ha^{-1} in rain fed lowlands and 3 to 4 t ha^{-1} in the irrigated zones [2], but new rice cultivars have a potential yield of greater than 10 t ha^{-1} [3]. One of the major causes of low rice production is the decline in soil fertility, most especially N and P [4].

Nitrogen considered as the main factor limiting the productivity of rice under conditions of adequate water availability [5] and in improving the nutritional quality of rice grain [6] for positively affecting the protein fraction of glutelin, rich in essential amino acids [7]. Application of nitrogen fertilizer either in excess or less than optimum rate affects both yield and quality of rice to remarkable extent, hence proper management of crop nutrition is immense important [8]. The beneficial effects of nitrogen occur by influencing yield components like number of panicles per unit area, number of spikelets per panicle, spikelet fertility and 100 grain mass, and panicle length [5].

Phosphorous fertilizer plays a critical role in soil P fertility and enhancing crop yields [9]. Phosphorus is a major component in ATP, the molecule that provides "energy" to plant for photosynthesis, protein synthesis, nutrient translocation, nutrient uptake and respiration [10]. Grain yield of rice are associated with P concentration in grains [11].

The level of fertilizer application is among the factors prioritized for rice production constraints in Ethiopia [12], Serraleon [13] and Angola [14]. Therefore, with the use of adaptable and high yielding rice variety where N and P fertilizer application was not at optimum rate, resulted in an imbalanced ratio of N and P, which led to a decline in yield. Also, some of our farmers did not use chemical fertilizers, they did not know the exact amount to apply and rely on the blanket recommendations. As a result, rice cultivation fields are experiencing nutrient deficiencies, and the necessary fertilizer rates to promote rice growth and improve productivity are not well understood. Therefore, studying the agronomic and physiological responses of rice to the appropriate application and management of nutrients is important for increasing productivity in upland rice production. This study was initiated with objective to determine the optimal nitrogen and phosphorus fertilizer rates for rice production under upland conditions.

2. Materials and Methods

2.1. Description of Study Area

The study was conducted at Tsukuba International Center Japan from May to September 2025 cropping season. The location is found at latitude of 36.03˚N and longitude of 140.12˚E with altitude of 25 m.a.s.l. The maximum precipitation of 191mm was observed in May, while the maximum temperature of 37.6°C was recorded in August (Figure 1). A lower amount of total rainfall of 59mm was obtained in August whereas the lowest temperature of 9˚C were obtained in May. During the growing season, very high temperatures of up to 37.6˚C coupled with high humidity and limited rainfall were experienced. Thus, supplementary irrigation to the field every one week was done starting from 2nd week of July up to end of August to ensure proper growth of the crop.

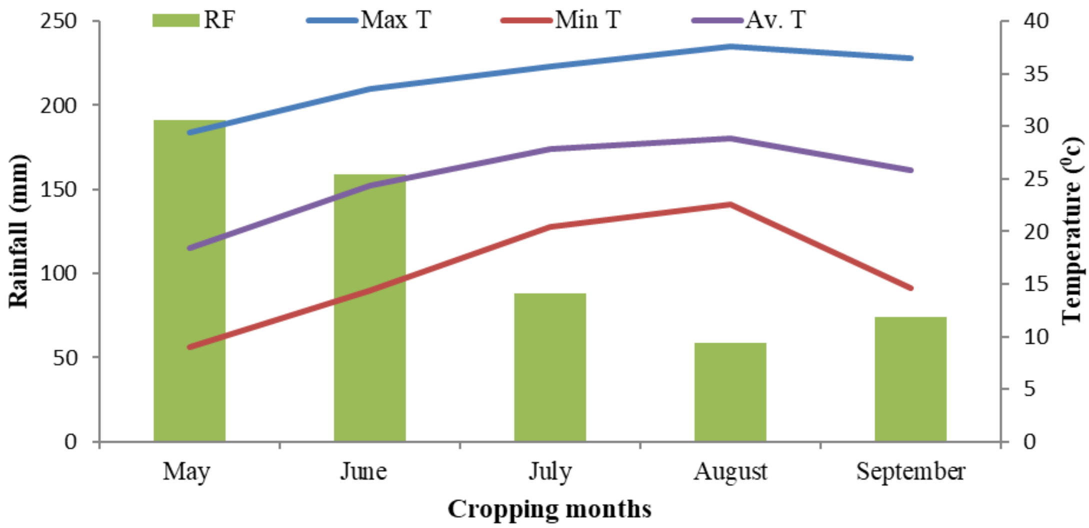


Figure 1. Maximum, average and minimum temperature and rainfall received at the experimental site during the period of cropping months in Tsukuba International Centre, Japan.

2.2. Treatments and Experimental Design

NERICA 4 rice variety was planted at the seed rate of 40 kg ha^{-1}. It was sown at 40 cm row spacing using drilling method with 2-4 cm soil depth. The design of experiment was 3×3 factorial with three replications laid out in RCBD. The plot size was 2.5m (L) × 4m (W) = 10 m^2. Nitrogen and Phosphorous fertilizer were applied in the form of ammonium sulphate (21% N) and super phosphate (17.5% P_2O_5), respectively. Nitrogen fertilizer was applied in two phases: as basal (2/3) and one time top dressings (1/3), with N amounts of 0, 60 and 120 kg N ha^{-1}, whereas P was applied as basal fertilizer at rates of 0, 50 and 100 kg P_2O_5 ha^{-1} with the total of 9 treatments (Table 1). Furthermore, K fertilizer was applied uniformly to all plots in the form of potassium chloride (61% K_2O) at basal (40 kg ha^{-1}) and once at top dressing (40 kg ha^{-1}). Top dressing of both N and K was done on June 27 at active tillering stage.

Table 1. *Treatment combinations.*

Nitrogen rate (kg ha^{-1})	Phosphorous (P_2O_5) rate (kg ha^{-1})		
	0	50	100
0	N_0P_0	N_0P_{50}	N_0P_{100}
60	$N_{60}P_0$	$N_{60}P_{50}$	$N_{60}P_{100}$
120	$N_{120}P_0$	$N_{120}P_{50}$	$N_{120}P_{100}$

2.3. Soil and Plant Tissue Analysis

The soil of the experimental field was characterized for selected physico-chemical properties before the application of the treatments from each replication and after harvesting from each plot at depth of 14cm to examine the residual effect of treatments on selected soil chemical properties (Table 2). The soil samples were air dried and ground to pass through 2 mm sieve. Soil pH and EC was measured. 20ml of distilled water was added to 4g of soil at a mixture of 1:5 and after mechanical shaking for 1hr, pH and EC measured using LAQUA (pH/ION METER F-72) and LAQUAact (CONDMETER ES-71), respectively. Total carbon content in the soil was determined by NC- analyzer (SUMIGRAPH NC-22F). For available phosphorus, extraction by the Bray II method was conducted on 1g of soil and 20 mL of extractant. Then the P concentration was determined at 880nm using a UV vis spectrophotometer (UV-1280, Shimadzu Co. Ltd.). 20 mL of 1N ammonium acetate was added to 1 g of soil, and the mixture was subjected to mechanical shaking for 1 hour. After filtering with No. 6 filter paper, the cation concentration was determined using an ICPE-9820.

Composite samples of above ground (stalk and grain together) were collected from 20cm line randomly at harvesting per plot for analysis of N and P. The above ground parts of rice were cut at ground level at harvest stage. The plant samples were dried in air temperature and ground into 0.25 mm size and analyzed for total nitrogen, phosphorous and potassium. To determine K and P content in the plant the mixture of 0.5g plant samples and 10 mL of citric acid in the pressure vessel was digested using a microwave digestion system. After filtration through a membrane filter, the concentrations of K and P were measured using ICP-9820 (Shimadzu Co. Ltd). Total Nitrogen content in the plant was determined by NC-analyzer (SUMIGRAPH NC-22F). For available phosphorus, extraction by the Bray II method was conducted on 1g of soil and 20 mL of extractant. The soil and plant tissue analysis were carried out at Japan International Cooperation Agency (JICA) Tsukuba International Center soil and plant tissue analysis laboratory.

Nutrient uptake and Agronomic efficiency for N and P were computed as following equation [15, 16].

$$\text{Nutrient uptake} = \frac{\text{Total dry biomass x nutrient content in the plant}}{100}$$

$$AE_{N+P} = \text{(Yield from the plot fertilized with both N and P)-(Yield from control plot)}$$

The rate of N fertilizer applied+ the rate of P fertilizer applied.

Table 2. Selected chemical properties of the soil of the experimental site before planting.

Soil parameter tested	Result	Rating	Reference
Total N (%)	0.309	Very high	[17]
Available P_2O_5 (mg kg^{-1})	105.3	Very High	[18]
Total Carbon (%)	3.64	Medium	[19]
Ca (mg $100g^{-1}$)	188.7	Very high	[20]
K (mg $100g^{-1}$)	61.9	Very high	[20]
Mg (mg $100g^{-1}$)	22.1	Very high	[20]
Na (mg $100g^{-1}$)	3.3	Very high	[20]
Total cations (meq $100g^{-1}$)	13.13	-	
CEC (meq $100g^{-1}$)	43.7	Very high	[20].
Base saturation (%)	30.2	Low	[17]

Values are the means from each replications.

2.4. Seed Preparation and Pest Management

The seeds were selected with tap water (1.0 specific gravity) disinfected with hot water (at 60℃ for 10 minutes). The seeds were then soaked in a Benlate T (Thiram 20% - Benomyl 20% powder) fungicide for an overnight to avoid seed borne diseases (1:200 dilute by water). The seed then air dried and coated with Kihigen birds expellant solution (Thiuram 80%) 1% of the rice seed was mixed before planting then air dried. Diazinon 5G (Diazinon 5%) insecticide was applied 7 days before sowing with the rate of 6 kg per 1000m^2. Three days after planting Go-Go-San (2% Pendimethalion) herbicide was applied with 6 kg per 1000m^2. To prevent bacterial and mold growth and to promote growth of the rice at early growth stage fungicide (hydroxyisoxazol metalaxyl-M) and water soluble granular comprehensive trace elements that is quickly absorbed by plants and prevents nutritional disorders were applied.

2.5. Data Collection and Sampling Method

The data collection was categorized into growth observation data, yield and yield components data. The other data collected was plant nutrient uptake and soil nutrient content after harvesting from each plot. Plant length was obtained from five plant samples per plot from ground to fully grown leaf or highest part of the plant using a meter ruler. The fully grown leaf of five plant samples per plot was identified to measure the chlorophyll levels using SPAD meter (Model: SPAD-502). The stem number from 50 cm length was demarcated with each and the number were obtained by counting the stems one by one from the base in all five lines of each plot. Plant length, SPAD value, and stem number were collected six times for each two weeks difference: at early growth (35DAS), active tillering (49DAS), maximum tillering (63DAS), panicle initiation (81DAS), 50% heading (97DAS) and 14 days after 50% heading (111DAS) stage. The shoot samples were collected from 30cm length from each plot and the leaf was detached from the stems and the total leaf area was measured using automatic area meter (Model No: AAM9). The leaf area index was calculated by dividing the total leaf area by the sampled land area. Dry weight was determined by harvesting rice from 30cm length of each experimental plot. The rice plants were cut at ground level with all above ground biomass, and oven dried for 72 hours at 80°C (oven dry model: DKM600) and weighted using sensitive balance (model METTLER PB303 Delta Range). The leaf area index and dry weight data were collected four times: at maximum tillering (63DAS), panicle initiation (81DAS), 50% heading (97DAS) and 14 days after 50% heading (111DAS) stage. The length of the panicle and culm were obtained from 15 samples of plant per plot, measuring from the node of the panicle to its tip for the length of the panicle, and from the base of the stem to the node of the panicle for the length of the culm.

Yield and yield components were determined by harvesting plants from a 1 m central row of each experimental plot at maturity stage (85% ripening). The harvested plants were subsequently dried in a greenhouse for one week. The dried samples were weighted by sensitive balance to determine above ground dry biomass. The all panicles are detached from the harvested sample from each plot and counted to determine number of panicle per square meter. The rice grains were removed from the panicles, weighed and counted using an automatic seed counter, which were subsequently immersed in pure water to differentiate the filled (complete grains) and unfilled grains. Then the number of spikelet per panicle calculated as total number of spikelet per unit area divided by total number of panicle per unit area. The percentage of ripened grains was calculated as number of complete spikelet divided by total number of spikelet x 100. The thousand grain weight was determined by measuring 10 grams of grain and counting them with a seed counter. The number of grains in 10 grams was then determined. Then, the thousand grain weight was calculated by dividing 10,000 by the weight of the 10-gram sample. The grain weight was adjusted to a moisture content of 14%. Grain yield (t ha^{-1}) was calculated as number of spikelet per panicle × number of panicle per m^2 × percentage of ripened grains (%) × 1000 grains weight (g) $\times 10^{-7}$.

2.6. Data Analysis

The data were analyzed using SAS software version 9.3. Least significant difference (LSD) at 5% level of significance was used to separate treatment means. Correlation and regression analysis were performed to determine the association among studied variables.

3. Results and Discussions

3.1. Growth Parameters

3.1.1. Stem Number

The application of different nitrogen fertilizer levels had highly significant effect (P < 0.01) on stem number throughout the growth stages of active tillering, maximum tillering, panicle initiation, 50% heading, and 14 days after heading, except during the early growth stage when stem number was not significantly affected (P > 0.05). However, there was no significant difference (P > 0.05) in phosphorus fertilizer rates and the interaction effect at any stage of data collection (Table 3).

Table 3. *Mean square of Nitrogen and Phosphorous fertilizer rate influence on growth of rice during 2025 cropping seasons at JICA Tsukuba Center, Japan.*

Growth stages	Parameter	Mean square for source of variation				
		N rate (2)	P rate (2)	Rep (2)	Nx P rate (4)	MS of Error (16)
Early Growth stage	Plant length (cm)	77.99^{**}	0.52^{ns}	14.43^{ns}	4.47^{ns}	4.30
	Stem number	1713.37^{ns}	49.59^{ns}	725.90^{ns}	333.15^{ns}	488.93
	SPAD value	11.16^{*}	12.39*	35.77^{**}	5.07^{ns}	3.00
Active Tillering stage	Plant length (cm)	347.52^{**}	12.02^{ns}	1.70^{ns}	9.82^{ns}	8.51
	Stem number	25876.26^{**}	69.37^{ns}	3946.7*	779.76^{ns}	905.62
	SPAD value	56.25^{**}	0.13^{ns}	1.31^{ns}	0.75^{ns}	2.30
Maximum Tillering stage	Plant length (cm)	509.74^{**}	81.40^{ns}	20.40^{ns}	26.56^{ns}	31.52
	Stem number	25225.30^{**}	243.11^{ns}	1711.40^{ns}	793.11^{ns}	655.53
	SPAD value	99.85^{**}	1.51^{ns}	9.01*	1.04^{ns}	2.39
	Leaf Area Index	3.06^{**}	0.15^{ns}	0.17^{ns}	0.251^{ns}	0.25
	Dry weight (g $m^{-2)}$	31616.83^{**}	1240.84^{ns}	5250.29^{ns}	2006.91^{ns}	2444.11
Panicle Initiation Stage	Plant length (cm)	416.42^{**}	0.51^{ns}	3.89^{ns}	8.44^{ns}	11.52
	Stem number	24815.44^{**}	424.33^{ns}	2088.44^{ns}	750.11^{ns}	682.69
	SPAD value	47.37^{**}	6.85*	1.58^{ns}	0.176^{ns}	1.30
	Leaf Area Index	12.6^{**}	0.82^{ns}	0.075^{ns}	0.227^{ns}	0.47
	Dry weight (g $m^{-2)}$	165250.50^{**}	7050.09^{ns}	1093.12^{ns}	6205.40^{ns}	2124.06
50% Heading Stage	Plant length (cm)	255.43^{**}	6.90^{ns}	10.10^{ns}	7.20^{ns}	23.2
	Stem number	21544.48^{**}	497.37^{ns}	353.59^{ns}	428.59^{ns}	392.26
	SPAD value	127.1^{**}	6.16^{ns}	1.53^{ns}	2.59^{ns}	2.35
	Leaf Area Index	4.05^{**}	0.37^{ns}	0.02^{ns}	0.65^{ns}	0.28
	Dry weight (g $m^{-2)}$	143134.78^{**}	24331.9^{*}	5483.67^{ns}	1148.88^{ns}	5794.40

Growth stages	Parameter	Mean square for source of variation				
		N rate (2)	P rate (2)	Rep (2)	Nx P rate (4)	MS of Error (16)
14 days after 50% Heading Stage	Plant length (cm)	263.94**	8.07ns	11.92ns	6.61ns	19.1
	Stem number	17887.26**	632.26ns	1045.59ns	159.71ns	30.0
	SPAD value	58.4**	0.54ns	9.57*	2.09ns	1.98
	Leaf Area Index	8.21**	0.04ns	0.61ns	0.21ns	0.38
	Dry weight (g m^{-2})	254559.35**	9225.59ns	9658.79ns	24248.17ns	9170.02

Numbers in parenthesis = Degrees of freedom; NS=Not significant difference; *= Significant (P < 0.05) difference; ** = Highly significant (p<0.01) difference; N=Nitrogen; P=Phosphorous; Rep=Replication; MS=Mean square.

The highest number of stems through the growth period was numerically recorded from the highest nitrogen (N) application of 120 kg ha^{-1}. The lowest stem number, however, was obtained from the control treatment (N0) (Figure 2a). There was a general increase in the stem number per square meter in all treatments throughout the growth period, from the early growth stage to the panicle initiation stage. However, the number of tillers began to decline slightly at the 50% heading stage. This was due to the late tillers beginning to senesce. The significant difference among N levels might be attributed to application of nutrients which enhanced vegetative growth of crop and have a positive effect on rice stem number. Akram *et al.* [21] also reported the increased number of tillers in rice as a result of increase in the nitrogen fertilizer rate.

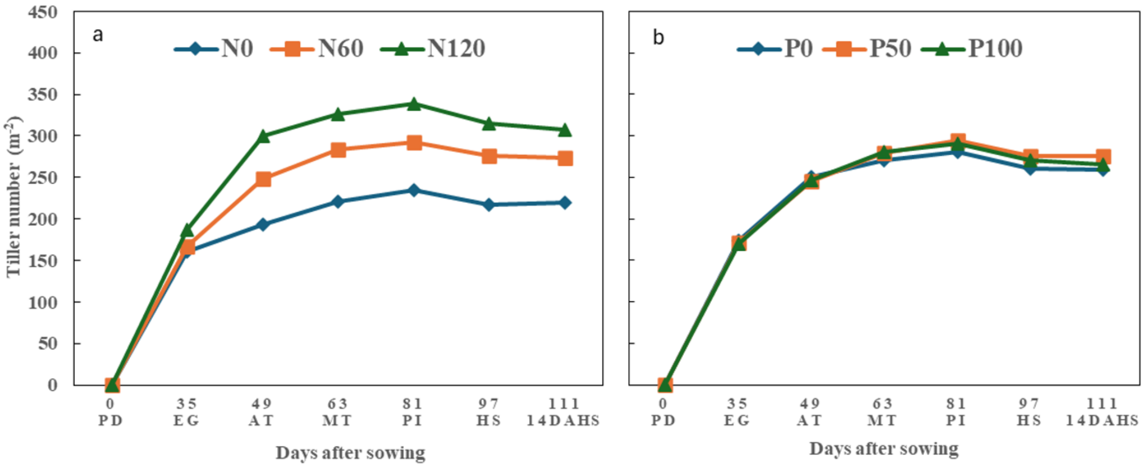


Figure 2. *Nitrogen (a) and Phosphorous (b) fertilizer rates influence on the number of stems of rice throughout the growth period: Early Growth (EG), Active Tillering (AT), Maximum Tillering (MT), Panicle Initiation (PI), 50% Heading Stage (HS) and 14 days after 50% Heading Stage (14DAHS).*

3.1.2. Plant Length

The plant length of rice was highly significantly (P < 0.01) affected by the applications of nitrogen fertilizer rates throughout the growth stages (early growth, active tillering, maximum tillering, panicle initiation, 50% heading, and 14 days after heading), except at the 50% heading stage when plant length significantly affected (P < 0.05) by treatment difference. However, there was no significant difference (P > 0.05) in phosphorus fertilizer rates and the interaction effect throughout growth stage of data collection. At all growth stages of rice, significantly the longest plant length was recorded from highest nitrogen application of 120 kg ha^{-1}. While the lowest plant length was obtained from no applications of N (Figure 3a).

The increase in plant length with increasing rate of N fertilizer could be due to nitrogen is considered as one of the major limiting nutrients in plant growth and adequate supply of it promotes the formation of chlorophyll which in turn resulted in higher photosynthetic activity, vigorous vegetative growth and taller plants. P in the soil of experimental area was very high (Table 1) so that it did not showed differences for plant length as increased from no application of P to 100 kg P_2O_5 ha^{-1} (Figure 3b).

Similar results were reported by Lu *et al.* [22], who stated that the application of high nitrogen (N) rates significantly affected the length of rice plants. As Dorar *et al.* [23] stated, the maximum plant length of rice was attained from the highest application of N at 138 kg ha^{-1} combined with zero phosphorous rate. Also he stated that without P application, increasing N from 0-138 kg ha^{-1} consistently increased plant length and there is significant difference between the control and the other treatments. The increase in plant length with increased N application might be primarily due to enhanced vegetative growth with more nitrogen supply to plant [24].

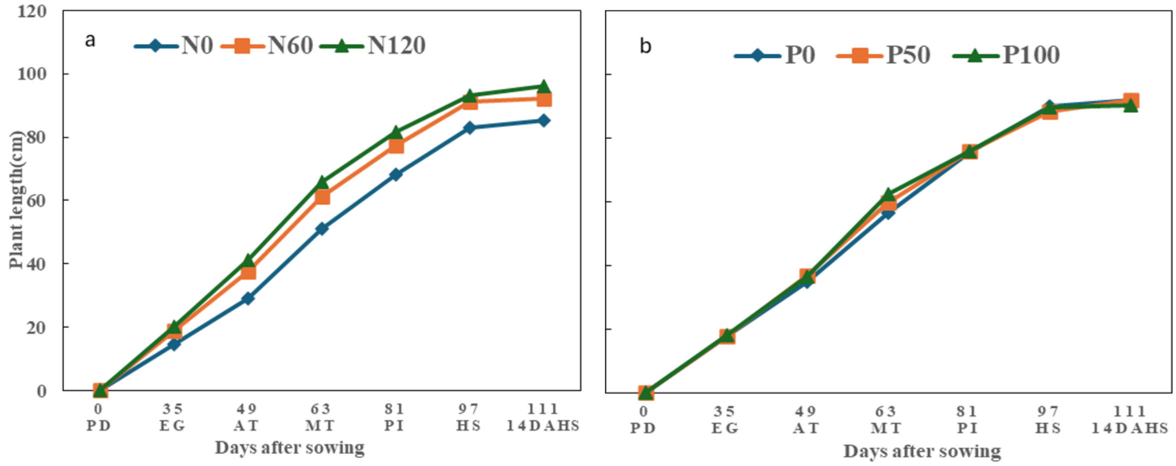


Figure 3. Nitrogen and Phosphorous fertilizer rates influence on the plant length throughout the growth period of rice: Early Growth (EG), Active Tillering (AT), Maximum Tillering (MT), Panicle Initiation (PI), 50% Heading Stage (HS) and 14 days after 50% Heading Stage (14DAHS).

3.1.3. SPAD Value

The SPAD value was highly significantly ($P < 0.01$) affected by the applications of nitrogen fertilizer rates throughout the growth stages of rice (active tillering, maximum tillering, panicle initiation, 50% heading, and 14 days after heading), except at the early growth stage at which it was significantly affected ($P < 0.05$) by N rate. However, there was no significant difference ($P > 0.05$) in phosphorus fertilizer rates and the interaction effect throughout growth stage of data collection except at early growth stage and panicle initiation stage at which P significantly ($P < 0.05$) affected SPAD value. During the rice growth periods, the highest SPAD value was obtained with an N rate of 120 kg ha^{-1}, while the lowest SPAD value was recorded with no N application (Figure 4a). Nitrogen is known to increase the photosynthetic rate of plant and this is the basis for enhanced biomass production of a crop. From the early growth stage to the 50% heading stage, the SPAD value increased slightly. However, from 50% heading to 14 days after 50% heading, the SPAD values decreased (Figure 4a and b). Soil nitrogen deficiency leads to chlorosis in leaves, stunted growth, and ultimately, decreased crop productivity. Decreasing the nitrogen application rates significantly decreased the SPAD values of the rice [25].

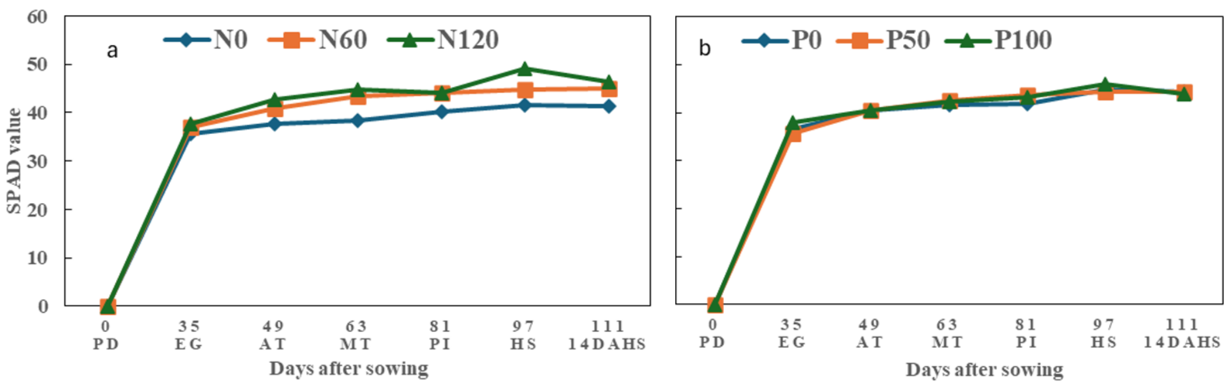


Figure 4. Nitrogen and Phosphorous fertilizer rates influence on the SPAD value throughout the growth period of rice: Early Growth (EG), Active Tillering (AT), Maximum Tillering (MT), Panicle Initiation (PI), 50% Heading Stage (HS) and 14 days after 50% Heading Stage (14DAHS).

3.1.4. Leaf Area Index

Leaf area index was highly significantly (P <0.01) affected by the N fertilizer rates, but not significantly (P >0.05) affected by P fertilizer rates and interaction of N and P across growth stages of rice i.e. maximum tillering, panicle initiation, 50% heading stages and 14 days after 50% heading stage. The significant highest leaf area index was recorded from highest N application rate of 120 kg N ha^{-1} and the lowest was obtained from no application of N across all growth stages of rice (maximum tillering, panicle initiation, 50% heading stage and 14 days after heading) (Figure 5a).

The leaf area index was increased with increased N fertilizer rate because of vigorous growth of the crop and leaf expansion in length and width. Leaf area index has primary importance in increasing the yield of crop. The reason for an increase of leaf area index could be attributed to more production of leaves with expanded leaves produced in response to nitrogen. This funding was in agreement with Mahajan *et al.* [26] who investigated that as nitrogen fertilizer rate increased the leaf area index was also increased.

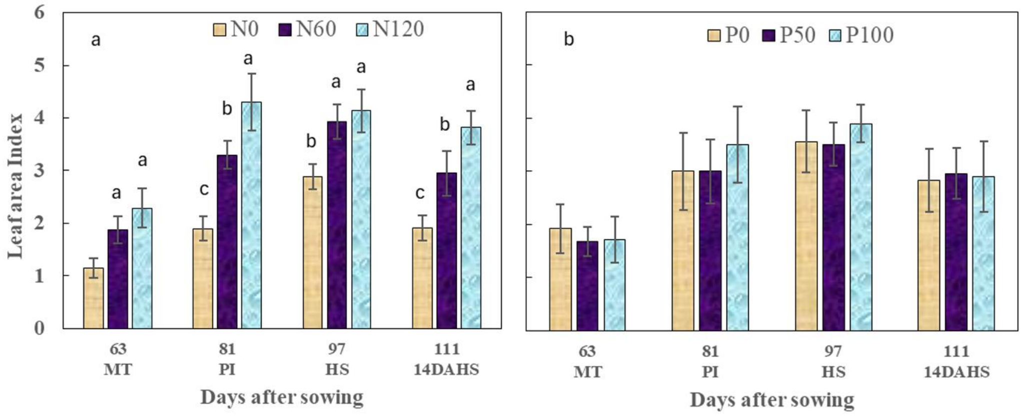


Figure 5. *Nitrogen and Phosphorous fertilizer rates influence on the leaf area index throughout the growth period of rice: Maximum Tillering (MT), Panicle Initiation (PI), 50% Heading Stage (HS) and 14 days after 50% Heading Stage (14DAHS).*

3.1.5. Shoot Dry Weight

The application of nitrogen fertilizer highly significantly (P <0.01) affected shoot dry weight through the growth stages of rice (maximum tillering, panicle initiation, 50% heading, and 14 days after heading). However, phosphorus fertilizer rates and the interaction effect did not show a significant (P >0.05) difference at any stage of data collection, except at 50% heading stage at which phosphorous rates significantly (P <0.05) affected the dry weight. The significant maximum dry weight was recorded with application of 120 kg N ha^{-1} throughout growth stage of the rice (maximum tillering, panicle initiation, 50% heading, and 14 days after heading), while the lowest value was obtained from no application of N (Figure 6a). Regarding the phosphorus fertilizer rate, the highest dry weight was recorded at the 50% heading stage with an application of 100 kg P_2O_5 ha^{-1}, while the lowest was recorded with no phosphorus application (Figure 6b).

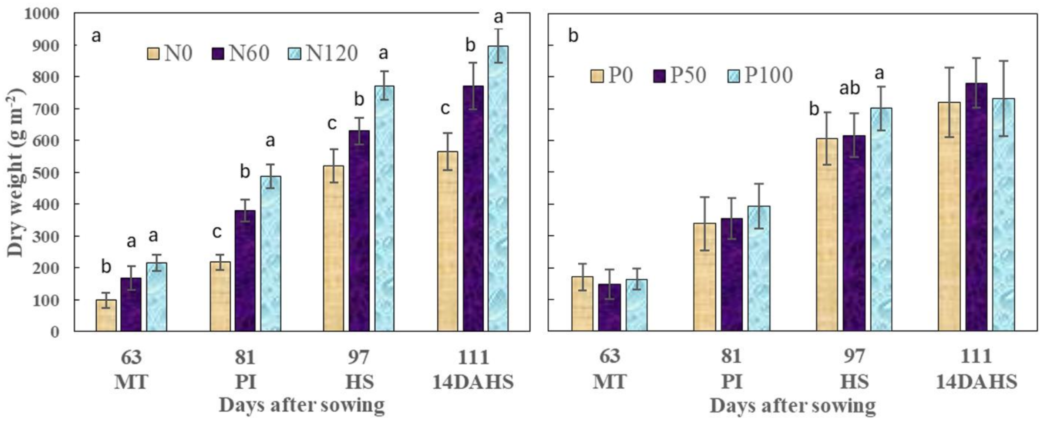


Figure 6. *Influence of NP fertilizer rates on the shoot dry weight throughout the growth period of rice: Maximum Tillering (MT), Panicle Initiation (PI), 50% Heading Stage (HS) and 14 days after 50% Heading Stage (14DAHS).*

The increasing dry shoot weight through the growth period is because of accumulation of nutrients in the plant body and resulting from photosynthesis, as demonstrated by SPAD values, and increase of leaf area index and plant length with increased application of nitrogen fertilizer rate (Figures 3, 4 and 5). Shiferaw *et al.* [27] reported that increase in plant length in response to N application was probably due to enhanced enlargement of leaf area that, in turn, enhanced photo assimilates and thereby resulted in more dry matter accumulation.

3.2. Yield and Yield Components

There were highly significant differences ($p < 0.01$) among the N levels with the number of panicles per m^2, and grain yield but not significant difference ($p>0.05$) for number of spikelet per panicle, percentage of ripened grains, thousand grain weight and harvest index. Regarding the phosphorous levels and the interaction effect there were no significant differences ($p>0.05$) for any of collected yield and yield components (Table 4).

Table 4. *Mean square of Nitrogen and Phosphorous fertilizer rate influence on Yield and yield components of rice during 2025 cropping seasons at JICA Tsukuba Center, Japan.*

Yield and yield components	**Mean square for source of variation**				
	N rate (2)	**P rate (2)**	**Rep (2)**	**Nx P rate (4)**	**MS of Error (16)**
No. of panicle per m^2	16227.1^{**}	1159.03^{ns}	121.53^{ns}	236.11^{ns}	1271.53
No. of spikelet per panicle	181.82^{ns}	52.34^{ns}	57.33^{ns}	25.39^{ns}	64.79
%ge of Ripened grains	2.75^{ns}	121.48^{ns}	141.71^{ns}	42.28^{ns}	59.44
1,000 grain weight (g)	0.035^{ns}	0.12^{ns}	0.81*	0.13^{ns}	0.18
Above ground biomass (t ha^{-1})	29.51^{**}	1.34^{ns}	0.86^{ns}	0.83^{ns}	0.96
Yield (t ha^{-1})	3.90^{**}	0.31^{ns}	0.56^{ns}	0.25^{ns}	0.21
Harvest Index	0.00^{ns}	0.001^{ns}	0.006^{ns}	0.001^{ns}	0.002

Numbers in parenthesis = Degrees of freedom; NS=Not significant difference; *= Significant ($P < 0.05$) difference; ** = Highly significant ($p<0.01$) difference; N=Nitrogen; P=Phosphorous; Rep=Replication; MS=Mean square.

The highest numbers of panicles per square meter (281.7), and grain yield (3.49 t ha^{-1}) were recorded from applications of 120 kg N ha^{-1} which were statistically at par with 60 kg N ha^{-1}. Whereas, the lowest number of panicles per square meter, and grain yield were recorded with no N application (Table 5). Compared with no application of N, there was a 57% and 42% yield increase with the application of 120 and 60 kg N ha^{-1} respectively. Even if there was numerically a yield increase as P rate increased, there were no significant difference with yield and yield components for phosphorous rates (Table 5). These may be due to soils of the experimental field used had sufficient phosphorous (Table 2).

Table 5. *Nitrogen and Phosphorous fertilizer influence on the yield and yield components of rice during 2025 cropping season at Tsukuba International Center, Japan.*

N levels kg ha^{-1}	**No. of Panicles m^{-2}**	**No. of spikelet per panicle**	**%ge of Ripened grains**	**1,000 grain weight (g)**	**Yield (t ha^{-1})**	**Harvest index**
0	198.3^{b}	75.9	60.3	24.6	2.22^{b}	0.36
60	254.2^{a}	84.1	59.8	24.7	3.16^{a}	0.36
120	281.7^{a}	83.1	60.9	24.8	3.49^{a}	0.36
P_2O_5 levels kg ha^{-1}						
0	239.2	82.5	57.2	24.7	2.78	0.35

N levels kg ha^{-1}	No. of Panicles m^{-2}	No. of spikelet per panicle	%ge of Ripened grains	1,000 grain weight (g)	Yield (t ha^{-1})	Harvest index
50	237.2	78.2	64.4	24.6	2.94	0.37
100	257.8	82.3	59.4	24.8	3.15	0.36
Mean	244.7	81.0	60.3	24.7	2.96	0.36
MSD	43.4	9.8	9.4	0.5	0.56	0.06
Cv (%)	14.6	9.9	12.8	1.7	15.6	12.9
F-test						
N levels	**	ns	ns	ns	**	ns
P levels	ns	ns	ns	ns	ns	ns
N X P	ns	ns	ns	ns	ns	ns

Means values followed by the same letter(s) within the column are not significantly different at 0.05 probability level by the Tukey Honest Significant Difference (HSD). MSD=Minimum significant difference.

Nitrogen improved photosynthesis, stimulates root activity and other physiological processes and thus favored biomass accumulation. The higher number of panicles per square meter, and grain yield at highest N rate might be due to the healthier, more vigorous plant growth, and improved plant length, especially with increased nutrient input, particularly nitrogen (N). Nitrogen encourages biomass development and improvement in yield-contributing components. Application of N influences plant length, leaf area index, panicle number, spikelet number, ripening ratio and hence grain yield increase [28]. Dorar *et al.* [23] reported the higher grain yield of NERICA 4 rice was recorded with applications of 92 kg N ha^{-1} and 69 kg P_2O_5 ha^{-1}, representing an increase of 113.66% over the control treatment. Increase in the magnitude of yield attributes is associated with better root growth and increased uptake of nutrients favoring better growth and yield of the crop [24].

3.3. Plant Nutrient Concentration and Uptake at Harvesting Time

There were significant (p<0.05) effect of N levels for total N, available P content and highly significant (p<0.01) effect for N, P and K uptake of the plant. But there was no significant differences (p > 0.05) for phosphorous levels and interaction effect for total N, P and K content of the plant and N, P, K uptake by the plant (Table 6).

Table 6. *Mean square of Nitrogen and Phosphorous fertilizer rate influence on nutrient concentration and uptake of rice during 2025 cropping seasons at JICA Tsukuba Center, Japan.*

Nutrient concentration and Uptake	Mean square for source of variation				
	N rate (2)	P rate (2)	Rep (2)	Nx P rate (4)	MS of Error (16)
N concentration	0.036*	0.002^{ns}	0.01^{ns}	0.0036^{ns}	0.0085
P concentration	0.003*	0.001^{ns}	0.001^{ns}	0.0004^{ns}	0.0006
K concentration	0.0099^{ns}	0.002^{ns}	0.013^{ns}	0.007^{ns}	0.009
N uptake	4747.28**	205.96	230.91	97.64	92.2
P uptake	86.95**	3.20	7.44	6.81	7.936
K uptake	742.67**	74.51	136.44	105.61	75.895

Numbers in parenthesis = Degrees of freedom; NS=Not significant difference; *= Significant (P < 0.05) difference; ** = Highly significant (p<0.01) difference; N=Nitrogen; P=Phosphorous; Rep=Replication; MS=Mean square.

As shown in the Table 7, the significant highest total N (1.074%) content was recorded from application of 120 kg N ha^{-1}, whereas the lowest (0.961%) was recorded from no nitrogen application. Generally the total N content of the plant was increased by 11.8% as N rate increased to 120 kg ha^{-1}. Numerically no application of phosphorous was gave the highest total N (1.044%) and K (0.57%) concentration in the plant. The phosphorous concentration in the plant was decreased as the N fertilizer rate increased. As nitrogen levels rise, the availability of phosphorus decreases, leading to a decline in phosphorus concentration in the plant. This is a result of the limited mobility of phosphorus in the soil, which is often fixed in soil structures and unavailable to plants [29]. The increased application of nitrogen fertilizers can lead to a surplus of nitrogen and vigorous growth, which can outcompete phosphorus for uptake by plants, resulting in lower phosphorus concentration in plants.

The uptake of N, P, and K by the plant increased as the N and P fertilizer application levels increased. The highest plant uptake of N (103.8 kg ha^{-1}) and P (21.8 kg ha^{-1}) were obtained from 120 kg N ha^{-1}, whereas the lowest plant uptake of N (60.1 kg ha^{-1}) and P (16.2 kg ha^{-1}) were recorded from no N application (Table 7). The plant uptake of nitrogen and phosphorus increased by 72.7% and 34.6%, respectively, at the highest level of N fertilizer rate of 120 kg ha^{-1}, compared to no nitrogen application. This may be because of nitrogen stimulate root activity, thereby increasing N and P plant uptake. The plant potassium uptake was highest with the application of 60 kg N ha^{-1}, and lowest with no N application (Table 7). Increased application of N resulted in an increase in root density that caused additional mining of nutrients from the soil and resulted in better nutrient uptake [26].

Table 7. *Nitrogen and phosphorous fertilizer influence on plant nutrient concentration and uptake at harvesting time during 2025 cropping season at Tsukuba International Center, Japan.*

N levels kg ha^{-1}	Nutrient concentration (%)			Nutrient uptake (kg ha^{-1})		
	N	P	K	N	P	K
0	0.961^{b}	0.26^{a}	0.56	60.1^{b}	16.2^{b}	35.3^{b}
60	1.067^{ab}	0.24^{ab}	0.58	94.3^{a}	21.3^{a}	51.7^{a}
120	1.074^{a}	0.22^{b}	0.52	103.8^{a}	21.8^{a}	50.2^{a}
P_2O_5 Levels kg ha^{-1}						
0	1.044	0.24	0.57	84.2	19.1	45.3
50	1.017	0.25	0.54	82.5	20.0	43.1
100	1.041	0.23	0.56	91.5	20.2	48.8
Mean	0.40	0.24	0.55	86.7	19.75	45.75
MSD	0.112	0.03	0.115	11.68	3.43	10.6
Cv (%)	8.9	10.2	17.1	11.2	14.26	19.0
F-test						
N levels	*	*	ns	**	**	**
P levels	ns	ns	ns	ns	ns	ns
N X P	ns	ns	ns	ns	ns	ns

Means values followed by the same letter(s) within the column are not significantly different at 0.05 probability level by the Tukey HSD.MSD=Minimum significant difference.

3.4. Agronomic Efficiency

The highest agronomic efficiency (13.0) was recorded from application of 60 kg N ha^{-1} and no P application (Table 8). Agronomic efficiency of NP was decreased at highest N and P application rate of 120 kg N ha^{-1} and 100 kg P_2O_5 ha^{-1} respectively. This may be because of poor utilization of N by the crop at higher N levels and a quadratic response of N, as yield approached the ceiling at higher levels of N [30]. The higher N level (120 kg ha^{-1}) enhanced vegetative growth, but translocation of photosynthates to grain might be limited at higher N, possibly explaining the decreases in agronomic efficiency of rice at 60 kg N ha^{-1}.

Table 8. Nitrogen and phosphorous fertilizer influence on agronomic efficiency during 2025 cropping season at Tsukuba International Center, Japan.

N levels kg ha^{-1}	Phosphorous levels (P_2O_5) kg ha^{-1}		
	0	50	100
0	-	2.6	-1.6
6	13.0	6.2	8.3
120	7.3	7.6	7.3

3.5. Soil Chemical Analysis After Harvest

A highly significant difference (P < 0.01) was observed with the levels of N and P for electrical conductivity (EC). The levels of N had a significant effect (P < 0.05) on soil pH, total N, and K content, but non-significant difference (P >0.05) of available P and Total carbon in the soil. The phosphorous fertilizer rates did not show the significant difference (P >0.05) for soil pH, total N, available N, available P, K, and total carbon (Table 9).

Table 9. Mean square of Nitrogen and Phosphorous fertilizer rate influence on nutrient content of soil during 2025 cropping seasons at JICA Tsukuba Center, Japan.

Nutrient content of soil	Mean square for source of variation				
	N rate (2)	P rate (2)	Rep (2)	Nx P rate (4)	MS of Error (16)
Electrical conductivity	0.00271**	0.00158**	0.00018^{ns}	0.00004^{ns}	0.00014
pH	0.0715*	0.0015^{ns}	0.0904**	0.0037^{ns}	0.0141
Total N (%)	0.00007^{ns}	0.00003^{ns}	0.0001*	0.00001^{ns}	0.00003
Av. P (mg P_2O_5 kg^{-1})	180.94^{ns}	339.84^{ns}	2223.26*	814.97^{ns}	396.93
K (mg K_2O kg^{-1})	305.167*	117.006^{ns}	198.525^{ns}	14.826^{ns}	57.1644
Total carbon (%)	0.012^{ns}	0.004^{ns}	0.057*	0.002^{ns}	0.01064

Numbers in parenthesis = Degrees of freedom; NS=Not significant difference; *= Significant (P < 0.05) difference; ** = Highly significant (p<0.01) difference; N=Nitrogen; P=Phosphorous; Rep=Replication; MS=Mean square.

Table 10. Effect of Nitrogen and phosphorous fertilizer on chemical properties of soil after harvest during 2025 cropping season at Tsukuba International Center, Japan.

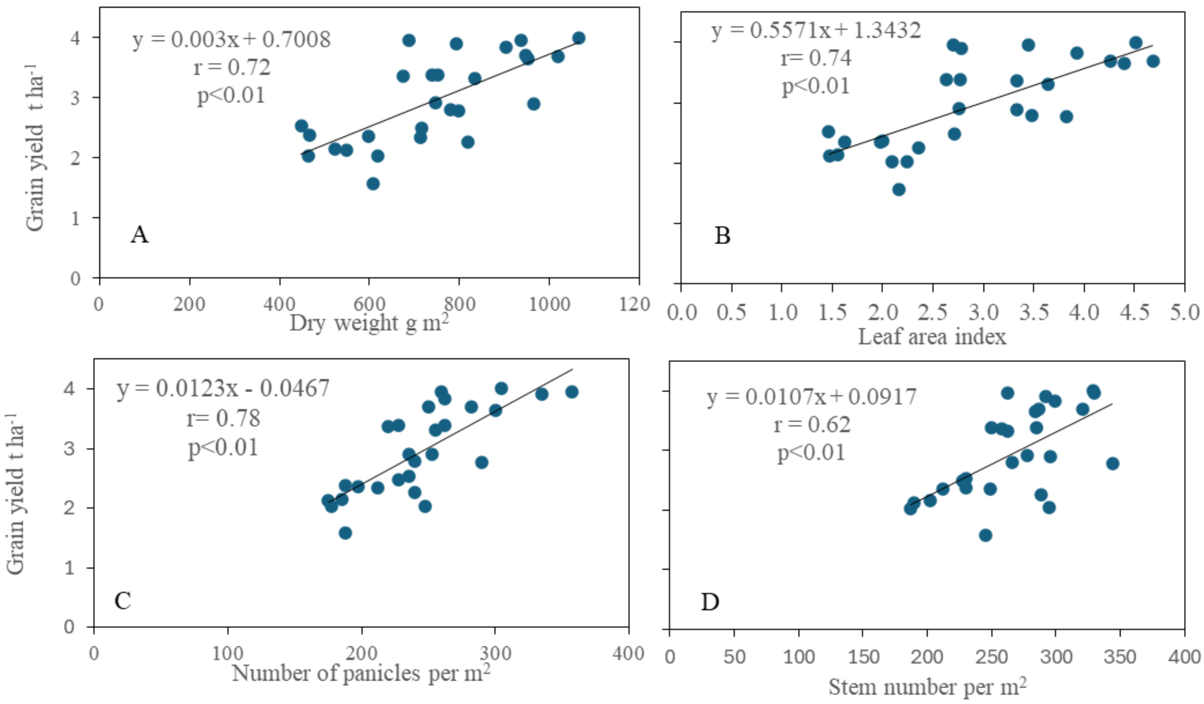
N levels kg ha^{-1}	EC (mS cm^{-1})	pH	Total N (%)	Available P (mg P_2O_5 kg^{-1})	K (mg K_2O kg^{-1})	Total carbon (%)
0	0.12^{b}	6.33^{a}	0.328	108.7	73.6^{a}	3.84
60	0.14^{a}	6.26^{ab}	0.331	106.2	70.6^{ab}	3.86
120	0.15^{a}	6.16^{b}	0.333	114.9	62.3^{b}	3.91
P_2O_5 Levels kg ha^{-1}						
0	0.12^{b}	6.23	0.333	103.0	69.7	3.87
50	0.14^{a}	6.26	0.330	114.8	71.9	3.85
100	0.14^{a}	6.26	0.330	112.0	64.9	3.89

N levels kg ha^{-1}	EC (mS cm^{-1})	pH	Total N (%)	Available P (mg P_2O_5 kg^{-1})	K (mg K_2O kg^{-1})	Total carbon (%)
Mean	0.14	6.25	0.33	109.9	68.8	3.87
MSD	0.01	0.145	0.006	24.23	9.2	0.125
Cv (%)	8.6	1.9	1.5	18.1	11.0	2.7
F-test						
N levels	**	*	ns	ns	*	ns
P levels	**	ns	ns	ns	ns	ns
N X P	ns	ns	ns	ns	ns	ns

Means values followed by the same letter(s) within the column are not significantly different at 0.05 probability level by the Tukey HSD. MSD=Minimum significant difference.

As indicated in the Table 10, the significant highest EC of 0.15 and 0.14mS cm^{-1} were obtained from the highest levels of nitrogen (120 kg ha^{-1}) and phosphorus (100 kg P_2O_5 ha^{-1}) respectively, whereas the lowest EC of 0.12 mS cm^{-1} was recorded from no application of N and P. As the levels of N and P fertilizers increased to the highest level, the EC value increased by 60% over the control. As the N fertilizer rates increased, the pH of the soil was significantly decreased by making soil more acidic. The total nitrogen in the soil increased as the N fertilizer levels increased, but decreased with P fertilizer application. The highest N (0.333%) in the soil was obtained from 120 kg N ha^{-1} application, whereas the lowest (0.328%) was recorded from no N application. The highest available P of 114.9 and 114.8 mg kg^{-1} were obtained from 120kg N ha^{-1} and 50kg P_2O_5 ha^{-1} respectively. The potassium in the soil decreased as the N and P fertilizer levels increased to highest levels. This may be due to vigorous growth of the crop and K removal from the soil. Numerically the highest total carbon of 3.91% and 3.89% in the soil was recorded from highest level of N and P respectively, whereas the lowest was obtained from no application of nitrogen and 50 kg P_2O_5 ha^{-1}. This indicates there was slightly increase of total carbon in the soil as N and P fertilizer rates increased.

3.6. Correlation and Regression Analysis



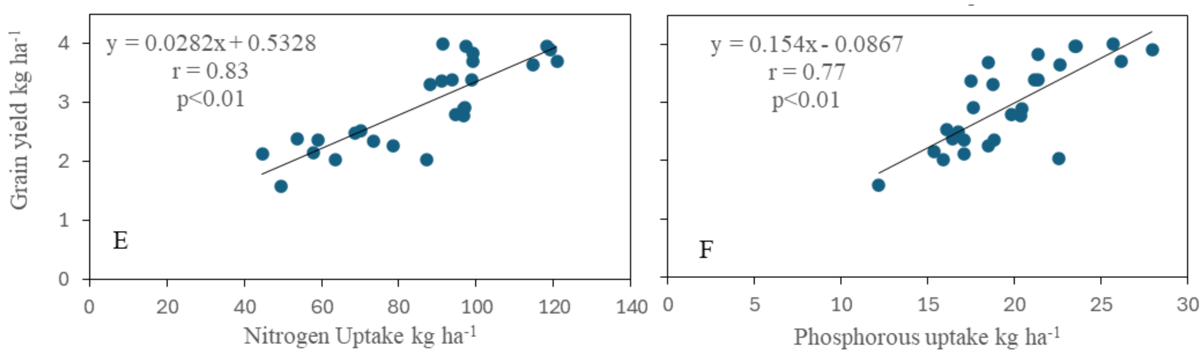


Figure 7. Relationships between grain yield and dry weight (A), leaf area index (B), number of panicles per m² (C), stem number per m² (D), nitrogen uptake (E) and phosphorous uptake (F).

As shown in the Figure 7, the grain yield was positively and highly significantly (P<0.01) correlated with dry weight (r=0.72**), leaf area index (r=0.74**), number of panicles per m^2 (r=0.78**), plant length (r=0.62**), stem number (r=0.62), SPAD value (r=0.77**), nitrogen (r=0.83**) and phosphorous (r=0.77**) uptake by the plant. Thus, these growth parameters and yield components mainly contribute to an increase in rice grain yield. Different studies have also indicated positive associations of grain yield with yield related traits [27] and growth parameters [23].

4. Conclusion

In general, the results revealed that the growth, yield, and yield components of NERICA 4 rice in the experimental area under upland condition were significantly affected by nitrogen levels but not by phosphorus fertilizer levels. This may be due to the high level of available phosphorus in the soil, as indicated by the soil laboratory results. At this experimental area the nitrogen is a more significant growth, yield and yield component limiting factor for rice than phosphorus, affecting its growth and development. As the application of nitrogen increased to 120 kg ha^{-1}, the growth, yield, and yield components increased with or without phosphorus fertilizer applications. The increased combined application of N with or without P fertilizer increased grain yield mainly due to higher LAI, number of panicles per square meter, plant length, and number of stem per square meter that leads to better grain development and higher biomass. Further investigation is needed to reach a conclusive conclusion and make recommendations.

Abbreviations

CV	Coefficient of Variation
CEC	Cation Exchange Capacity
DAS	Days After Sowing
EC	Electric Conductivity
HSD	Honest Significant Difference
JICA	Japan International Cooperation Agency
LAI	Leaf Area Index
LSD	Least Significant Difference
MSD	Minimum Significant Difference
m.a.s.l	Meter Above Sea Level
NERICA	New Rice for Africa
RCBD	Randomized Complete Bock Design

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Author Contributions

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Data Availability Statement

The datasets generated during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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