Original Research Article

Response of Upland Rice to Nitrogen and Phosphorus Fertilization on Vertisols of Tigray, Ethiopia

Abstract

Nitrogen and phosphorus are often cited as the most limiting nutrients in agricultural soils of Ethiopia. Their availability in the soil solution also determines the growth and productivity of the soils and crops. Thus, experiments were conducted to investigate the response of upland rice and determine the optimum rates of N and P fertilizers. The experiments were conducted at four sites of Tselemti district (Tsaeda-Kerni, Mizikir, Maitsebri and Sekota-Mariam), Northwestern Tigray, Ethiopia. A factorial combination of two factors, four levels of nitrogen (0, 23, 46, 69, kg Nha^{-1} designated as N0, N1, N2 and N3 respectively) and four levels of phosphorus (0, 10, 20, 30 kg Pha^{-1} designated as P0, P1, P2 and P3 respectively) were conducted on complete randomized block design (CRBD). Data on yield and yield components of upland rice were collected and subjected to ANOVA through SAS software V9. The results showed that, the plant height, number of spikelet and total seed per panicle of upland rice were significantly increased when nitrogen and phosphorus fertilizers interacted at higher doses. It was also observed significant differences of main effects on panicle length, grain yield and straw yields of rice. A significantly higher grain and straw yields were obtained in plots received 69 kg N ha^{-1} compared to preceding treatments and application of either 20 or 30 kg P fertilizer ha^{-1} can also boost the yields of upland rice in the district. However, the optimum grain yield of rice to the application of N and P fertilizers was not found in the response curve which indicates an extra application rates would be tried. Further, highest agronomic efficiency were also observed in the lower rates of both main effects.

Key words: agronomic efficiency, response curve, nutrients, upland rice, yield and yield components

Introduction

In Ethiopia, rice is among the target commodities that have received due emphasis in promotion of agricultural production, and as such it is considered as the "millennium crop" expected to contribute to ensuring food security in the country. Although rice is introduced to the country very recently, rice has proven to be a crop that can assure food security in Ethiopia, the second most populous nation in sub-Sahara Africa (SSA) with about 74 million people in 2007 [1]. The trend of rice production is increasing both in area coverage, participant farmers, and production [2]. Productivity in quintal per hectare has increased from 28.91in 2012 to 28.97 and the number of participant farmers increased from 115,832 to 119, 4970 in 2013 cropping season [3].

The national average yield of rice in Ethiopia is 2.9 t ha^{-1} [4], which is much lower than the world's average rice yield of 4.54 t ha-1 [5]. This is due to insect pest and diseases occurrence (rice blast and brown spot), weeds and environmental fluctuations. In addition, poor agronomic practices; human and institutional capacity and shortage of adapted varieties for different agro-ecologies are the major rice production constraints in the country. According to [6] improvement of rice production has not been possible due to low soil fertility, inadequate nutrient management, continuous cropping, and application of suboptimal levels of mineral fertilizers among other factors.

Nitrogen and phosphorus are often cited as the most limiting nutrients in agricultural soil of Ethiopia [7]. Relatively those nutrients are deficient in vertisols where nitrogen is subjected to leaching while the limited availability of phosphorus observed due to several factors. Nitrogen and phosphorus are required in huge amounts by crops than other nutrients. They are constituents of several plant organs and enzyme mediated biochemical processes. Their availability in the soil solution determines the growth and productivity of soils and crops. Yield and growth enhancements of crops have been reported due to application of N and P fertilizers in the country and world. According to [8] and [9] application of N and P fertilizers significantly increased Teff and Wheat grain yields respectively compared to control plots. Additionally, studies from Fogera; area Amhara region [6], Bambasi and Kamashi area; Benshangul-Gumuz region [10] and [11] respectively, Gambella region [12] and Uganda [13] showed a positive rice yield increments due N and P fertilization.

However, farmers of the district are reluctant in to using chemical fertilizers due to several reasons and the absence of site specific fertilizer guideline particularly for Rice is the main problem as the blanket recommendation was initially developed for the major cereal crops of the country. In the study area application of macro nutrients especially N and P were not clearly documented. Furthermore, effective rate of application for N and P to increase rice productivity at four districts has not been established. Therefore, the objectives of this study were to determine N and P level on yield and yield components of rice and quantify agronomic efficiency of the crop.

Material and Methods

Description of the Study Area

The experiments were conducted at four sites of Tselemti district, Northwestern Tigray, Ethiopia. The experimental locations were Tsaeda-Kerni (located at 13^{o} 33’ 04.29.29” N, 38^{o} 01’ 52.18” E and 1116 masl), Mizikir (located at 13^{o} 32’ 56.99” N, 38^{o} 03’ 22.97” E and 1145 masl), Maitsebri(located at 13^{o} 35’ 28.68” N, 38^{o} 08’ 57.01” E and 1325 masl) and Sekota-Mariam (located at 13^{o} 32’ 58.64” N, 38^{o} 13’ 33.91” E and 1145 masl).

Tselemti district is found 1172 km far from the capital city Addis Ababa and geographically located 13°48′N latitude and 38°15′E longitude. It is bordered with Asgede Tsimbla, Welkait, Tanqua Abrgelle districts and Amhara region to the north, west, east and south, respectively. The district covers an altitude ranging from 800 to 2870 m above sea level. The mean annual temperature of the area is 16 °C (November–January) and 38 °C (February–May) minimum and maximum, respectively. Some of the major crops grown in the area include sorghum, finger millet, maize, chickpea and sesame [14].

Experimental Treatments, Design, and Procedures

The treatments were factorial combination of two factors, four levels of nitrogen (0, 23, 46, 69, kg Nha^{-1} designated as N0, N1, N2 and N3 respectively) and four levels of phosphorus (0, 10, 20, 30 kg Pha^{-1} designated as P0, P1, P2 and P3 respectively). Urea (46% N) and Triple Super Phosphate (46% P_2O_5) were used as fertilizer sources for N and P, respectively. At each site then, the field experiment had arranged in randomized complete block design with three replications. Gross plot size for the trial was 12.8m^2 (4m*3.2m) and the space between blocks and plots were 1m and 0.5m respectively. Planting was done in row method with 20cm inter row spacing and 5cm planting depth at a rate of 70kg/ha. The newly adopted upland rice *i.e.*NERICA-13 was used as a test crop. All of the phosphorus fertilizer for each treatment (except the control plots) were applied at planting while Nitrogen fertilizers was split applied (the first1/3 was applied at sowing, and the remaining at tillering stage). All other agronomic, cultural and management practices including weeding, disease and pests were followed the recommended practices of the crop.

Soil Sampling and Analysis

Composite soil samples for chemical and physical characterization were collected up to 20 cm soil depth from each field before fertilizer application. Each parameter were analyzed using standard procedure as prescribed by [15]. Soil texture was determined by the hydrometer method. Soil pH and EC was also determined using a pH meter from 1:2.5 soil:water ratio suspension and using EC meter from 1:5 soil water saturation extract respectively. As there is a lot of information about the interpretation of ECe in relation to plant growth, it was useful to convert EC (1:5) to ECe [16].

$$ECe\ (dSm^{-1}) = EC1{:}5\ (dSm^{-1}) \times \text{multiplier factor;}$$

where the multiplier factor was used for heavy clay i.e. 5.8

The determination of soil organic carbon was based on the Walkley-Black chromic acid wet oxidation method. The Kjeldhal process (digestion, distillation, and titration) was followed to determine the total nitrogen. Olsen Method (Bicarbonate extractable P) was used to extract and determine available phosphorus, using 0.5 M NaHCO at adjusted pH 8.5. Determination of CEC at pH 7 was carried out with Ammonium Acetate method.

Data Collection and Analysis

Grain yield**,** straw yield, plant height, panicle length, number of tillers, effective tillers, number of total seeds and unfertilized seeds per panicle, thousand seed weight and harvest index was collected. The data was arranged in factorial format and subjected to analysis of variance (ANOVA) using SAS statistical software. The response curve and Agronomic use efficiency were also worked out in excel worksheets.

Result and Discussion

Soil Physicochemical characteristics of the Experimental studies

Textural classes of Sekota Silassie, Maitsebri and Tsaeda Kerni experimental sites were clay loam and clay for Mizikir experimental site (Table 1). The pH of soils of the experimental sites varied from 5.8 to 6.5, which ranges from slightly acidic to moderately acidic [17]. Thus, the pH of the experimental site soils was within the range for productive soils. According to the ratings of [17] the organic carbon content of soils of experimental sites were medium and total nitrogen was low in all fields [18].

Table - 1:- Physicochemical characteristics of the study sites

Soil Physicochemical Parameters		**Locations**			
		SekotaSilassie	**Mizikir**	**Maitsebri**	**TsaedaKerni**
pH (1:2.5 H_2O)		5.8	6.5	6.2	6.1
EC		0.38	0.11	0.21	0.38
Texture	% Sand	28	30	28	26
	% Clay	28	50	38	40
	% Silt	44	20	34	34
Textural Class		Clay Loam	Clay	Clay Loam	Clay Loam
%OC		2.44	1.75	2.20	2.10
CEC meq/100gm Soil		35	57.2	46.4	40.8
% TN		0.0230	0.0448	0.0148	0.0145
Available P (ppm)		11.88	5.38	4.42	7.34

Available soil phosphorous (Olsen P) at Maitsebri and SekotaSilassie sites was very low and medium, respectively while it was low at Mizikir and Tsaeda Kerni sites [19]. According to the ratings of [16], the CEC were high to very high for soils of the experimental sites.

Yield Attributes of Upland Rice

Application of Nitrogen and Phosphorus fertilizers individually and/or in combination at different rates does not show significant difference (P≤0.05) on number of tillers and effective tillers per plant of Up-land rice on the district (Table 2). [10] had also reported insignificant differences over fertilized and unfertilized plots due to Phosphorus fertilization on tiller production of rice at Benshangul-Gumuz region of Ethiopia. On other hand, there were interaction effects of nitrogen and phosphorus fertilizer rates on plant height, number of spikelet and total seed per panicle and the fertilized plots have shown an increase over the control. The result showed that, the plant height of upland rice significantly increased at higher doses of fertilizer N and P applications. The tallest rice plants (94.87 cm) were recorded at plots fertilized with 69 kg N ha^{-1} and 20 kg P ha^{-1}while the shortest plants measured from the unfertilized plots. Comparable with this, rice plants treated with N2-P3, N3-P3, N3-P1 and N1-P1 were tallest by 43%, 41%, 35% and 33% over the unfertilized plants. In line with the findings of the present study, it has been reported that the application of nitrogen and phosphorus fertilizers significantly enhanced the growth of upland rice [6], [10], [11]. The growth enhancement might be in line with remarkable increase of fertilizer application which could boost availability in the soil solution and crop uptake.

Combined application of highest doses of nitrogen and phosphorus were produced highest number of spikelets and total seeds per panicle. The higher spikelets were counted from plots received 46 kg N ha^{-1} along with 30 kg P ha^{-1} followed by combined applications of higher doses of N and P fertilizers (N3-P2, N3-P3 and N2-P2) significantly. Application of 69 kg N ha^{-1} and 20 kg P ha^{-1} also resulted in highest seed numbers (126.9) per panicle of rice than did other plots, with an advantage of 106.5% over control. These results were comparable with plots received combined applications of 46 kg N ha^{-1} with 20 and 30 kg P ha^{-1}. Similar trend were also observed by [6], [11], [20].

Hence, there were no interaction effects on panicle length and number of unfertilized seed per panicle of upland-rice. However, there were significant differences of main effect nitrogen and phosphorus on panicle length. The longest panicles was 20.19 cm recorded from plots treated with 46 kg N ha^{-1}, while the shortest panicles were found in the control plots for main effect nitrogen. Fertilized treatments with main effect phosphorus fertilizer had a significant difference in panicle length ($p < 0.05$) from the unfertilized treatment but not among each other. [12] also observed an increment in the panicle length of rice plants due to applied nitrogen and phosphorus fertilizer effects at southwestern Ethiopia. Number of unfertilized seeds per panicle showed significant response to the application of phosphorus fertilizer, whereas no significant difference among nitrogen fertilizer rates. The lowest unfertilized seed number was found in plots received 20 kg P ha^{-1} and the highest from plots treated with low and/or no phosphorus fertilizer. It was understood that phosphorus had a key role in grain filling and fertility of seeds [21]..

Table - 2:-Main effects of nitrogen and phosphorus fertilizer levels on yield components of upland-rice

Treatments	NTP^{-1}	NETP^{-1}	PH	PL	NSP^{-1}	NTSP^{-1}	NUSP^{-1}
Nitrogen Levels (kg N ha^{-1})							
N0	4.20^{A}	3.46^{A}	74.46^{C}	18.44^{C}	7.14^{C}	69.25^{C}	10.59^{A}
N1	4.23^{A}	3.47^{A}	79.42^{B}	18.95^{BC}	8.35^{B}	79.30^{B}	9.10^{A}
N2	4.38^{A}	3.52^{A}	84.37^{AB}	20.19^{A}	10.48^{A}	102.50^{A}	9.63^{A}
N3	4.15^{A}	3.49^{A}	86.62^{A}	19.96^{AB}	10.94^{A}	104.55^{A}	8.24^{A}
LSD	NS	NS	4.96	1.23	0.71	5.33	NS
Phosphorus levels (kg P_2O_5 ha^{-1})							
P0	4.19^{A}	3.53^{A}	73.77^{B}	18.27^{B}	8.01^{B}	73.37^{C}	10.26^{AB}
P1	4.48^{A}	3.60^{A}	83.06^{A}	19.82^{A}	8.65^{B}	82.79^{B}	10.84^{A}
P2	4.13^{A}	3.43^{A}	83.16^{A}	19.76^{A}	9.96^{A}	99.12^{A}	7.94^{B}
P3	4.18^{A}	3.39^{A}	84.90^{A}	19.69^{A}	10.30^{A}	100.32^{A}	8.50^{AB}
LSD	NS	NS	4.96	1.23	0.71	5.33	2.35
N*P	NS	NS	**	NS	*	***	NS
CV %	34.62	39.23	15.16	15.8	19.12	14.90	62.28

Means with the same letter are not significantly different ($P \leq 0.05$). NTP^{-1}= Number of tillers per plant; NETP^{-1}= Number of Effective Tillers per plant; PH= Plant height (cm); PL= Panicle Length (cm); NSP^{-1} = Number of spikelets per panicle; NTSP^{-1}= Number of Total seed per panicle; NUSP^{-1}= Number of unfertilized seed per panicle

Yield of Upland rice

The interaction effect of nitrogen and phosphorus fertilizers at different levels showed no significant differences on grain yield and straw yields of upland-rice. However, analysis of variance from the four sites showed that both the main factor N and P fertilizers effects on grain and straw yield were significant ($P < 0.0001$). Fertilization of upland-rice with nitrogen fertilizer at a rate of 23, 46 and 69 kg ha^{-1} consistently increased grain yield and were significantly higher

(24%, 46% and 63% respectively) than the unfertilized fields. It is also observed that a significant differences among each treatments. Rice fields treated with phosphorus fertilizer at the rate of 20 and 30 kg ha^{-1} had significantly higher grain yield (34% and 43% respectively over control) than preceding treatment, though P increase beyond 20 kg ha^{-1} did not give statistically significant ($p > 0.05$) grain yield increase. Application of 10 kg P ha^{-1} also had a significant effect compared to the control plots.

Table - 3:- Main effects of nitrogen and phosphorus fertilizer levels on yields of upland-rice

Treatments	GYLD	SYLD	TSW	HI
Nitrogen Levels (kg N ha^{-1})				
N0	2636.30^{D}	4029.80^{D}	35.38^{A}	39.63^{B}
N1	3263.30^{C}	4646.40^{C}	35.91^{A}	41.15^{A}
N2	3852.60^{B}	5520.60^{B}	35.37^{A}	41.37^{A}
N3	4306.30^{A}	6198.50^{A}	35.35^{A}	40.83^{AB}
LSD	389.37	575.12	NS	NS
Phosphorus levels (kg P_2O_5 ha^{-1})				
P0	2851.90^{C}	4385.00^{B}	35.50^{A}	39.76^{B}
P1	3320.00^{B}	4807.20^{B}	35.13^{A}	40.95^{AB}
P2	3815.70^{A}	5483.60^{A}	36.17^{A}	40.71^{AB}
P3	4070.80^{A}	5719.60^{A}	35.21^{A}	41.54^{A}
LSD	389.37	575.12	NS	NS
N*P	NS	NS	NS	NS
CV %	27.5	27.99	9.02	8.87

Means with the same letter are not significantly different ($P \leq 0.05$). GYLD= Grain Yield (kg ha^{-1}); SYLD= Straw yield (kg ha^{-1}); TSW= Thousand Seed Weight (g); HI= Harvest Index (%)

Similar to grain yield, straw yield had similar increasing trend for both main effects. The results showed that application of 23, 46 and 69 kg N ha^{-1} produced highest straw yield, and it was significantly higher by 15%, 37% and 54%over control. A significantly higher straw yield was also obtained in plots received 30 kg P fertilizer ha^{-1} than other treatments; on par with plots treated with 20 kg P fertilizer ha^{-1}. Increments in grain and straw yields of rice due to main effect nitrogen and phosphorus fertilizers were reported in different regions of the country [6], [10],

[12] and elsewhere [13]. Similarly, [22] and [8] also reported a significant yield difference for Teff and Wheat respectively. The thousand grain weight and harvest index of rice were not significantly affected by interactions as well as the main effects of N and P fertilizers in this experiments.

The response curve revealed that optimum grain yield of rice to the application of N and P fertilizers were not found. Application of N and P fertilizers showed increasing trend (Figure 1). Application of N and P at a rate of 69 kg N ha^{-1}and 30 kg P ha^{-1}were not enough to boost up the production and productivity of rice in the district and application of higher rates of N and P should be tried.

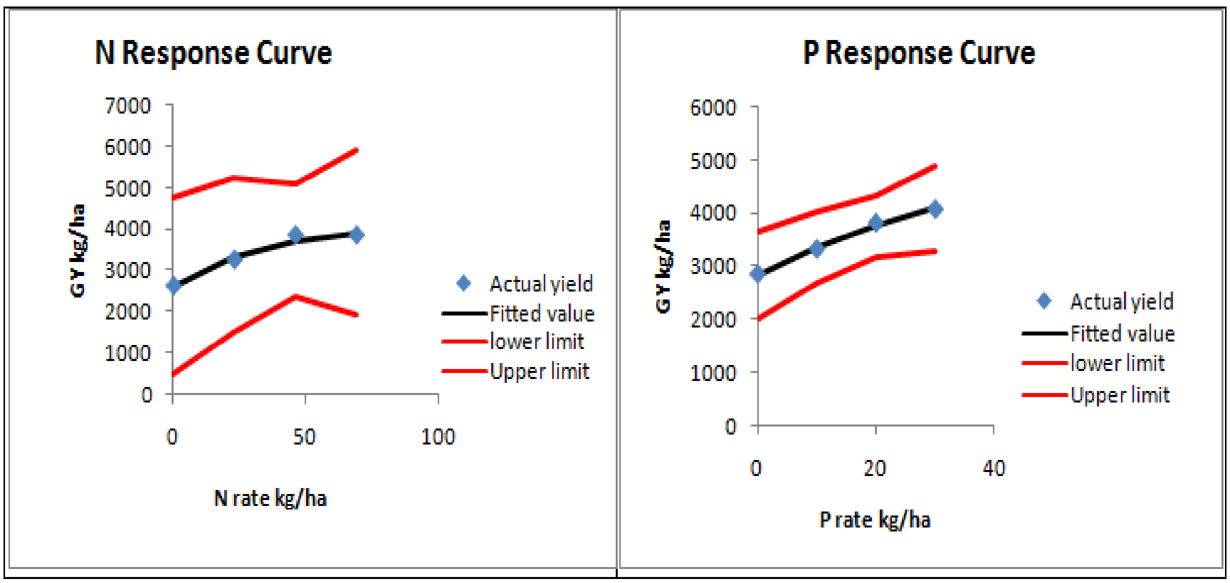

Figure - 1:- Response curve of rice to Nitrogen and phosphorus fertilizer levels

Agronomic efficiency of rice to the application of N and P

Agronomic efficiency is the amount of additional yield obtained for each additional kg of nutrient applied [21]. Agronomic efficiency of rice showed decreasing trend with increasing rate of N fertilizer application (Table 4).Therefore, application of one kg of N caused increase in grain yield of rice by 27.26 kg from plots treated with 23 kg N ha^{-1}. Even though there were some inconsistent trends, agronomic efficiency of rice to application of P decreased with P rates. The highest agronomic efficiency was recorded on plots treated with 20 kg P ha^{-1}. The result from site was nearly in line with the findings of [9], where AE decreases with N and P rates.

Table - 4:- Agronomic efficiency of rice to the application of N and P

N (kg ha $^{-1}$) Rate	AEN (kg kg^{-1})	P (kg ha $^{-1}$) Rate	AEP (kg kg^{-1})
0		0	-
23	27.26	10	46.81
46	26.44	20	48.19
69	17.62	30	40.63

AEN (kg kg^{-1}) = Agronomic Efficiency of rice to Nitrogen fertilizer and AEP (kg kg^{-1}) = Agronomic Efficiency of rice to Phosphorus fertilizer

Conclusion

The growth and yield of upland rice were enhanced significantly due to application of nitrogen and phosphorus fertilization on vertisols of Tselemti area. Plant height, number of spikelet and total number of seeds per panicle were affected by the interaction of higher doses, while the panicle length, unfertilized seeds, grain yield as well as straw yield by the main effect of nitrogen and phosphorus fertilizers. Thus, according to the results, an optimum grain and straw yield of upland rice can be achieved in the district by applying nitrogen and phosphorus fertilizer at a rate of 69 kg ha^{-1}and 30 kg ha^{-1}respectively. However, these application rates were not enough to boost up the production and productivity of rice in the district and application of higher rates of N and P should be tried. Additionally, higher agronomic efficiency of rice was also obtained from fertilization of 23 kg N ha^{-1}and 20 kg P ha^{-1}.

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