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Effects of Mineral N and P Fertilizers on Yield and Yield Components of Flooded Lowland Rice on Vertisols of Fogera Plain, Ethiopia

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Abstract

Despite its very recent history of cultivation in Ethiopia, rice is one of the potential grain crops that could contribute to the efforts for the realization of food security in the country. However, the scientific information available with regards to the response of flooded rice to N and P fertilizers for its optimum production on Vertisols of Fogera Plain is very limited. Therefore, a field experiment was conducted on Vertisols of Fogera plain, northern Ethiopia to study the yield and yield components response of rice and to establish the optimum N and P fertilizer levels required for improved grain yield of flooded rice. Six levels of N (0, 30, 60, 90, 120 and 150 kg ha^{-1}) and five levels of P (0, 13.2, 26.4, 39.6 and 52.8 kg ha^{-1}) laid down in a randomized complete block design with four replications were used as treatments. Nitrogen was applied in two equal splits (50% basal and 50% at maximum tillering) as urea and the entire dose of P was applied basal as triple super phosphate at sowing. The main effects of N and P fertilizer levels showed significant differences ($P \leq 0.01$) for all yield and yield components studied. The effects of N by P interaction were significant only for grain yield ($P \leq 0.05$), number of panicles per m^2 ($P \leq 0.01$), number of spikelets per panicle ($P \leq 0.05$) and plant height ($P \leq 0.01$) among the different yield and yield components studied. Application of N and P significantly ($P \leq 0.01$) increased grain yield of rice up to the levels of 60 kg N and 13.2 kg P ha^{-1}. However, maximum grain yield (4282 kg ha^{-1}) was obtained with the combined application of 60 kg N and 13.2 kg P ha^{-1}, and the yield advantage over the control was 38.49% (1190 kg ha^{-1}). Moreover, application of both N and P fertilizers have increased the magnitudes of the important yield attributes including number of panicles per m^2, number of spikelets per panicle, panicle length, dry matter accumulation, straw yield and plant height significantly ($P \leq 0.01$). Besides, grain yield was positively and significantly associated with number of panicles per m^2 ($r = 0.61**$), number of spikelets per panicle ($r = 0.49**$), panicle length ($r = 0.54**$), dry matter accumulation ($r = 0.46*$), thousand grain weight ($r = 0.41*$) and harvest index ($r = 0.39*$). These indicate that N and P application increased grain yield of rice by positively affecting the important yield components of the crop. Therefore, taking

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the findings of the present study into consideration, it may be tentatively concluded that the farmers at the Fogera plain may apply a combination of 60 kg N and 13.2 kg P ha^{-1} to improve the grain yield of flooded lowland rice cultivated on heavy black clay soils (Vertisols) under rain fed conditions.

Keywords: Flooded rice, dry matter, Fogera plain, grain yield, NP fertilizers, panicle, spikelet, yield components

1 Introduction

The cultivation of rice in Ethiopia is of more recent history than its utilization as a food crop. Some evidences indicate that cultivation of rice in Ethiopia was first started at the Fogera and Gambella plains in the early 1970s. Currently, the Fogera, Gambella, Metema, and Pawe plains located in the northern, northwestern, and western regions are developing in to major rice-producing areas in Ethiopia (Mulugeta Seyoum, 1999, 2000). At the Fogera plain, rice plays an important role in relaxing the problem of food-insecurity of the farming community.

The rice crop offers variety of uses to the farming community. It is used in the preparation of local foods such *injera, dabbo, genffo, kinchie* and *shorba* in addition to the rice dish itself and local beverages like *tella* and *katikalla* either alone or mixed with other cereal grains such as teff, millet, wheat, barley, sorghum and maize. Moreover, rice could also be considered as one of the best and cheapest alternative technology available to farmers for efficient utilization of natural resources, such as land and water, under swampy and flooded environments (Mulugeta Seyoum, 1999, 2000; Mulugeta Seyoum and Heluf Gebrekidan, 2005).

Because of its wider adoption from farmers' social, economic, and environmental perspectives, rice production at the Fogera plain is expanding rapidly from year to year. As a result, between 1994 and 2000, the land cultivated with rice increased from 65 to 4,174 ha. However, the production and productivity of the crop under farmers' field conditions is low (about 2600 kg of rice grain ha^{-1} on the average) compared to its yield levels under farmers' conditions in other parts of the world. Yet, improvement of its production has not been possible due to a number of soil-plant-management related factors. Apparently, low soil fertility and inadequate nutrient management are among the major factors determining its yield level.

Results of several studies have indicated that application of N and P fertilizers increase grain yield of rice by increasing the magnitude of its yield attributes (Thakur, 1993; Channabasavanna and Setty, 1994; Panda *et al.*, 1995). Increase in yield attributing characters is associated with better nutrition and increased nutrient uptake which result in better and healthy plant growth and development (Kumar and Rao, 1992; Thakur, 1993), leading to greater dry matter production and its translocation to the sink (Dalal and Dixit, 1987). Panda *et al.* (1995) reported increased dry matter production including grain yield of rice due to increased N and P uptake in response to external supply of both N and P fertilizers. Therefore, this field experiment was conducted to investigate the effects of applied N and P fertilizer doses on yield and yield components and to establish the optimum levels of N and P required for improved grain yield and production of flooded rice on Vertisols of Fogera Plain under farmers' field conditions.

2 Materials and Methods

2.1 Description of the Study Area

A field experiment was conducted under rain fed conditions during the main rainy season (June to October) of 1999 to investigate the effects of N and P fertilizers on grain yield and yield components of flooded lowland rice under farmer's fields on Vertisols of the Fogera plain. The site is located near Woretta town at 13° 19' north latitude and 37° 03' E longitude at an average elevation of 1815 m amsl. The Woretta area receives an average annual rainfall of 1300 mm of which 1127 mm were received between June and October during the 1999 cropping season. The average yearly minimum and maximum temperatures are 11.7 and 27.5 °C, respectively (North Western Zone Meteorological Service, unpublished data).

According to MULUGETA SEYOUM (2000), the soil on which the field experiment was conducted is classified as Pellic Vertisol. Analysis of composite surface soil samples collected from the experimental field indicated that the soil is moderately acidic (pH in 1:1 soil:water ratio of 5.6) and clayey (71.3% clay). The surface soil was high in total N (0.28%), organic carbon (3.0%), percent base saturation (79.4%), cation exchange capacity (52.9 cmolc kg^{-1}) and in Olsen extractable available P (36.2 mg l^{-1}), and medium (265.2 mg l^{-1}) in available K contents (MULUGETA SEYOUM, 2000).

The land used for undertaking the field experiment had not been fertilized for the last over 10 years either with organic or mineral fertilisers. The area is usually flooded for most of the time during the cropping season. During the season the experiment was conducted, the depth of water above the surface of the soil at the site between July and October ranged from 5-10 cm. Based on the classification by IRRI (1993), the ecology and type of rice cultivation practiced at the Fogera plain is possibly categorized as rain fed lowland rice culture.

2.2 Experimental Treatments, Design, and Procedures

The fertilizer treatments considered in the study consisted of six levels of N (0, 30, 60, 90, 120 and 150 kg N ha^{-1}) and five levels of P (0, 13.2, 26.4, 39.6 and 52.8 kg P ha^{-1}) and their complete factorial combinations. The experiment was then conducted using a factorial experiment laid out in a randomized complete block design with four replications consisting of a total of 30 treatments. The field was oxen plowed four times before laying the experimental plots on the field. A 3m × 3m ($9m^2$) plot size was used as an experimental unit. The blocks were separated by a 2 m wide open space whereas the plots within a block were separated by a 1 m wide space. Soil bunds were constructed around each plot and around the entire experimental field to minimize nutrient and water movement from plot to plot.

A local well-adapted farmers' rice variety, known as *X-Jigna*, was used as planting material. Planting was made on 25 June 1999 by hand drilling the seeds at a rate of 80 kg ha^{-1} in rows spaced 25 cm apart. Nitrogen was applied in two equal splits, wherein 50% of the N rate was applied basal at planting and the remaining half was top dressed at the maximum tillering stage which occurred 32 days after germination, as urea (46% N). The field was drained off before top dressing the second half of N, and urea was hand drilled to the side of plant rows at 5-10 cm depth of the soil. Unlike N, the total dose of P was applied basal as triple super phosphate (20% P) during sowing. Due to the frequent prevalence of vigorous growth and high infestation of weeds, the field was hand weeded four times at 20, 40, 60, and 90 days after sowing.

2.3 Yield and Agronomic Data Collection and Analysis

Number of panicles per m^2 was counted before physiological maturity using 1m $\times$ 1m quadrant whereas panicle length was measured from the neck node to the tip of panicle on 20 random plants just before physiological maturity from 20 sample plants. Total number of spikelets (florets) and unfilled spikelets per panicle were determined at harvest by taking twenty random plants (tillers) from each plot. Number of filled spikelets per panicle was then obtained from the difference between the total number of spikelets per panicle and the number of unfilled spikelets per panicle. Plant height was determined by measuring the lengths of 20 random sample plants from the ground level to the top of the panicle just before physiological maturity.

At physiological maturity, the plants were harvested close to the ground level by hand using sickles, and the dry matter of the above ground plant parts was determined from 20 random pants collected at harvest. The sample plants were subsequently oven dried to constant weight and weighed using a sensitive balance. Grain yield was measured by threshing the plants harvested from the middle 6 rows (1.5m $\times$ 2m $=$ 3.0m^2) of each plot to avoid border effects. The moisture content of the rice seeds was determined using a hygrometer at the time of the measurement of the grain yield. Grain yield was then recorded on 14% seed moisture content basis. Straw yield was determined as the difference between the total above ground biomass (straw plus grain) recorded after air drying at harvest and the grain yield of the respective treatments. Thousand-grain weight was determined by counting the number of seeds in 250 g of seed samples randomly taken from each plot and recorded on 14% moisture basis. Harvest index was obtained from the ratio of grain yield to the grain plus straw yield of each plot expressed as percentage.

Analysis of variance and simple correlation coefficients were carried out for the yield and yield components studied following statistical procedures appropriate for the experimental design using MSTATC computer software. Whenever treatment effects were significant, the means were separated using the least significant difference (LSD) and Duncan's Multiple Range Test (DMRT) procedures.

3 Results and Discussion

3.1 Grain Yield of Rice

Analysis of variance for two factors randomized complete block design (Table 1) revealed significant difference ($P \leq 0.01$) due to the main effects of the levels of N and P application for the means of all of the yield and agronomic parameters studied. However, the magnitude of the mean squares for the effect of N for each crop parameter far exceeded that of the corresponding mean squares of P. The mean squares due to N×P interactions were significant only for number of panicles per m^2 ($P \leq 0.01$), plant height ($P \leq 0.01$), grain yield ($P \leq 0.05$) and number of spikelets per panicle ($P \leq 0.05$).

Table 1: Analysis of variance for yield and yield components of rice on Vertisols of Fogera plain.

Parameters studied	*Mean squares for source of variation*			
	N *(5)*	P *(4)*	N×P *(20)*	*Error (87)*
Grain yield (kg ha^{-1})	198.807**	110.039**	4.058*	2.030
Number of panicles m^{-2}	2931.548**	356.792**	17.457**	0.644
Number of spikelets panicle^{-1}	315.776**	45.112**	2.188*	0.962
Filled spikelets panicle^{-1}	642.329**	165.745**	1.890ns	4.042
Thousand grain weight (g)	58.945**	18.343**	0.569ns	0.399
Panicle length (cm)	12.580**	2.468**	0.086ns	0.098
Plant height (cm)	197.316**	15.241**	0.524**	0.248
Dry matter (g)	1.109**	0.322**	0.005ns	0.008
Straw yield (kg ha^{-1})	775.337**	81.726**	1.152ns	1.480
Harvest index (%)	170.581**	54.891**	1.176ns	1.254

Figures in parentheses ≙ Degrees of freedom; * ≙ Significant at $P = 0.05$; ** ≙ Significant at $P = 0.01$; ns ≙ Non-significant.

Nitrogen had a marked effect on grain yield of rice. Grain yield significantly increased ($P \leq 0.01$) from 3240 to 3962 kg ha^{-1} with an increase in the level of N from the control (no N) to 60 kg N ha^{-1} and decreased with further increase of applied N fertilizer (Table 2). This could mainly be attributed to the increase in the number of panicles per m^2 and total number of spikelets per panicle. On the other hand, increasing panicle length and plant height might have increased grain yield of rice indirectly by increasing the number of spikelets per panicle and panicle length, respectively. Kumar and Rao (1992); Thakur (1993); Channabasavanna and Setty (1994); Behera (1998) also reported findings indicating improvements in grain yields attributed to increments in yield components. Increases in yield components are associated with better nutrition, plant growth and increased nutrient uptake (Kumar and Rao, 1992; Thakur, 1993).

The magnitude of increase in grain yield over the control due to application of 30 and 60 kg of N ha^{-1} were 13.5% (436 kg ha^{-1}) and 22.3% (722 kg ha^{-1}), respectively.

Reduction of grain yield with further increment in applied N level beyond 60 kg ha^{-1} (Table 2) was mainly caused by successive reductions in the number of filled spikelets per panicle and thousand-grain weight. SINGH *et al.* (1995) have also reported a decrease in grain yield of rice with application of high doses of N fertilizer. REINKE *et al.* (1994) noted that where the grain yield response is negative, yield reduction is primarily caused by a reduction in the proportion of the number of filled spikelets per panicle. Moreover, the higher organic carbon (3.0%) and higher native total N (0.28%) contents observed on the surface soil of the experimental field (MULUGETA SEYOUM, 2000) have also negatively affected crop response and increment in rice grain yield at higher application doses of mineral N ($>$ 60 kg N ha^{-1}) fertilizer.

Table 2: Effects of N fertilizer levels on yield (paddy kg ha^{-1}) and yield components of rice on Fogera Vertisols.

Applied N	*Yield and yield components*									
(kg ha^{-1}*)*	*GY*	*NP*m^{-2}	*NSP*$^{-1}$	*NFSP*$^{-1}$	*TGW*	*PL*	*PH*	*DM*	*SY*	*HI*
0	3240^c	165.96^f	94.01^e	75.21^a	20.84^a	19.55^d	87.98^f	4.17^e	3971^e	44.93^a
30	3676^b	176.54^e	97.34^d	73.87^a	21.36^a	20.28^c	89.80^e	4.36d	4591^d	44.47^a
60	3962^a	188.38^d	100.08^c	71.48^b	21.15^a	20.74^b	92.02^d	4.57^c	4990^c	44.20^a
90	3957^a	194.42^b	102.85^b	66.93^c	19.79^b	21.44^a	93.82^c	4.67^b	5296^b	42.69^b
120	3847^a	197.12^a	104.20^a	63.91^d	18.84^c	21.57^a	95.36^b	4.73^{ab}	5507^a	41.05^c
150	3334^c	192.46^c	103.26^b	61.11^e	16.89^d	21.37^a	95.88^a	4.78^a	5606^a	37.22^d
LSD (0.01)	118.7	0.668	0.817	1.674	0.526	0.261	0.415	0.074	101.3	0.933
CV (%)	3.88	0.43	0.98	2.92	3.19	1.50	0.54	1.93	2.44	2.64

Means within a column followed by the same letter(s) are not significantly different at $P = 0.01$. GY = Grain yield (kg ha^{-1}); NPm^{-2} = Number of panicles per square meter; NSP^{-1} = Number of spikelets per panicle; NFSP^{-1} = Number of filled spikelets per panicle; TGW = Thousand grains weight (g); PL = Panicle length (cm); PH = Plant height (cm); DM = Dry matter (g); SY = Straw yield (kg ha^{-1}); HI = Harvest index

Application of phosphorus fertilizer had also significantly ($P \leq 0.01$) increased the grain yield of rice up to the applied level of 26.4 kg P ha^{-1} (Table 3). However, the response of grain yield obtained at 26.4 kg P did not show significant differences compared with application of 13.2 kg ha^{-1} of P. The magnitudes of increase in rice grain yield over the control due to application of 13.2 kg and 26.4 kg P ha^{-1} were 10.5% (366 kg ha^{-1}) and 11.2% (390 kg ha^{-1}). In line with applied N, application of P increased rice grain yield through its effects on major yield attributes such as number of panicles per m^2 and spikelets per panicle. ZAMAN *et al.* (1995) also reported similar response in rice yield and yield components to increasing rates of applied P fertilizer. Increase in the magnitude of yield attributes is associated with better root growth and increased uptake of nutrients favoring better growth of the crop (KUMAR and RAO, 1992; PANDA *et al.*, 1995). Phosphorus application has also improved 1000-grain weight, panicle length and plant height thereby indirectly contributing to increment in grain yield.

Successive increase in the levels of P beyond 13.2 and 24.6 kg P ha^{-1} application showed reduction of grain yield (Table 3). ZAMAN *et al.* (1995) also reported similar trends in rice with higher doses of P fertilization. At higher doses of P, reduction of grain yield was caused mainly by the successive reduction in the number of filled spikelets per panicle and 1000-grain weight of rice. Thus, the results of this investigation substantiated the works of NI-WUZHONG *et al.* (1997) who reported that at higher levels of applied P , grain yield increased marginally or decreased due to the reduction in the number of filled spikelet and 1000 grain weight, particularly in soils with high soil test values of available P.

Moreover, the response of rice grain yield above 13.2 and 24.6 kg P ha^{-1} was possibly affected by the higher amount of inherent Olsen extractable available P (36.2 mg l^{-1}) of the experimental field soils. The availabilities of both native and applied P have also been reported to increase on soils under flooded rice production (ZIA *et al.*, 1992). The flooded condition that prevailed at the experimental site might have therefore increased the availability of P to the extent the rice crop benefits from it. As a result, significant grain yield response of the crop was obtained only at lower level (13.2 kg ha^{-1}) of P fertilization (Table 3). Similarly, DE DATTA and GOMEZ (1982) stated that due to the increase in the availability of P, yield responses to P fertilization are not as significant in flooded rice as in upland crops.

Table 3: Effects of P fertilizer levels on yield (paddy kg ha^{-1}) and yield components of rice on Fogera Vertisols.

Applied P	*Yield and yield components*									
(kg ha^{-1}*)*	*GY*	*NP*m^{-2}	*NSP*$^{-1}$	*NFSP*$^{-1}$	*TGW*	*PL*	*PH*	*DM*	*SY*	*HI*
0	3485^{c}	180.18^{e}	98.09^{c}	71.82^{a}	19.87^{b}	20.32^{c}	91.30^{d}	4.36^{c}	4705^{d}	42.68^{bc}
13.2	3851^{a}	186.28^{c}	100.23^{b}	70.35^{ab}	20.81^{a}	20.90^{ab}	92.15^{c}	4.54^{b}	4923^{c}	43.93^{a}
26.4	3875^{a}	188.97^{b}	101.22^{a}	69.16^{b}	20.37^{a}	21.08^{a}	92.92^{b}	4.62^{a}	5059^{b}	43.42^{ab}
39.6	3730^{b}	189.62^{a}	101.61^{a}	67.35^{c}	19.43^{b}	21.10^{a}	93.39^{a}	4.66^{a}	5153^{a}	42.06^{c}
52.8	3404^{c}	184.02^{d}	100.31^{b}	65.08^{d}	18.55^{c}	20.73^{b}	92.63^{b}	4.54^{b}	5128^{ab}	40.04^{d}
LSD (0.01)	108.3	0.610	0.746	1.528	0.480	0.238	0.379	0.068	92.5	0.851
CV (%)	3.88	0.43	0.98	2.92	3.19	1.50	0.54	1.93	2.44	2.64

Means within a column followed by the same letter(s) are not significantly different at $P = 0.01$. GY = Grain yield (kg ha^{-1}); NPm^{-2} = Number of panicles per square meter; NSP^{-1} = Number of spikelets per panicle; NFSP^{-1} = Number of filled spikelets per panicle; TGW = Thousand grains weight (g); PL = Panicle length (cm); PH = Plant height (cm); DM = Dry matter (g); SY = Straw yield (kg ha^{-1}); HI = Harvest index

The interaction effect of applied N and P levels on grain yield (Table 1) was significant ($P \leq 0.05$). The highest mean yield (4282 kg ha^{-1}) was obtained with the applications of 60 kg N and 13.2 kg P ha^{-1}, representing an increase of 38.5% (1190 kg ha^{-1}) over the control treatment followed by 4214 kg ha^{-1} with the applications of 60 kg N and 26.4 kg P ha^{-1} (Table 4). These findings were in agreement with the results obtained from mineral fertilizer studies by KUMAR and RAO (1992) on upland rice and RAJU and REDDY (1993) on winter rice. Without P application, the grain yield increased from 3092 kg ha^{-1} to 3716 kg ha^{-1} when the level of applied N increased from zero (control) to 120 kg N, while it increased from 3092 kg ha^{-1} to 3413 kg ha^{-1} when the level of applied P increased from zero to 26.4 kg P ha^{-1} under no applied N (Table 4).

Table 4: Interaction effect of N and P fertilizers on grain yield (paddy kg ha^{-1}) of rice

P *levels* (*kg* ha^{-1})	N *levels (kg* ha^{-1}*)**						*Mean*
	0	*30*	*60*	*90*	*120*	*150*	
0	3092^{q}	3445^{lm}	3617^{k}	3714^{ij}	3716^{ij}	3328^{nop}	3485
13.2	3326^{nop}	3865^{h}	4282^{a}	4149^{bc}	4024^{def}	3461^{l}	3851
26.4	3413^{lmn}	3972^{fg}	4214^{ab}	4196^{abc}	4014^{ef}	3442^{lm}	3875
39.6	3253^{p}	3740^{i}	4115^{cd}	4102^{cde}	3896^{gh}	3277^{op}	3731
52.8	3114^{q}	3360^{mno}	3580^{k}	3626^{jk}	3583^{k}	3162^{q}	3404
Mean	3240	3676	3962	3957	3847	3334	

* Means across all rows and columns followed by the same letter(s) are not significantly different at $P = 0.05$; LSD (0.05) = 0.8955; CV (%) = 3.88

3.2 Yield Components of Rice

3.2.1 Panicles per square meter

Application of N up to 120 kg ha^{-1} increased the number of panicles per m^2 significantly ($P \leq 0.01$) apparently by increasing the number of productive tillers (Table 2). This finding was in agreement with the results reported by BEHERA (1998). On the other hand, reduction in the number of panicles per m^2 observed at the highest doses of N application was due to reduction in the number of productive tillers which was caused by excessive vegetative growth of the rice crop. Phosphorus fertilization also increased the number of panicles per m^2 significantly ($P \leq 0.01$) up to 39.6 kg P ha^{-1} (Table 3) by increasing the number of productive tillers of the crop. ZAMAN *et al.* (1995) also observed increments in the number of panicles per m^2 of rice plant due to applied P by enhancing the production of effective tillers.

The interaction effect of applied N and P levels on panicles per m^2 (Table 1) was also significant ($P \leq 0.01$). Applied N levels exhibited significant positive effect up to 26.4 kg P ha^{-1} with the exceptions of 90 and 120 kg N ha^{-1} which significantly increased the number of panicles per m^2 up to 39.6 kg P ha^{-1} (Table 5). Similarly, all the P levels significantly increased panicle number up to 120 kg N ha^{-1} with the exceptions of 26.4 and 39.6 kg P ha^{-1} which significantly increased the number of panicles per m^2 up to 90 kg N ha^{-1}. The highest mean number of panicles per m^2 (201.8 m^{-2}) was obtained with the applications of 120 kg N and 39.6 kg P ha^{-1} (Table 5), representing an increase of 25.3% (40.8 panicles per m^2) over the control treatment. Among the yield attributes of rice, panicle number was associated positively ($r = 0.61**$) with grain yield (Table 6). In conformity with the findings of the present study, THAKUR (1993) noted that panicle number is the most important factor that causes variation in the grain yield of rice.

Table 5: Interaction effect of N and P fertilizers on number of panicles per m^2 of rice.

P *levels* (*kg* ha^{-1})	N *levels (kg* ha^{-1}*)**						*Mean*
	0	*30*	*60*	*90*	*120*	*150*	
0	161.0^q	169.0^o	179.3^l	187.3^k	193.0^{fg}	191.5^{hi}	180.18
13.2	166.0^p	177.3^m	189.8^j	194.8^e	197.3^d	192.5^{gh}	186.28
26.4	168.0^o	180.3^l	192.5^{gh}	199.0^c	200.0^{bc}	194.0^{ef}	188.97
39.6	168.3^o	180.3^l	193.8^{efg}	200.5^{ab}	201.8^a	193.0^{fg}	189.62
52.8	166.5^p	175.8^n	186.5^k	190.5^{ij}	193.5^{efg}	191.3^{hi}	184.02
Mean	165.96	176.54	188.38	194.42	197.12	192.46	

* Means across all rows and columns followed by the same letter(s) are not significantly different at $P = 0.01$; LSD (0.01) = 1.494; CV (%) = 0.43

3.2.2 Total and filled spikelets per panicle

In agreement with the findings reported by THAKUR (1993), the present study indicated that increasing the levels of applied N resulted in higher number of total spikelets per panicle. Nitrogen fertilization significantly increased ($P \leq 0.01$) number of spikelets per panicle up to the applied level of 120 kg ha^{-1} (Table 2) mainly due to an increase in panicle length and panicle number. Application of more than 120 kg ha^{-1} of N reduced the number of spikelets per panicle, which may be caused by an increase in competition for metabolic supply among tillers thereby decreasing the production of spikelets (WU *et al.*, 1998) or possibly due to vigorous vegetative growth causing heavy drain on soluble carbohydrate resulting in its reduced availability for spikelet formation (HASEGAWA *et al.*, 1994).

Increasing the levels of P up to 26.4 kg ha^{-1} also significantly increased ($P \leq 0.01$) the number of spikelets per panicle (Table 3). CHANNABASAVANNA and SETTY (1994) and RAJU and REDDY (1993) also reported that application of P increases the total number of spikelets per panicle in rice thereby contributing to increment in grain yield. Increased number of spikelets with P application is mainly attributed to an increase in the number of panicles per m^2 and panicle length. Number of spikelets was the second important yield-forming attribute of rice. It was associated positively and highly significantly with grain yield and panicle length (Table 6). The results of the study confirmed similar findings reported by THAKUR (1993) and RATHI and SHARMA (1996). Number of spikelets per panicle was also correlated positively and highly significantly with the number of panicles per m^2 and panicle length (Table 6) indicating that N and P fertilization increases the number of spikelets of rice crop by increasing number of panicles per m^2 and panicle length.

The interaction effect of applied N and P levels on number of spikelets per panicle (Table 1) was also significant ($P \leq 0.05$). The responses of 30 and 60 kg N ha^{-1} levels showed significant positive effect up to 26.4 kg ha^{-1} of P application (Table 7). However, the levels of N at 90 and 120 kg N ha^{-1} significantly increased number of spikelets per panicle up to 13.2 kg ha^{-1} of P fertilization. Similarly, at 0 and 13.2 kg ha^{-1} of P application, the response was positive and significant up to 120 kg ha^{-1} of N application. The highest mean number of spikelets per panicle (105.1) was obtained with the applications of 120 kg N and 26.4 kg P ha^{-1} and 120 kg N and 39.6 kg P ha^{-1} (Table 7), representing an increase of 14.0% (12.98 spikelets per panicle) over the control treatment where the lowest (92.2) on number of spikelets per panicle was recorded.

Table 6: Simple correlation coefficients (r) among yield and yield attributes of rice.

Parameter	*GY*	*NP*m^{-2}	*NSP*$^{-1}$	*NFSP*$^{-1}$	*TGW*	*PL*	*PH*	*DM*	*SY*	*HI*
GY	-									
NPm^{-2}	0.61**	-								
NSP^{-1}	0.49**	0.98**	-							
NFSP^{-1}	0.02	-0.76**	-0.84**	-						
TGW	0.41*	-0.47**	-0.59**	0.88**	-					
PL	0.54**	0.97**	0.99**	-0.80**	-0.52**	-				
PH	0.29	0.93**	0.96**	-0.92**	-0.73**	0.94**	-			
DM	0.46*	0.96**	0.97**	-0.85**	-0.58**	0.96**	0.96**	-		
SY	0.35	0.94**	0.97**	-0.91**	-0.68**	0.95**	0.98**	0.96**	-	
HI	0.39*	-0.48**	-0.60**	0.90**	0.97**	-0.53**	-0.75**	-0.61**	-0.73**	-

* ≘ Significant at $P = 0.05$; ** ≘ Significant at $P = 0.01$; GY = Grain yield (kg ha^{-1}); NPm^{-2} = Number of panicles per meter square; NSP^{-1} = Number of spikelets per panicle; NFSP^{-1} = Number of filled spikelets per panicle; TGW = Thousand grains weight (g); PL = Panicle length (cm); PH = Plant height (cm); DM = Dry matter (g); SY = Straw yield (kg ha^{-1}); HI = Harvest index

Nitrogen application significantly reduced ($P \leq 0.01$) the number of filled spikelets per panicle up to 150 kg ha^{-1} (Table 2). Likewise, increasing the level of P significantly reduced ($P \leq 0.01$) the number of filled spikelets per panicle up to 52.8 kg ha^{-1} (Table 3). Application of both N and P fertilizers reduced the number of filled spikelets per panicle by increasing the proportion of unfilled spikelets per panicle. Increasing the levels of N and P fertilizers favored vigorous growth of the rice crop, which resulted in competition for metabolic supply among spikelets thereby affecting the production of fertile spikelets. HASEGAWA *et al.* (1994) and WU *et al.* (1998) also reported similar results in that with increasing levels of soil fertility, the number of filled spikelets per panicle decreased with corresponding increase in unfilled spikelets.

In this study, the highest number of filled spikelets per panicle was recorded at the control plot (no N and no P application). Compared with the number of filled spikelets obtained at the control treatment, reduction in the fertility of spikelets recorded at 150 kg ha^{-1} N and 52.8 kg ha^{-1} P application were 18.7% (14.10) and 9.4% (6.74), respectively (Tables 2 and 3). Thus, the results further revealed that N fertilization has more contribution over P to the reduction of the fertility of spikelets in rice. The cool daily minimum temperature (9.8-10.0 °C), which occurred during the flowering stage of the rice crop between September and October, might have also contributed to the reduction of the fertility of spikelets by increasing spikelet sterility. NISHIYAMA (1995) reported that the prevalence of cool air temperature at flowering of the stage increases sterility in rice crop by affecting pollination and fertilization.

Table 7: Interaction effect of N and P fertilizers on number of spikelets per panicle of rice.

P *levels* (*kg* ha^{-1})	N *levels (kg* ha^{-1}*)**						
	0	*30*	*60*	*90*	*120*	*150*	*Mean*
0	92.21^{n}	94.75^{l}	96.40^{jk}	99.97^{g}	102.60^{cde}	102.60^{cde}	98.09
13.2	93.35^{mn}	96.65^{ij}	100.10^{g}	103.10^{cd}	104.40^{ab}	103.80^{abc}	100.23
26.4	94.61^{lm}	98.53^{h}	101.50^{ef}	103.90^{abc}	105.00^{a}	103.80^{abc}	101.22
39.6	95.21^{kl}	98.92^{gh}	102.20^{de}	104.70^{ab}	105.10^{a}	103.50^{bcd}	101.61
52.8	94.68^{lm}	97.86^{hi}	100.20^{fg}	102.60^{cde}	103.90^{abc}	102.60^{cde}	100.31
Mean	94.01	97.34	100.08	102.85	104.20	103.26	

* Means across all rows and columns followed by the same letter(s) are not significantly different at P = 0.05; LSD (0.05) = 1.378; CV (%) = 0.98

On the other hand, reduction in the number of filled spikelets per panicle has contributed more to the negative yield response of rice under higher levels of N and P fertilizers in this study. In line with this, REINKE *et al.* (1994) concluded that where the yield response to fertilizer application is negative, yield reduction is primarily caused by a reduction in the proportion of unfilled spikelets. Moreover, the number of filled spikelets per panicle was highly and negatively associated with the total number of spikelets per panicle and plant height (Table 6).

3.2.3 Thousand grain weight

In this study, application of N fertilizer did not significantly ($P > 0.01$) improve 1000-grain weight of rice crop (Table 2) which was in agreement with the findings reported by THAKUR (1993). On the contrary, CHANNABASAVANNA and SETTY (1994) reported positive response of rice grain weight to N application. Similarly, only application of 13.2 kg ha^{-1} of P fertilization significantly increased ($P \leq 0.01$) 1000-grain weight of rice (Table 3). This was in agreement with the findings of CHANNABASAVANNA and SETTY (1994) and RAJU and REDDY (1993). Reduction in 1000-grain weight with increasing applied levels of N and P is probably the result of insufficient supply of carbohydrates to individual spikelets due to competition effect resulted by vigorous rice growth and the increased number of its spikelets. This effect further results in poor dry matter accumulation in the spikelets of rice. Similarly, HASEGAWA *et al.* (1994) also indicated that increased number of spikelets and vigorous growth of rice due to high rates of N fertilizer application induce competition for carbohydrate available for grain filling and spikelet formation. High doses of P are also believed to cause reduction in grain weight of rice in similar conditions explained for high rates of N fertilizer application.

3.2.4 Panicle length and plant height

Applications of N and P fertilizers increased panicle length significantly ($P \leq 0.01$) up to 90 and 13.2 kg N and P ha^{-1}, respectively (Tables 2 and 3). Since one of the most important functions of N is promotion of rapid growth, application of N fertilizer increased panicle length of rice crop more than P fertilizer. The increment in panicle length due to application of low levels of P observed in the present study was in agreement with KAVIMANI and KRISHNARAJAN (1991) and BEHERA (1998) who noted increases in panicle length of rice with increasing P fertilizer rates. The study further revealed that panicle length was correlated positively and significantly with number of panicles per m^2 ($r = 0.97**$), number of spikelets per panicle ($r = 0.99**$), dry matter yield ($r = 0.96**$), straw yield ($r = 0.95**$), plant height ($r = 0.94**$) and grain yield ($r = 0.54**$) of rice (Table 6). In accordance to the findings reported by BEHERA (1998), panicle length has contributed to increment of rice grain yield indirectly by increasing the number of panicles per m^2 and number of spikelets per panicle.

Plant height responded highly significantly and positively to the increasing application levels of both N and P fertilizers and their interaction effects (Table 1). Increasing the levels of N up to 150 kg ha^{-1} increased rice plant height significantly ($P \leq 0.01$) from 87.98 cm in the control treatment to 95.88 cm with the application of 150 kg N ha^{-1} (Table 2). Likewise, plant height increased significantly with increasing applied P levels up to 39.6 kg P ha^{-1} while further increase in P rates beyond 39.6 kg P ha^{-1} resulted in a negative effect on plant height (Table 3). With regards to the interaction between N and P fertilizers, the responses of all N levels were significant ($P \leq 0.01$) up to 26.4 kg ha^{-1} of P application except at no N (Table 8). With no N, P significantly increased plant height at the application rate of 13.2 kg ha^{-1} of P. On the other hand, all of the P levels significantly ($P \leq 0.01$) increased plant height up to 120 kg N ha^{-1}. Among all of the N and P treatment combinations, the maximum plant height of rice (96.59 cm) was attained at 150 kg N and 39.6 kg P ha^{-1} (Table 8).

Table 8: Interaction effect of N and P fertilizers on plant height (cm) of rice.

P *levels* (*kg* ha^{-1})	N *levels (kg* ha^{-1}*)**						
	0	*30*	*60*	*90*	*120*	*150*	*Mean*
0	87.11^{l}	88.42^{k}	90.53^{h}	92.38^{g}	94.28^{ef}	95.10^{cde}	91.30
13.2	88.36^{k}	89.47^{j}	91.35^{h}	93.17^{g}	95.02^{def}	95.51^{bcd}	92.15
26.4	88.46^{k}	90.40^{hi}	92.58^{g}	94.15^{f}	95.75^{abcd}	96.18^{ab}	92.92
39.6	88.38^{k}	91.10^{h}	93.18^{g}	94.91^{def}	96.19^{ab}	96.59^{a}	93.39
52.8	87.60^{kl}	89.59^{ij}	92.48^{g}	94.50^{ef}	95.57^{bcd}	96.02^{abc}	92.63
Mean	87.98	89.80	92.02	93.82	95.36	95.88	

* Means across all rows and columns followed by the same letter(s) are not significantly different at P = 0.01; LSD (0.01) = 0.927; CV (%) = 0.54

The promotion of rice plant height in the present study due to applications of N and P fertilizers is apparent as N is essential for plant growth since it is a constituent of all proteins and nucleic acids whereas P is essential for the production and transfer of energy in plants. Thakur (1993), Hari *et al.* (1997) and Behera (1998) have also observed enhanced rice plant height due to N fertilization. Similarly, Raju and Reddy (1993) and Zaman *et al.* (1995) reported increases in rice plant height due to increasing P fertilizer application rates.

3.2.5 Dry matter accumulation and straw yield

The data in Table 2 indicate that increasing the levels of applied N increased dry matter accumulation and straw yield of rice significantly ($P \leq 0.01$) up to 90 and 120 kg N ha^{-1}, respectively, while further increment in N increased both dry matter accumulation and straw yield non-significantly. Generally, straw yield increased from 3971 kg ha-1 in the control (no N) treatment to 5606 kg ha^{-1} with application of 150 kg N ha^{-1} (Table 2).

Increasing the levels of applied P also increased dry matter accumulation of rice significantly ($P \leq 0.01$) up to 26.4 and 39.6 kg P ha^{-1}, respectively (Table 3). However, the response in dry matter obtained at 39.6 kg P ha^{-1} was at par ($P > 0.01$) with that at 26.4 kg P ha^{-1} while further increase in applied P levels resulted in reduction of dry matter accumulation of rice plant. The increase in dry matter application due to application of increasing rates of N fertilizer is apparently attributed to its effect in enhancing vigorous vegetative growth of the rice plant. In this study, dry matter accumulation was associated positively and significantly ($P \leq 0.01$) with plant height, panicle length, number of panicles per m^2, spikelets per panicle and straw yield (Table 6).

The results of the present study are in agreement with the findings of Hari *et al.* (1997) who observed increasing dry matter accumulations due to increasing rates of applied mineral N fertilizer. This is attributed to enhanced plant N uptake (Dalal and Dixit, 1987) thereby promoting vigorous vegetative growth of the rice crop plants (Kumbhar and Sonar, 1980; Mulugeta Seyoum and Heluf Gebrekidan, 2005). Likewise, Zaman *et al.* (1995) also reported that increasing rates of P increased dry matter accumulation as a result of increased vegetative growth favored by enhanced nutrient uptake by rice plants.

3.2.6 Harvest index

Nitrogen showed a highly significant negative effect on harvest index of rice crop (Table 1). As indicated in Table 2, harvest index consistently declined with increasing levels of applied N up to the highest level (150 kg) of N ha^{-1}. On the other hand, application of 13.2 kg P ha^{-1} significantly ($P \leq 0.01$) increased harvest index of rice (Table 3). However, the harvest index recorded with the application of P fertilizer at the rate of 26.4 kg P ha^{-1} was at par ($P > 0.01$) with that at 13.2 kg P ha^{-1} while further increase in applied P beyond 26.4 kg P ha^{-1} resulted in highly significantly different reduction of harvest index.

Generally, increasing the levels of N fertilizer from 0 to 150 kg ha^{-1} decreased the harvest index of rice from 44.93 to 37.22% (Table 2). Results of a number of similar studies (Kumar and Rao, 1992; Patra *et al.*, 1992; Hari *et al.*, 1997) have also revealed decreasing trends of harvest index with increased rates of applied N fertilizer. They also stated that harvest index in rice is closely related to the percentage of productive tillers which generally decreases with increase of N fertilizer. Accordingly, harvest index of the rice crop was negatively and significantly ($P \leq 0.01$) correlated with plant height, panicle length, number of panicles per m^2, number of spikelets per panicle and straw yield (Table 6). This explains that vigorous vegetative growth of the rice plants promoted by higher rates of N application results in lower harvest index by favoring higher dry matter accumulation in the vegetative parts than in the grains of rice. The increase in harvest index at lower doses of P indicates that N enhances vegetative growth of rice more than P. In agreement with the results of this study, Budhar (1992), Kumar and Rao (1992) and Panda *et al.* (1995) showed that harvest index increased initially with increasing rates of applied P and decreased finally with further increase in application rates of P fertilizer.

4 Conclusions

The grain yield and yield components of the rice crop responded more to N than to P fertilization. However, the maximum grain yield and greater magnitude increase in yield and yield components were obtained with combined application of N and P fertilizers. In this study, number of panicles per m^2 and number of filled spikelets per panicle as well as panicle length were the most important yield forming attributes causing significant variation in grain yield of rice. Panicle length contributed to grain yield increment indirectly by increasing the number of spikelets per panicle. The results of the study indicate that farmers at the Fogera plain need to apply a combination of 60 kg N and 13.2 kg

P ha^{-1} in order to improve the grain yield and yield components of flooded lowland rice grown on black clay soils (Vertisols) under rain fed conditions. Moreover, fertilizer application under flooded rice production should consider soil-water-environment related factors that affect the availability and evaluation of nutrients in soils as integral parts of efforts to improve rice production and soil fertility. Thus, in the light of the significant response of rice to both N and P fertilizers, further studies aimed at promoting integrated soil fertility management and formulation of fertilizer recommendation on soil test basis over locations are desirable.

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References

Behera, A. K.; Response of scented rice (*Oryza sativa*) to nitrogen under transplanted condition; *Indian J. Agron.*; 43(1):64–67; 1998.

Budhar, M. N.; Effect of source and time of application of phosphorus on rice (*Oryza sativa*) yield; *Indian J. Agron.*; 37(1):162–163; 1992.

Channabasavanna, A. S. and Setty, R. A.; Response of broadcast rice (*Oryza sativa*) to level of nitrogen, phosphorus and potassium and time of N application; *Indian J. Agron.*; 39(3):457–459; 1994.

Dalal, P. K. and Dixit, L.; Response of newly developed medium duration and high yielding rice genotypes to nitrogen; *Indian J. Agron.*; 30(1):114–116; 1987.

De Datta, S. K. and Gomez, K. A.; Changes in phosphorus and potassium response in wetland rice soils in Southeast Asia; in: *Phosphorus and Potassium in the Tropics*, edited by Pushparajah, E. and Sharifuddin Hamid, H. A.; 127–147; Malaysian Society of Soil Science, Kuala Lumpur; 1982.

Hari, O. M., Katyal, S. K. and Dhiman, S. D.; Effect of nitrogen and seed rate in nursery on growth and yield of hybrid rice (*Oryza sativa*); *Indian J. Agron.*; 42(2):275–277; 1997.

Hasegawa, T., Koroda, Y., Seligma, N. G. and Horie, T.; Response of spikelet number to plant nitrogen concentration and dry weight in paddy rice; *Agron. J.*; 86:673–676; 1994.

IRRI; Rice Almanac; International Rice Research Institute (IRRI), Manila, Philippines; 1993.

Kavimani, R. and Krishnarajan, J.; Effect of method, level and time of phosphorus application on yield and yield components of IR. 20 rice; *Madras Agric. J.*; 78:9–12; 1991.

Kumar, K. and Rao, K. V. P.; Nitrogen and phosphorus requirement of upland rice in Manipur; *Oryza*; 29:306–309; 1992.

Kumbhar, D. D. and Sonar, R.; Dry matter production and nutrient uptake pattern of two rice varieties grown under upland conditions; *J. Indian Soc. Soil Sci.*; 28(2):178–

183; 1980.

MULUGETA SEYOUM; Rice: Potential crop for food security in Amhara Region; Agri-Topia: The quarterly newsletter of Ethiopian Agricultural Research Organization; 14(3/4): 1-2;; 1999.

MULUGETA SEYOUM; *Uptake and response of rice (Oryza sativa L.) to nitrogen and phosphorus fertilization under rain fed lowland condition of the Fogera Plain, Northern Ethiopia*; Master's thesis; Alemaya University; 2000.

MULUGETA SEYOUM and HELUF GEBREKIDAN; Effects of N and P fertilisers on yield and N uptake of flooded rice grown on Vertisols of Fogera Plain of Ethiopia; *Indian Journal of Fertilizers*; 1(1):47–51; 2005.

NI-WUZHONG, HE-NIANZU, NI-WZ and HE-NZ; Effect of excess fertilizer phosphorus on some chemical properties of paddy soil derived from red soil and its relation to rice growth; (Abstract), Institution of Soil Sci. Academia Sinica; 7: 1;; 1997.

NISHIYAMA, I.; Physiological basis of the damage caused by unfavorable climatic conditions, disease and insect pests. I. Damage due to extreme temperatures; in: *The Science of the Rice Plant*, edited by MATSUO, T., KUMAZAWA, K., ISHII, R., ISHIHARA, K. and HIRATA, H.; vol. 2; 769–810; Food and Agriculture Policy Research Center, Tokyo; 1995.

PANDA, S. C., PANDA, P. C. and NANDA, S. S.; Effect of levels of N and P on yield and nutrient uptake of rice; *Oryza*; 32:18–20; 1995.

PATRA, S. K., PADHI, A. K., MISHRA, S. N. and SAHOO, B. K.; Response of rainfed direct seeded upland rice to levels and time of nitrogen application; *Oryza*; 29:265–299; 1992.

RAJU, R. A. and REDDY, K. A.; Response of winter rice (*Oryza sativa*) to nitrogen, phosphorus, and potassium fertilization on Godavari alluvial; *Indian J. Agron.*; 38(4):637–638; 1993.

RATHI, G. S. and SHARMA, R. S.; Effect of rate and time of N application on direct sown rice; *Oryza*; 33:140–142; 1996.

REINKE, R. F., LEWIN, L. G. and WILLIAMS, R. L.; Effect of sowing time and nitrogen on rice cultivars of differing growth duration in New South Wales. I. Yield and yield components; *Australian Journal of Experimental Agriculture*; 34(7):933–938; 1994.

SINGH, A. K., THAKUR, S. and SINGH, S. K.; Response of rice to nitrogen and zinc application in calcareous situation; *International Rice Research Institute Notes*; 20(2):16–17; 1995.

THAKUR, R. B.; Performance of summer rice (*Oryza sativa*) to varying levels of nitrogen; *Indian J. Agron.*; 38(2):187–190; 1993.

WU, G., WILSON, L. T. and MCCLUNG, A. M.; Contribution of rice tillers to dry matter accumulation and yield; *Agron. J.*; 90:317–323; 1998.

ZAMAN, S. K., RAZZQUE, M. A., KARIM, S. M. R. and BHUIYAN, N. I.; Rice response to phosphorus in wetland soil; *Pakistan J. Sci.*; 38:11–12; 1995.

ZIA, M. A., MUNSIF, M., ASLAM, M. and GILL, M. A.; Integrated use of organic manure and inorganic fertilizers for cultivation of lowland rice in Pakistan; *Soil Sci. Plant Nutri.*; 38:331–338; 1992.