

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

27 **Introduction**

28 In Ethiopia, rice is among the target commodities that have received due emphasis in promotion
29 of agricultural production, and as such it is considered as the “millennium crop” expected to
30 contribute to ensuring food security in the country. Although rice is introduced to the country
31 very recently, rice has proven to be a crop that can assure food security in Ethiopia, the second
32 most populous nation in sub-Saharan Africa (SSA) with about 74 million people in 2007 [1]. The
33 trend of rice production is increasing both in area coverage, participant farmers, and production
34 [2]. Productivity in quintal per hectare has increased from 28.91 in 2012 to 28.97 and the number
35 of participant farmers increased from 115,832 to 119,4970 in 2013 cropping season [3].

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

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

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

64 **Material and Methods**

65 **Description of the Study Area**

66 The experiments were conducted at four sites of Tselemti district, Northwestern Tigray,
67 Ethiopia. The experimental locations were Tsaeda-Kerni (located at 13° 33' 04.29.29" N, 38° 01'
68 52.18" E and 1116 masl), Mizikir (located at 13° 32' 56.99" N, 38° 03' 22.97" E and 1145 masl),
69 Maitsebri (located at 13° 35' 28.68" N, 38° 08' 57.01" E and 1325 masl) and Sekota-Mariam
70 (located at 13° 32' 58.64" N, 38° 13' 33.91" E and 1145 masl).

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

78 **Experimental Treatments, Design, and Procedures**

79 The treatments were factorial combination of two factors, four levels of nitrogen (0, 23, 46, 69,
80 kg Nha⁻¹ designated as N0, N1, N2 and N3 respectively) and four levels of phosphorus (0, 10,
81 20, 30 kg Pha⁻¹ designated as P0, P1, P2 and P3 respectively). Urea (46% N) and Triple Super
82 Phosphate (46% P₂O₅) were used as fertilizer sources for N and P, respectively. At each site
83 then, the field experiment had arranged in randomized complete block design with three
84 replications. Gross plot size for the trial was 12.8m² (4m*3.2m) and the space between blocks

85 and plots were 1m and 0.5m respectively. Planting was done in row method with 20cm inter row
86 spacing and 5cm planting depth at a rate of 70kg/ha. The newly adopted upland rice
87 *i.e.*NERICA-13 was used as a test crop. All of the phosphorus fertilizer for each treatment
88 (except the control plots) were applied at planting while Nitrogen fertilizers was split applied
89 (the first1/3 was applied at sowing, and the remaining at tillering stage). All other agronomic,
90 cultural and management practices including weeding, disease and pests were followed the
91 recommended practices of the crop.

92 **Soil Sampling and Analysis**

93
94 Composite soil samples for chemical and physical characterization were collected up to 20 cm
95 soil depth from each field before fertilizer application. Each parameter were analyzed using
96 standard procedure as prescribed by [15]. Soil texture was determined by the hydrometer
97 method. Soil pH and EC was also determined using a pH meter from 1:2.5 soil:water ratio
98 suspension and using EC meter from 1:5 soil water saturation extract respectively. As there is a
99 lot of information about the interpretation of ECe in relation to plant growth, it was useful to
100 convert EC (1:5) to ECe [16].

101 $ECe \text{ (dSm}^{-1}\text{)} = EC_{1:5} \text{ (dSm}^{-1}\text{)} \times \text{multiplier factor};$

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

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

108 **Data Collection and Analysis**

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

114 **Result and Discussion**

115 **Soil Physicochemical characteristics of the Experimental studies**

116
 117 Textural classes of Sekota Silassie, Maitsebri and Tsaeda Kerni experimental sites were clay
 118 loam and clay for Mizikir experimental site (Table 1). The pH of soils of the experimental sites
 119 varied from 5.8 to 6.5, which ranges from slightly acidic to moderately acidic [17]. Thus, the pH
 120 of the experimental site soils was within the range for productive soils. According to the ratings
 121 of [17] the organic carbon content of soils of experimental sites were medium and total nitrogen
 122 was low in all fields [18].

123 **Table - 1:-** Physicochemical characteristics of the study sites

Soil Physicochemical Parameters	Locations			
	SekotaSilassie	Mizikir	Maitsebri	TsaedaKerni
pH (1:2.5 H ₂ O)	5.8	6.5	6.2	6.1
EC	0.38	0.11	0.21	0.38
% Sand	28	30	28	26
Texture % 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

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

127

128 **Yield Attributes of Upland Rice**

129 Application of Nitrogen and Phosphorus fertilizers individually and/or in combination at
130 different rates does not show significant difference ($P \leq 0.05$) on number of tillers and effective
131 tillers per plant of Up-land rice on the district (Table 2). [10] had also reported insignificant
132 differences over fertilized and unfertilized plots due to Phosphorus fertilization on tiller
133 production of rice at Benshangul-Gumuz region of Ethiopia. On other hand, there were
134 interaction effects of nitrogen and phosphorus fertilizer rates on plant height, number of spikelet
135 and total seed per panicle and the fertilized plots have shown an increase over the control. The
136 result showed that, the plant height of upland rice significantly increased at higher doses of
137 fertilizer N and P applications. The tallest rice plants (94.87 cm) were recorded at plots fertilized
138 with 69 kg N ha⁻¹ and 20 kg P ha⁻¹ while the shortest plants measured from the unfertilized plots.
139 Comparable with this, rice plants treated with N2-P3, N3-P3, N3-P1 and N1-P1 were tallest by
140 43%, 41%, 35% and 33% over the unfertilized plants. In line with the findings of the present
141 study, it has been reported that the application of nitrogen and phosphorus fertilizers significantly
142 enhanced the growth of upland rice [6], [10], [11]. The growth enhancement might be in line
143 with remarkable increase of fertilizer application which could boost availability in the soil
144 solution and crop uptake.

145 Combined application of highest doses of nitrogen and phosphorus were produced highest
146 number of spikelets and total seeds per panicle. The higher spikelets were counted from plots
147 received 46 kg N ha⁻¹ along with 30 kg P ha⁻¹ followed by combined applications of higher doses
148 of N and P fertilizers (N3-P2, N3-P3 and N2-P2) significantly. Application of 69 kg N ha⁻¹ and
149 20 kg P ha⁻¹ also resulted in highest seed numbers (126.9) per panicle of rice than did other plots,
150 with an advantage of 106.5% over control. These results were comparable with plots received
151 combined applications of 46 kg N ha⁻¹ with 20 and 30 kg P ha⁻¹. Similar trend were also
152 observed by [6], [11], [20].

153 Hence, there were no interaction effects on panicle length and number of unfertilized seed per
154 panicle of upland-rice. However, there were significant differences of main effect nitrogen and
155 phosphorus on panicle length. The longest panicles was 20.19 cm recorded from plots treated
156 with 46 kg N ha⁻¹, while the shortest panicles were found in the control plots for main effect
157 nitrogen. Fertilized treatments with main effect phosphorus fertilizer had a significant difference

158 in panicle length ($p < 0.05$) from the unfertilized treatment but not among each other. [12] also
 159 observed an increment in the panicle length of rice plants due to applied nitrogen and phosphorus
 160 fertilizer effects at southwestern Ethiopia. Number of unfertilized seeds per panicle showed
 161 significant response to the application of phosphorus fertilizer, whereas no significant difference
 162 among nitrogen fertilizer rates. The lowest unfertilized seed number was found in plots received
 163 20 kg P ha⁻¹ and the highest from plots treated with low and/or no phosphorus fertilizer. It was
 164 understood that phosphorus had a key role in grain filling and fertility of seeds [21].

165 **Table - 2:-**Main effects of nitrogen and phosphorus fertilizer levels on yield components of
 166 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 P₂O₅ 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

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

170 Yield of Upland rice

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

176 (24%, 46% and 63% respectively) than the unfertilized fields. It is also observed that a
 177 significant differences among each treatments. Rice fields treated with phosphorus fertilizer at
 178 the rate of 20 and 30 kg ha⁻¹ had significantly higher grain yield (34% and 43% respectively over
 179 control) than preceding treatment, though P increase beyond 20 kg ha⁻¹ did not give statistically
 180 significant (p > 0.05) grain yield increase. Application of 10 kg P ha⁻¹ also had a significant
 181 effect compared to the control plots.

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

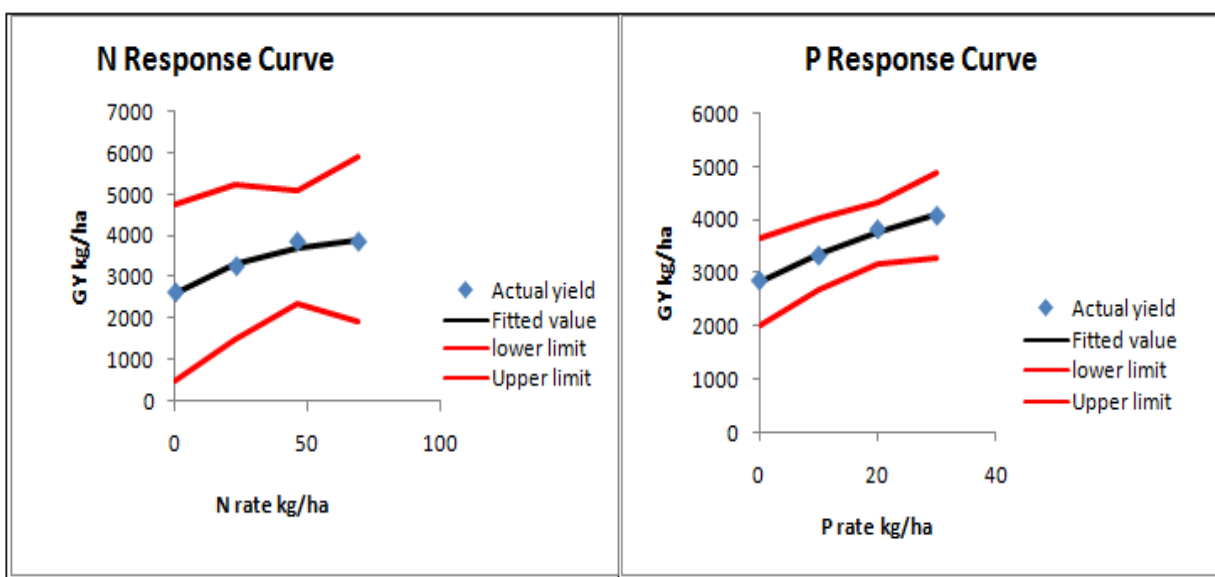
Treatments	GYLD	SYLD	TSW	HI
Nitrogen Levels (kg N ha⁻¹)				
N0	2636.30 ^D	4029.80 ^D	35.38 ^A	39.63 ^B
N1	3263.30 ^C	4646.40 ^C	35.91 ^A	41.15 ^A
N2	3852.60 ^B	5520.60 ^B	35.37 ^A	41.37 ^A
N3	4306.30 ^A	6198.50 ^A	35.35 ^A	40.83 ^{AB}
LSD	389.37	575.12	NS	NS
Phosphorus levels (kg P₂O₅ ha⁻¹)				
P0	2851.90 ^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

183 Means with the same letter are not significantly different (P ≤ 0.05). GYLD= Grain Yield (kg ha⁻¹); SYLD= Straw
 184 yield (kg ha⁻¹); TSW= Thousand Seed Weight (g); HI= Harvest Index (%)

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

191 [12] and elsewhere [13]. Similarly, [22] and [8] also reported a significant yield difference for
192 Teff and Wheat respectively. The thousand grain weight and harvest index of rice were not
193 significantly affected by interactions as well as the main effects of N and P fertilizers in this
194 experiments.

195 The response curve revealed that optimum grain yield of rice to the application of N and P
196 fertilizers were not found. Application of N and P fertilizers showed increasing trend (Figure 1).
197 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
198 production and productivity of rice in the district and application of higher rates of N and P
199 should be tried.



200
201 Figure - 1:- Response curve of rice to Nitrogen and phosphorus fertilizer levels

202 Agronomic efficiency of rice to the application of N and P

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

210 **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

211 AEN (kg kg⁻¹) = Agronomic Efficiency of rice to Nitrogen fertilizer and AEP (kg kg⁻¹) = Agronomic Efficiency of
 212 rice to Phosphorus fertilizer

213 **Conclusion**

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

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