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Amount of nitrogen and phosphorus fertilizer required to optimize growth and yield of rice

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Soil nutrient management is an important factor in plant growth for increased crop production and productivity in Sub-Saharan Africa whose food demand is over the threshold. Rice production in Uganda is still very low with current yield less than 2.5 ton ha^{-1}. The impressive production increase is mainly on to farmer area expansion. A fertilizer trial was established to determine a New Rice for Africa (NERICA) 4 variety response to the nitrogen and phosphorus application. At Tsukuba International Center, Japan, 2014 an experiment with objective to obtain the minimum fertilizer recommendation amount of nitrogen and phosphorus application dose was established during rice growing season May to September. The nitrogen (N) fertilizer rates were 0, 40 and 80 kg ha^{-1} while phosphorus (P) 0 and 70 kg ha^{-1} fertilizer quantities applied. Several data were obtained and indicated tiller number, panicle number m^{-2}, plant dry matter were significantly (P<0.05) different from control. Yield and yield components were not significantly (P>0.05) different on application of different nitrogen doses. However, in P conditions, both nitrogen doses (40 and 80 kg ha^{-1}) did not vary in ripened grains and number of spikelets/ m^{2}. A significant amount of N was utilized when 40 kg N ha^{-1} was applied compared to 80 kg N ha^{-1} in similar P condition through growth stages. Applying N and P fertilizers at 80 and 70 kg ha^{-1} respectively, as well as applying N fertilizer 80 kg ha^{-1} alone increased growth parameters and yield compared to other rates of N and P fertilizers applied.

Key words: Fertilizer rate, upland rice, New Rice for Africa (NERICA), N use efficiency

INTRODUCTION

Soil nutrient management is an important plant growth factor to increase crop production. In Sub-Saharan Africa, soil fertility is declining especially in areas occupied by smallholder farmers. In Uganda, rice consumption demand is increasing and rice farmers are experiencing yields less than 2.5 t ha^{-1}, the impressive current production increase is mainly due to extension of cultivated area (Ahmed, 2012). According to Oonyu (2011), paddy rice growing areas significantly improved rural farmer household income when yields of up to 2.5 t ha^{-1} were attained in the 1980s. This is because for the last decade, rice has become the most important food

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Table 1. Chemical properties of soil used.

Nutrient tested	Amount (Units)
Soil pH (1: 2.5)	6.4
Total N (%)	0.23
Avail. P (mg kg^{-1})	52.0
Potassium (mg kg^{-1})	420.0
Magnesium (mg kg^{-1})	240.0
Calcium (mg kg^{-1})	710.0

resource in homes for small scale communities (Balasubramanian et al., 2007) and changing a traditional norm of most rice consumption to be associated with urbanization (Africa Rice Center, 2008). However, the incomes declined primarily due to declining soil fertility levels, farmers' inability to control water use, low yielding varieties and the poor farming practices (Oonyu, 2011; Nhamo et al., 2014).

Smallholder farmers of rice need to have potential to increase production and productivity of rice yields through using improved rice cultivars and agronomic management techniques (Rodenburg et al., 2014), enhance nutrient and water availability and use efficiencies (Balasubramanian et al., 2007) and to control weeds (Africa Rice Center, 2008). Ecosystem is vulnerable to degradation when farmers do not change their farming practices and indiscriminately develop skills for the sole purpose of agricultural production. Rodenburg et al. (2014) estimates that, employing improved water and weed management practices, production of rice from a small percentage of inland valley areas could mount to total current demand in Africa. The rice production indices to increase, the farmers in Sub Sahara African region need to orient their outs to the markets and strategies required to meet the market demands. This leaves farmers with no choice but to improve productivity and a significant amount of land will be safeguarded for other tenacities (Mwaseba et al., 2006).

One of the major causes of low rice production is the decline in soil fertility, most especially nitrogen (N) and phosphorus (P) (Oonyu, 2011). Nitrogen is largely limiting nutrient in most soils (Bekunda et al., 2002) for rice production. Application of N influences plant length, leaf area, panicle number, spikelet number, ripening ratio and hence grain yield increase (Dobermann and Fairhurst, 2000). On the other hand, P has developmental activity in plant's root growth (Rose et al., 2013). Unfortunately, this nutrient is highly deficient in soils around the country (IFDC, 2006). The introduction of New Rice for Africa (NERICA) varieties in the western highlands agro-ecological zone of Uganda left farmers using blanket fertilizer application for other crops or not even single fertilizer rates are applied (Kijima et al., 2011). Rice cultivation fields of smallholder farmers are experiencing nutrient deficiencies and farmers lack knowledge on the fertilizer rates required to be applied to boost rice growth and improve yields. Therefore, an appropriate application and management of these nutrients is essential for optimizing rice grain yields. The purpose of this research is therefore, to examine NERICA 4 performance on fertilizer rates and establish an optimal fertilizer amount of N and P and their influence on plant growth, yield and yield components in rice production for smallholder farmers.

MATERIALS AND METHODS

Site characterization

The study area is located on the eastern central of Japan, with an average altitude of 578 meters above sea level, an annual precipitation of 1200 mm and maximum temperature of 19.0°C and minimum temperature of 12.0°C through the year. The soil type is an oxisol with chemical and soil pH composition as shown in table 1. The study was conducted with the aim of investigating the effect of fertilizer application of nitrogen and phosphorus on growth and yield of NERICA 4 rice variety at Tsukuba International Center, Japan from April to September 2014 cropping season. This variety is characterized with high panicle weight compared to others, high yielding potential, early to medium maturing, adaptable upland conditions and it of medium resistant to leaf blast. The variety was investigated in an upland condition for various parameters like plant height, tiller number, SPAD value, shoot dry matter, panicle dry matter, nitrogen uptake, panicle number, spikelet number, panicle length, ripening ratio, thousand grain weight, harvest index and paddy yield.

Seed preparation and planting

Seeds were selected using 1.03 specific gravity of salt-water solution. The seeds were then soaked in a Benlate T (Thiram 20% - Benomyl 20% powder) fungicide for an overnight to avoid seed borne diseases. They were then air dried and coated with Keyhigen birds expellant solution 1% of the rice seed was mixed then air dried. The experiment was arranged in RCB design with three replicates in a non-irrigated condition. At the seed rate of 50 kg ha^{-1} NERICA 4 was planted, sown at 0.3 m spacing between lines using drilling method and about 2-4 cm soil depth. Fertilizers N and P were applied in the form of ammonium sulphate (21% N) and single super phosphate (17.5% P), respectively. Nitrogen fertilizer was applied in two phases: as basal and two top dressings, with N amounts of 0, 40 and 80 kg N ha^{-1}, whereas P was applied as basal fertilizer at rates of 0 and 70 kg ha^{-1}. Furthermore, K fertilizer was broadcasted uniformly to all plots in the form of potassium chloride in two splits 70 and 30 kg k ha^{-1}, as basal and top dressing respectively. Top dressing was done on July 8, just after identifying the panicle initiation (about 8 mm length).

Sampling and plant growth analysis

The data collection was categorised into growth observation data, yield and yield components data. The other data collected was plant nutrient uptake (N and P) at different plant stages. To help in minimizing errors, several observation lines were marked within each plot lines and their plant population was adjusted to 17 plants per 30 cm for all the plots. In each plot, 2 center lines were marked and left undisturbed through the growth period for yield data collection, other 5 lines were selected and marked for growth data collection. The outer lines on either side of the plot were used as guard rows. At growth observation data collection stage, two 30 cm

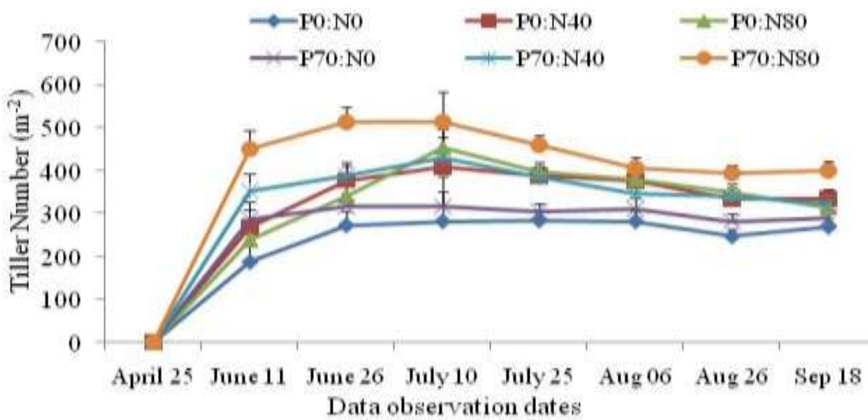

Figure 1. Changes in tiller number per square meter through rice 'NERICA 4' growth to harvest influenced with N and P application. The error bars are LSD values at 0.05 level of probability.

lines were sampled from each plot in diagonal manner to obtain a uniformly representative sample for the plot. The data collected at this stage included measuring plant length (cm), leaf area, measuring indirectly the chlorophyll content of second fully opened leaf by SPAD meter, tiller number and plant shoot dry matter. The other set of data was yield and yield components collected 35 days after plant heading and including: number of panicle/m^2, number of spikelets/panicle, ripened grains (%), 1000 grains weight (g), yield (t/ha) and straw weight (t/ha).

On the other hand, plant nutrient uptake of N and P for different plant parts (shoot and panicle) were analysed at plant stages: panicle initiation, full heading, filling stage and full maturity. The plant samples were dried in an oven at 80°C for 48 h, separated into shoot (leaves and stem) and panicle and ground finely. Plant absorbed N was determined in 0.03 - 0.05 g analyzed using dry combustion method by NC analyzer SUMIGRAPHJ NC-22F apparatus. Plant P was obtained by weighing 1.00 g of ground plant material, burnt in a muffle furnace for 8 h at 500°C, followed by procedures described in Bray I method (ascorbic acid molybdenum blue method) for extraction of plant P (Bray and Kurtz, 1945).

Plant N results were used to explain two conditions: Nitrogen Use Efficiency (NUE) and Production Efficiency (E_p). In case of NUE, absorbed N was expressed as percentage of applied N (Equation 1). This helped to determine an amount at which more N was maximally utilized by the plant. Whereas, E_p is a ratio to express the importance of accumulated plant N in producing grain yield (Equation 2), it was obtained by expressing unit grain yield over unit total plant N absorbed.

$$NUE = \frac{AbsorbedplantNinNappliedplot - AbsorbedplantNinnoNappliedplot}{AppliedN} x100 \quad (1)$$

$$E_p = \frac{Grainyield(kg/ha)}{TotalAbsorbedplantN(kg/ha)} \quad (2)$$

Statistical analysis

Analysis of Variance (ANOVA) was used to compare means of growth, yield and yield components data. Fisher's protected Least Significant Difference (LSD) at P ≤ 0.05 level of significance was used to separate means. Correlation analysis was used to analyze the relationship between fertilizer application rates and crop yield. It was also used to estimate the optimal amount required for maximum yield of NERICA 4.

RESULTS AND DISCUSSION

Growth observation parameters

Tiller number

There was a general increase in the number of tillers per square meter in all treatments (Figure 1). However, a significant difference among treatment combinations was observed only for P70:N80 (Phosphorus: 70 kg ha^{-1}; Nitrogen: 80 kg ha^{-1}), with the highest number of tillers through the growing season.

Leaf area index

Figure 2 indicates the leaf area index performance of rice'NERICA 4' for the different N and P treatments. There was a general increase in the leaf area in all treatments, however, treatments with no application of N performed significantly lower than those with N application. In the months of August, maximum area was registered in all treatments but treatment P0:N80 mainatained the performance to september.

SPAD readings

Makino (2011) and Figueiredo et al. (2014) stated that a

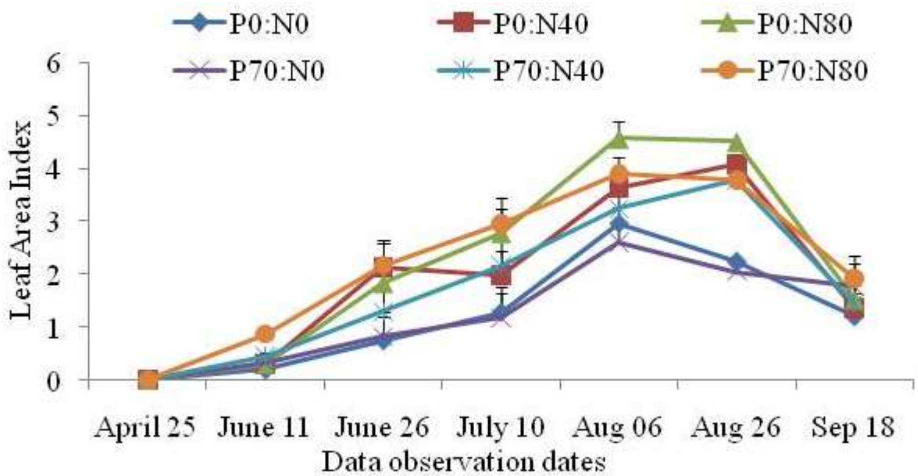

Figure 2. Performance of Leaf Area Index (LAI) through the growth period of rice 'NERICA 4' in different N and P application. The error bars are LSD values at 0.05 level of probability.

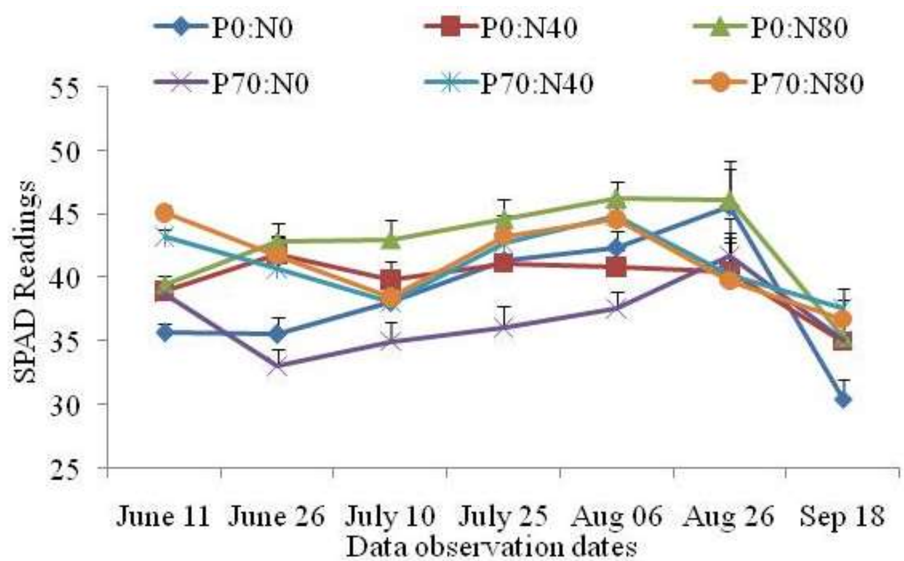

Figure 3. Changes in SPAD values in rice 'NERICA 4' leaves as influenced by N and P fertilizer combinations over the growth period. The error bars are LSD values at 0.05 level of probability.

SPAD value of 35 in any rice genotype is about the critical leaf N status to attain optimal plant growth and then yield (Figure 3). Nitrogen is known to increase the photosynthetic rate of plant and this is the basis for enhanced biomass production of a crop. Therefore, the application of certain amount of N stimulated plant growth. There was a significant difference between P70:N0 performing lower than other treatments in SPAD values until August (Figure 3), however, towards the ending of the month all treatments were insignificantly different and SPAD values started declining to harvest time. Maximum N application alone was not significant until early July, however, later in the months and the rest of other days it was not significantly different from other treatments (Figure 3).

Plant dry matter

In Figure 4 there was a general trend in all treatments for the dry matter to increase through the growth period. N and P treatment combinations did not have significant differences among them until July, but thereafter dry matter increased significantly above P0:N0 and P70:N0

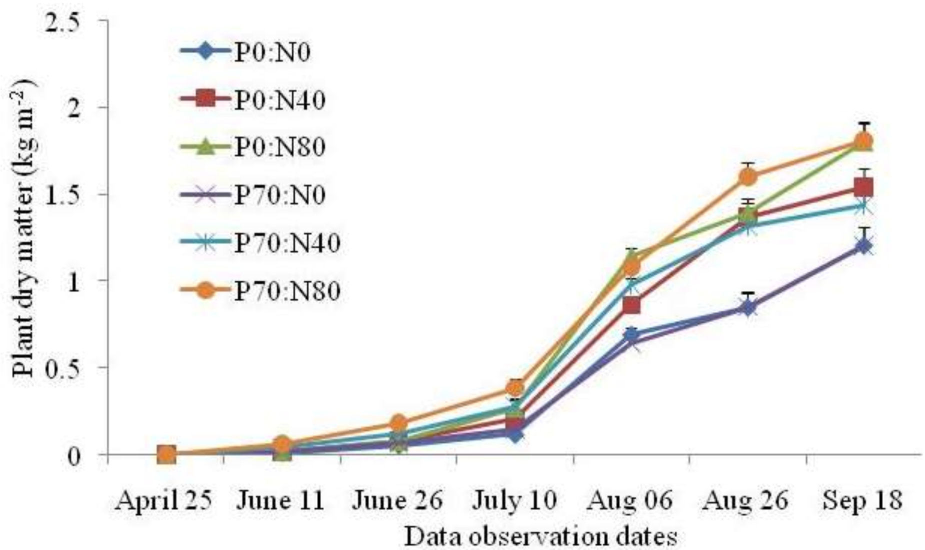

Figure 4. Plant dry matter (kg m^{-2}) changes over the rice 'NERICA 4' growth period to maturity under different N and P application rates. The error bars are LSD values at 0.05 level of probability.

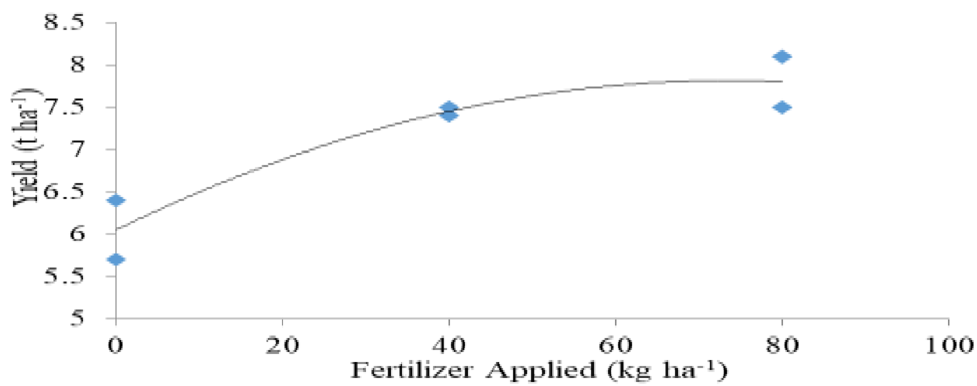

Figure 5. The rice 'NERICA 4' yield (t ha^{-1}) response to different levels of N (0, 40 and 80 kg ha^{-1}) and P (0 and 70 kg ha^{-1}) fertilizers

(not significantly different from each other), from July 10 to September 18. The increasing dry matter through the growth period is because of accumulation of nutrients in the plant body and resulting from photosynthesis, as demonstrated by SPAD values (Figure 3).

Rice yield

There was significant difference among the N levels applied to 'NERICA 4' (Figure 5). However, the response of 'NERICA 4' was relatively high to lower N dose. The findings however, indicate that an increase in N above 60 kg N ha^{-1} had similar results in terms of yield (t ha^{-1}). The results is in agreement with Oikeh et al. (2008) who reported a strong response to fertilizers by NERICA and considered application of 60 kg N ha^{-1} and 13 kg P ha^{-1} appropriate for low to moderate input smallholder farmers has proved double grain yield as compared to zero fertilizer application. Furthermore, Mghase et al. (2011) suggest that NERICA can be grown in low fertility upland soils in Africa where soil fertility amendment options are not practical due to farmer's poor access to fertilizers resulting in their low purchasing power.

Yield components

Application of fertilizers generally improved the yield components performance of the 'NERICA 4' (Table 2).

Table 2. Yield components of NERICA 4 on varrying N and P fertilizer application.

Phosphorus x Nitrogen (kg/ ha)	No. of panicle / m^2	Ripening ratio (%)	1,000 grains weight (g)	No. of spikelets / m^2 (x 10^3)	Yield components (t / ha)	Total straw weight (t / ha)	Harvest index
P0:N0	281 (100)	74.5 (100)	29.2 (100)	26.3 (100)	5.69 (100)	6.5 (100)	0.50 (100)
P0:N40	328 (116)	77.8 (104)	29.0 (99)	33.0 (125)	7.46 (131)	6.8 (104)	0.49 (99)
P0:N80	341 (121)	73.3 (98)	29.7 (102)	37.6 (143)	8.13 (143)	8.4 (130)	0.48 (96)
P70:N0	298 (106)	82.9 (111)	28.7 (98)	26.6 (101)	6.35 (112)	6.4 (99)	0.48 (97)
P70:N40	324 (115)	79.1 (106)	29.5 (101)	31.7 (120)	7.37 (130)	6.9 (107)	0.50 (100)
P70:N80	378 (134)	77.2 (104)	29.0 (99)	33.7 (128)	7.50 (132)	9.4 (147)	0.48 (96)
$LSD_{0.05}$	99.1	7.6	1.6	13.8	2.62	2.3	0.04
CV%	17	5.4	3.0	24	20.4	17.3	4.90

*values in blakets are percent aganist a control plot N and P (0 kg ha^{-1}) fertilizer applied.

Table 3. The Nitrogen Use Efficiency (NUE) of rice 'NERICA 4' at different plant phases as treated with varying rates of N and P (kg/ha).

Phosphorus x Nitrogen	Applied N (kg/ha)	NUE (%) at panicle initiation	NUE (%) at heading	NUE (%) at mid maturity	NUE (%) at full maturity
P0:N0	0	-	-	-	-
P0:N40	40	73.2	-	-	43.0
P0:N80	80	84.0	54.5	53.4	78.1
P70:N0	0	-	-	-	-
P70:N40	40	85.0	74.0	76.5	55.7
P70:N80	80	76.3	66.6	91.3	67.7

Application of nitrogen with or without phosphorus had no significant effect on the yield obtained. When 80 kg N ha^{-1} was applied with 70 kg P ha^{-1}, the combination produced the highest number of panicle per square meter (378), however, it had less yield when compared with 80 kg N ha^{-1} without P applied (Table 2). Application of 80 kg N ha^{-1} and 70 kg P ha^{-1} produced a significant amount of straw weight (9.4 t ha^{-1}) compared to 40 kg N ha^{-1} with and without phosphorus applied. Nitrogen application with or without P did not have significant effect on both ripening ratio (%) and number of spikelets m^{-2}. The soils of the experimental field used had sufficient potassium (Table 1). Dobermann et al. (1998) and Dobermann and Fairhurst (2000) reported that K increases the yield components in rice especially the number of grains per panicle, percentage of filled grains and grain weight. On the other hand, the high dose of N applied produced more straw weight compared to lower dose applied (Table 2). The harvest index value obtained when applied 80 kg N ha^{-1} was low compared to 40 N kg ha^{-1} dose applied (with no phosphorus effect).

Nitrogen use efficiency (NUE) and production efficiency (E_p)

The results indicate that Nitrogen Use Efficiency (NUE) after application of N fertilizer at different levels of P was high through the growth stages (Table 3). There was relatively high NUE when 40 kg N ha^{-1} and 70 kg P ha^{-1} fertilizers were applied through different growth stages of rice NERICA 4. The plant when compared to nutritional application level 80 kg N ha-1 and 70 kg P ha-1 at some stages of plant growth (Table 3) obtained a significant amount of N. The findings clearly indicate that nitrogen dose 40 kg ha^{-1} was highly recovered and utilized by the plant. In this case, it appears that relatively lower amount of N when applied to the plant, the plant utilization capacity is high than the rate of loss of N into the soil. The increase in the amount of N application decreases production efficiency with linear relation regardless of phosphorus application (Table 4). However, there was a sharp decline in treatments with no P application compared to when P was applied. The likelihood that increasing plant N concentration can induce sterility, this was even experienced in yield reduction when number of spikelets m^{-2} was relatively lower yet a high number of panicle was obtained (Table 4).

Conclusion

Generally, there was an increased performance of NERICA 4 when N and P fertilizers were applied

Table 4. Production efficiency (E_p) of rice 'NERICA 4' under different treatments in upland conditions.

Phosphorus × Nitrogen	Plant N (kg ha^{-1})	Grain yield (kg ha^{-1})	Production efficiency (E_p)
P0:N0	106.0	6430.5	60.6
P0:N40	123.2	6652.1	54.0
P0:N80	168.5	7711.0	45.8
P70:N0	100.7	5986.0	59.5
P70:N40	123.0	7008.1	57.0
P70:N80	154.8	8680.3	56.1

compared to no N and P fertilizers application in the upland conditions. Applying N and P fertilizers at 80 and 70 kg ha^{-1} respectively, as well as applying N fertilizer 80 kg ha^{-1} increase growth parameters and yield compared to other rates of N and P fertilizers applied. However, production efficiency is high with lower rates of N fertilizer application; in fact, it increases further with 0 kg N fertilizer application. Further investigation should be made under uniform and lower soil N content.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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