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Original Paper

Response of Upland Rice to N and P Fertilizers on Vertisols of West Gondar Zone, Ethiopia.

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***Abstract*—Rice (Oryza sativa L.) is an increasingly important food security crop in Ethiopia. However, its productivity is limited by poor soil fertility and the absence of specific fertilizer recommendations. A two-year field experiment was conducted on Vertisols in Metema district, West Gondar Zone, northwestern Ethiopia. The study aimed to evaluate the response of upland rice (cv. FOGERA-1) to nitrogen and phosphorus fertilizer rates and to identify economically optimal application rates. The treatments consisted of a factorial combination of four N rates (0, 46, 92, and 138 kg N ha^{-1}) and three P_2O_5 rates (0, 23, and 46 kg P_2O_5 ha^{-1}), arranged in a randomized complete block design with three replications. Combined analysis of variance revealed that N application significantly improved all measures of traits, whereas P had a smaller, though positive effect, especially when combined with N. The highest grain yield (5,916 kg ha^{-1}) was obtained with 138 kg N ha^{-1}, a 66.7% increase over the control. The application of 138 kg N ha^{-1} combined with 23 kg P_2O_5 ha^{-1} produced the highest thousand-grain weight (40.7 g) and net benefit (171,759 ETB ha^{-1}), with a marginal rate of return of 846%, substantially exceeding the 100% minimum acceptable rate. Pearson correlation analysis revealed strong positive relationships between grain yield and key yield components. In conclusion, the application of 138 kg N ha^{-1} and 23 kg P_2O_5 ha^{-1} is economically optimal and is recommended for upland rice production on Vertisols in Metema and similar agro-ecologies.**

Keywords*—Upland rice, Nitrogen, Phosphorus, Economic analysis, Vertisols

I. INTRODUCTION

Rice (Oryza sativa L.) serves as the primary crop for ensuring food security for nearly half of the global population [1]. It ranks third in terms of area after wheat and second in both production and productivity, coming after maize on a global scale [2]. Rice cultivation in Ethiopia began three decades ago, during the 1970s. The country possesses significant potential for growing various types of rice, particularly in rain-fed lowlands, uplands, and irrigated ecosystems [3]. Although rice was only recently introduced to the country, its production expanded from approximately 10,000 hectares in 2006 to more than 91,122.35 hectares in 2022 [4]. The expansion of rice production has significantly increased, driven by the introduction of suitable rice varieties for both wetland and upland agro-ecologies. This growth in cultivated areas has led to a consistent rise in production levels over the years [3].

Upland rice grows well in many parts of Ethiopia. The Amhara Region is a major rice producer, especially in the Fogera plains and West Gondar zones, thanks to favorable climate factors like water availability, fertile soil, and suitable temperatures. These areas are key to local food supply and national security, while farming improvements steadily increase rice production. With global and Ethiopian population growth, addressing the food shortage is crucial. Increasing rice production is receiving special focus as a key solution to help close this gap. The Amhara region dominates national rice production, accounting for 64 % of the cultivated area and 68% of the total production in the 2021/22 season; nevertheless, the average rice yield at the national level in Ethiopia remains relatively low, at around 3.2 tons ha^{-1} [4].

Weeds, pests, soil nutrient deficiencies, and terminal moisture stress are the major causes of low rice productivity in Ethiopia [5]. Low soil fertility and inadequate nutrient management are among the major factors determining its yield level. The use of chemical fertilizers are important determinant to improve its productivity. Poor soil fertility is among the major factors limiting rice production in Ethiopia [6]. Nitrogen, phosphorus, and potassium are applied as fertilizers in large quantities to rice fields, and a deficiency of any of these nutrients leads to yield losses [7]. Nitrogen and phosphorus are often cited as the most limiting nutrients in agricultural soils of Ethiopia [8]. Appropriate fertilizer application is an important management practice to improve soil fertility and production of rice [9]. On Vertisols of northwestern Ethiopia, upland rice is increasingly adopted, yet no location-specific N and P recommendations exist. This study, therefore, aimed to (i) quantify the agronomic response of upland rice (cv. FOGERA-

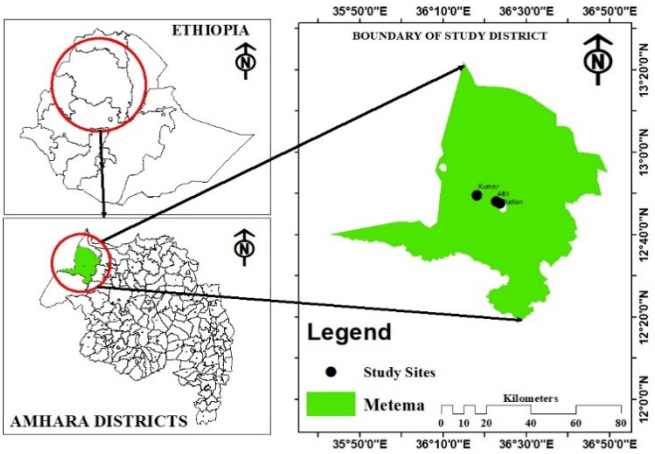


Fig. 1. Map of the study area

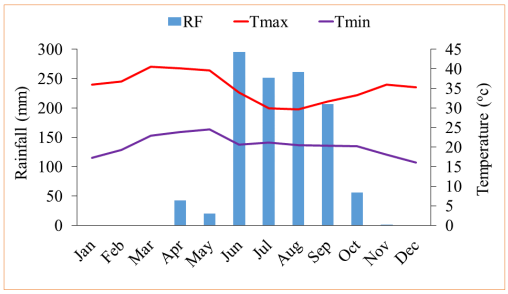


Fig. 2. Climate conditions of Metema at the 2021 cropping season.
Source: Ethiopia Meteorological Agency

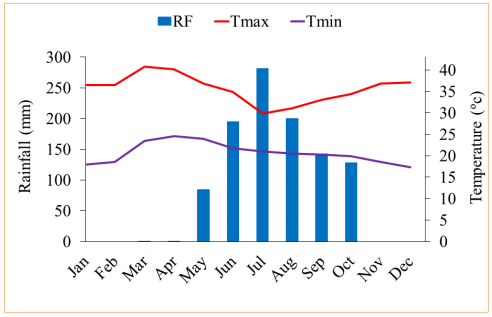


Fig. 3. Climate conditions of Metema at 2022 cropping season
Source: Ethiopia Meteorological Agency

1) to different N and P application rates, and (ii) determine the economically optimal fertilizer combination for upland rice on Vertisols in the Metema district.

II. Materials and Methods

A. Description of the study area

The field experiment was conducted in the Metema district, situated in the northwestern lowlands of the Amhara region in Ethiopia. This area is geographically positioned between 12° 17′ 31″ and 13° 5′ 40″ North latitude, and 36° 0′ 15″ and 36° 46′ 30″ East longitude (Fig 1). The study area is mostly flat, with a vast spread of Vertisols, and has been mainly used for growing sesame, sorghum, and cotton [10].

B. Climatic Condition

According to [11], the climate in the study area is categorized as a moist lowland agroecological zone. The study area receives an average annual rainfall of approximately 1031.6 mm and 1134.4 mm in the 2021 and 2022 main seasons, respectively, with a unimodal distribution that occurs between April and October (Figures 2 and 3). The average monthly maximum temperature was recorded at 35.6°C in 2021 and 35.2°C in 2022, while the minimum temperature averaged 20.6°C and 20.4°C in the 2021 and 2022 main cropping seasons respectvely. Figures 2 and 3 illustrate the mean monthly rainfall along with the maximum and minimum temperatures during the period from 2021 to 2022.

C. Treatments , Experimental Design and Procedure

The treatments consisted of a factorial arrangement of four levels each of N (0, 46, 92, and 138 kg N ha^{-1}) and three levels of P2O5 (0, 23, and 46 kg P_2O_5 ha^{-1}) in a randomized complete block design in three replications. The land was plowed by oxen, and after plowing, the experimental field was blocked into three parts depending on land uniformity. A suitable seedbed was prepared to get proper germination and root development. The plot size was 3 m x 3 m (12 m2). The rice variety FOGERA-1 was sown in the last week of July and harvested in the third week of October each year. Nitrogen fertilizer was applied in splits, ⅓ each at sowing, tillering, and panicle initiation stages as urea, while whole P (TSP as source of P) was applied at sowing. Rice seeds were drilled by hand in rows at 20 cm apart at the rate of 100 kg ha-1. All the recommended agronomic practices were followed. There were 15 rows in each plot, and one outermost rows of each plot were considered as a border. Of the 3 m x 3 m (12 m2) gross plot size, 3.0 m x 2.6 m (7.8 m2) was harvested when two-thirds of the length of the panicle axis in 50% of the plant population attained yellow color.

D. Soil Sampling and Analysis Methods

A composite surface soil (0-20 cm depth) sample was collected with a gauge auger. Plant residues on the sampling soil surface were removed. Eight soil sub-samples, each for a composite surface soil sample per block, were collected for characterization of selected soil physicochemical properties. The sample was analyzed for soil texture using the hydrometer method [12]. Soil pH was determined in a 1:2.5 soil-water suspension using a combination of a glass electrode. Organic carbon was estimated by the wet digestion method [13], and organic matter was calculated by multiplying the percent organic carbon (OC) by a factor of 1.724. Exchangeable K, calcium (Ca), and magnesium (Mg) were extracted with 1 M ammonium acetate solution adjusted to pH 7.0 [14]. From the extract, exchangeable K was determined using a flame photometer, while Ca and Mg were determined using an atomic absorption spectrophotometer. To determine the cation exchange capacity (CEC), the soil sample was first leached

using 1 M ammonium acetate, washed with ethanol, and the adsorbed ammonium was replaced by sodium (Na). Then, the CEC was determined titrimetrically by distillation of ammonia that was displaced by Na [14].

E. Data Collection

Data were collected for the following traits: plant height, panicle length, fertile panicles/m², filled grains per panicle, thousand-grain weight, grain yield, biomass, and straw yield.

At maturity, plant height was determined by averaging measurements (cm) from the base to the panicle tip of ten randomly selected plants within the net plot, using a measuring tape. Effective total tillers were counted within a 0.25 m x 0.25 m quadrant placed in the net plot of each experimental unit at physiological maturity. Average panicle length, measured from base to tip at maturity, was calculated using ten randomly sampled plants per net plot. The average number of filled grains per panicle was determined by counting grains on ten randomly selected panicles within each treatment's net plot. Thousand-grain weight (g) was determined for each plot by weighing 1000 seeds on a sensitive balance. Biomass, or biological yield, was quantified as the dry weight of the total above-ground plant material harvested from the net plot following sun-drying. Grain yield was measured by threshing grain from the net plot area, weighing it, adjusting the weight to 12% moisture content, and converting the result to tons per hectare. Straw yield was calculated by subtracting the grain yield from the total above-ground plant biomass (which comprises both straw and grain).

F. Data analysis

All data were analyzed using analysis of variance (ANOVA) in R software (version 4.3.3). As tests for homogeneity of variance were non-significant for each parameter, a combined ANOVA across years was performed to assess main and interaction effects. Treatment means were separated using Fisher's Least Significant Difference (LSD) test at the 0.05 significance level.

G. Partial Budget Analysis

Partial budget analysis was carried out using the CIMMYT partial budget approach [15]. For the computation, the average price of the inputs (fertilizers) and output (grains and straw yield) was noted. Because they were very equal for all treatments, all expenses were computed without taking into account the cost of additional agronomic operations, such as seed, land plowing, planting, weeding, protecting the farm, and harvesting, except for fertilizer application. Each cost and profit was expressed on a per-hectare basis and measured in Ethiopian Birr (ETB). To represent the actual farmer yield expected under production management conditions, the grain and straw yield of rice was adjusted to 10% lower. Only application costs and prices of N and P were taken as variable costs. The price of rice grain and straw yield was changed into hectare basis. Following CIMMYIT's partial budget procedure, total variable cost (TVC), Gross benefit (GB), and Net benefit (NB) were calculated. The treatments were arranged in the order of increasing TVC, and dominance analysis was done to exclude dominated treatments from the marginal rate of return (MRR) analysis. A treatment is said to be dominated if it has a higher TVC than the treatment that has a lower TVC next to it but has a lower NB. A treatment that is non-dominated, having an acceptable MRR value (greater than 100%), and having the maximum NB is said to be economically profitable.

TABLE I. PHYSIOCHEMICAL SOIL PROPERTIES OF STUDY SITES

Location	**Site 1**	**Site 2**	**Site 3**
pH (H2O)	6.29	6.28	6.11
OC (%)	1.3	1.2	1.14
Total N (%)	0.09	0.04	0.05
Ava. P (ppm)	3.62	2.54	4.7
CEC(cmol kg^{-1})	67.67	70.43	83.03
Sand	24	14	16
Silt	25	21	37.28
Clay	51	65	56.72
Textural class	Clay	Clay	Clay

III. RESULTS AND DISCUSSION

A. Soil Properties of the Experimental Sites Before Sowing

Based on [16] soil classification, the soil in the study area was slightly acidic, with pH values ranging from 6.11 to 6.29. Although the optimal pH range for rice cultivation is between 5.5 and 6.6, the crop is adaptable and can tolerate a broader pH range of 4.5 to 8.5. The total nitrogen content of the soil ranged between 0.04–0.09%, which classifies it as low according to the standards set by [17]. Similarly, the soil organic matter content, varying from 1.14–1.28%, also falls within the low category for Ethiopian soils, based on the classification criteria established by [18]. In addition, the available phosphorus content of the experimental soil was found to be 2.54–4.7 ppm, a level considered deficient when compared with the critical requirement of most crops, which is generally in the range of 20–40 mg/kg [19]. These results collectively indicate that the experimental soil is characterized by low fertility status in terms of essential macronutrients, particularly nitrogen, organic matter, and phosphorus, which are critical for optimal crop growth and productivity. In contrast, the soil exhibited a relatively high cation exchange capacity (CEC), ranging from 67.67–83.03 cmol(+)/kg, which, according to [20], is categorized as high, suggesting a good potential for nutrient retention despite the low levels of nitrogen, organic matter, and phosphorus.

B. Effects of N and P_2O_5 on Growth Parameters of Rice

1) Plant Height (cm) The analysis of variance indicated that the plant height of rice was highly significantly ($p<0.001$) affected by the main effects of nitrogen rates, but not by phosphorus rates and their interaction. The highest plant height (110.6 cm) was recorded from 138 kg ha^{-1} N, while the lowest plant height (74.19 cm) was recorded from the control (without N application) (Table II). The result indicated that plant height increased significantly by increasing the amount of N fertilizer. In line with the present findings, [21] reported that different levels of N caused a significant difference in plant height, with the height of the plant found to increase from 60 kg N to 120 kg N ha^{-1}. The increase in plant height of rice in response to the increase in N fertilizer rates was probably due to enhanced availability of N, which enhanced further cell division and more leaf area, which in turn resulted

TABLE II. MAIN EFFECTS OF N AND P2O5 ON GROWTH COMPONENTS OF RICE.

N levels (kg ha^{-1})	PH (cm)	PL (cm)
0	74.19^{d}	17.26^{d}
46	86.44^{c}	20.11^{c}
92	95.69^{b}	21.44^{b}
138	110.68^{a}	22.91^{a}
LSD $_{(0.05)}$	5.65	0.92
P_2O_5 levels (kg ha^{-1})		
0	89.75^{a}	19.88^{b}
23	92.06^{a}	20.46^{ab}
46	93.44^{a}	20.95^{a}
Mean	91.75	20.43
LSD $_{(0.05)}$	4.89	0.8
CV (%)	13.2	9.7

in higher photo assimilates and thereby resulted in more dry matter accumulation [1].

2) Panicle Length The analysis of variance showed that the panicle length of rice was highly significantly ($p<0.01$) affected by the main effects of nitrogen rates, but not by phosphorus rates and their interaction. The highest panicle length (22.91 cm) was exhibited at the rate of 138 kg N ha^{-1}, followed by 92 and 46 kg N ha^{-1}, which were statistically different, whereas the lowest panicle length (17.29 cm) was observed at the control without N fertilizer application (Table II). This result might be due to nitrogen taking part in panicle formation as well as panicle elongation, and for this reason, panicle length increased with the increase of N fertilization. The findings of many authors have confirmed the significant effect of nitrogen levels on panicle length [21, 22]. Reference [21] reported the highest panicle length was recorded with 180 kg N application, while [23] stated nitrogen application of 210 kg ha^{-1} exhibited larger panicle length. Reference [24] indicated that the highest and significant panicle length (27.06 cm) was recorded with the application of fertilizer dose at 60 kg N ha^{-1} compared to the control without N fertilizer. On the other hand, [25] reported the longest panicles of 20.19 cm at the highest N rate, while the shortest panicles were in the control plots.

Plant Height (PH), Panicle Length (PL), Least Significant Difference (LSD), Coefficient of Variance(CV)

C. *Effects of N and P_2O_5 on yield and yield related traits*

1) Number of effective tillers per m^2 The analysis of variance showed that the effect of nitrogen and the interaction between N and P were highly significant ($p<0.01$) for the number of productive tillers. The maximum (273.58) number of tillers was recorded for 138 kg N and 23 kg of P_2O_5 ha^{-1}, and the minimum value (158.92) was obtained at the control (unfertilized) plot (Table III). This result showed that the increased development of effective tillers in plants receiving higher rates of nitrogen and phosphorus may be due to a synchronized increase in the uptake of these nutrients through the roots. Increased tillering resulting from higher nitrogen and phosphorus application may be due to greater nitrogen availability to the plant during the active tillering stage. The current result is in agreement with [26], who reported higher

TABLE III. INTERACTION EFFECTS OF N AND P2O5 ON THE YIELD RELATED TRAITS OF RICE.

P_2O_5 levels (kg ha^{-1})	N levels (kg ha^{-1})	NFG	ET (m^2)	TSW (g)
0	0	77.18^{e}	158.92^{d}	22.73^{de}
	46	90.19^{d}	193.92c	25.34^{cd}
	92	97.13^{bcd}	267.75^{a}	24.87^{cde}
	138	101.92^{abc}	194.25^{c}	31.95^{b}
23	0	81.42^{e}	152.92^{d}	21.86^{e}
	46	89.95^{d}	229.08^{b}	24.71^{cde}
	92	97.75^{bcd}	266.92^{a}	25.27^{cd}
	138	103.98^{ab}	273.58^{a}	40.70^{a}
46	0	96.33^{bcd}	213.58^{bc}	21.86^{e}
	46	95.42^{cd}	212.75^{bc}	23.79^{de}
	92	95.85^{bcd}	220.75^{bc}	27.89^{c}
	138	107.87^{a}	223.42^{b}	38.40^{a}
MEAN		94.58	217.31	27.4
CV (%)		10.96	16.39	15.19
LSD $_{(0.05)}$		8.37	28.78	3.36

tillering and maximum survival percentage of tillers with increasing N and P application. Supporting the findings of this study, [1] noted that increased tillering resulting from high nitrogen application may be attributed to its beneficial influence on cytokine synthesis. Similarly, [27] indicated that seed rate influences the number of tillers per panicle, and that different combinations of nitrogen and phosphorus fertilizers can be equally effective when applied properly.

2) Number of Filled Grains Per Spiklets The result of the analysis of variance revealed that there was a significant difference ($p<0.01$) in the number of filled grains per spikelet for nitrogen and the interaction between N and P. The number of filled grains per spikelet is the most important yield component, which affects rice yield. The maximum number of filled grains (107.87) was recorded for the combined application of 138 kg N ha^{-1} and 46 kg of P ha^{-1}, while the minimum value (77.10) was obtained from the control (no N and P) plots (Table III). The above result indicated that the enhancement of the number of filled grains of plants that received higher rates of nitrogen and phosphorus might be attributed to their availability. In agreement with this result, [28] has reported that nitrogen promotes rapid growth and increases spikelet number per panicle and percentage of filled spikelets per panicle. In contrast, [29] also reported similar results in that with increasing levels of soil fertility, the number of filled grains per panicle decreased with a corresponding increase in unfilled spikelets.

Number of Filled Grain per Spikelet (NFG), Effective Tillers per Plant (ETP), 1000 Seeds Weight (TSW), Least Significant Difference (LSD), Coefficient of Variance (CV)

3) Thousand Seed weight(g) Rice grain weight was strongly affected by N, P, and their interaction ($p< 0.01$). The maximum 1000 grain weight (40.7 gm) was achieved with 138 kg ha^{-1} N and 23 kg ha^{-1} P, followed by (38.4 gm) with 138 kg of N and 46 kg of P ha^{-1}. The control (unfertilized) plot had a minimum 1000-grain weight of 22.73 g (Table III). The rise in 1000-grain weight at higher N and P rates may be attributed mostly to an increase in chlorophyll content in leaves, which led to a greater photosynthetic rate and, as a

TABLE IV. MAIN EFFECTS OF N AND P2O5 ON YIELD COMPONENTS OF RICE

N levels (kg ha^{-1})	GY (kg ha^{-1})	BY (kg ha^{-1})	STY (kg ha^{-1})
0	2529.47^{d}	6424.33^{d}	3894.81^{c}
46	3797.58^{c}	9759.81^{c}	5962.22^{b}
92	5192.81^{b}	13275.22^{b}	8082.39^{a}
138	5916.86^{a}	14957.78^{a}	9040.86^{a}
LSD (0.05)	463.53	1286.41	1015.13
P_2O_5 levels (kg ha^{-1})			
0	3685.62^{b}	9813.17^{b}	6127.54^{b}
23	4681.00^{a}	11687^{a}	7006.02^{ab}
46	4710.92^{a}	11812.69^{a}	7101.65^{a}
Mean	4359.18	11104.28	6745.07
LSD (0.05)	401.43	1114.06	870.13
CV (%)	22.8	24.84	23.27

NB: Biomass Yield (BY), Grain Yield (GY), Straw Yield (STY), Least Significant Difference (LSD), Coefficient of Variance (CV).

result, an abundance of assimilates during grain development. Furthermore, plants have the best access to P when the soil pH is between 6.0 and 6.5 [30].

4) Aboveground Biomass (kg ha^{-1}) Rice biomass yield showed a highly significant response ($p < 0.001$) to nitrogen (N) fertilizer application and the Site × N interaction, whereas phosphorus (P) fertilizer rates exerted a significant effect ($p < 0.05$). In contrast, the interaction between N and P fertilizer rates, as well as the Site × P interaction, did not significantly affect biomass yield ($p > 0.05$). Maximum biomass yield (14,957.78 kg ha^{-1}) occurred at 138 kg N ha^{-1}, whereas the minimum yield (6,424.33 kg ha^{-1}) was recorded in the unfertilized control (Table IV). This might be increased nitrogen application likely improved N availability during critical growth stages (active tillering and panicle development), potentially leading to higher numbers of productive tillers and grains. This outcome aligns with [31], who found that biomass yield significantly increased with higher nitrogen application rates compared to control (unfertilized) plots. According to [29, 32, and 33], applying nitrogen at rates of 100 kg ha^{-1} or more resulted in the highest biomass yield. Regarding phosphorus, the highest (11812 kg) and lowest (9812 kg) biomass yield was recorded for 46 kg P_2O_5 ha^{-1} and the untreated (control) plot, respectively. The application of phosphorus fertilizer at 23 and 46 kg P_2O_5 ha^{-1} significantly increased rice biomass yield by 19.09% and 20.37 %, respectively, compared to the control. However, the increase beyond 23 kg ha^{-1} was not statistically significant ($p > 0.05$). A notable improvement in biomass yield was observed with the 23 kg P_2O_5 ha^{-1} treatment relative to untreated plots. In this experiment, the coefficient of variation (CV) for grain yield was relatively high. One possible reason for this is the variation in soil nutrient status among the experimental sites. Evidence supporting this explanation is the highly significant site × nitrogen interaction, which indicates that crop responses to nitrogen differed across sites due to differences in soil characteristics and fertility levels.

5) Grain Yield (kg ha^{-1}) Analysis of variance indicated significant ($p < 0.01$) effects of the Site × N interaction, as well as the main effects of N and P application, on rice grain yield. In contrast, the Site × P interaction and the remaining interaction effects were not significant ($p > 0.05$). The effect of N showed a significant increase in grain yield from 2529 to 5916 kg ha^{-1} with an increase in the level of N from the control (no N) to 138 kg ha^{-1}. The highest grain yield (5916 kg ha^{-1}) obtained with the application of 138 kg N ha-1 was 66.7% higher than the control, while the lowest (2529 kg ha^{-1}) was obtained from the control plot (Table IV). The higher grain yield may be attributed to better growth with higher nutrient availability and higher photosynthetic rate of the plants, and more photosynthetic partitioning into the reproductive parts. In line with this study, [34] reported that the highest grain yield (4.56 ton-/ha) was obtained from 368 kg ha^{-1} N, followed by 276 and 184 kg N ha^{-1} (4.29 and 4.29 ton ha-1) respectively, which were statistically similar, while the lowest grain yield (1.86 t ha^{-1}) was recorded from no N. Similar results with higher N rates were also reported by [35] and [36]. Further, [37] found a significant increase in the grain yield of rice up to 60 kg N ha^{-1}. Application of P brings a significant difference in grain yield, which varied between 3685 and 4610 kg ha^{-1}. This may be due to the higher amount of inherent available P in the soil (Table IV). In addition, in Vertisols the high content of smectitic clay minerals promotes rapid adsorption of applied phosphate, while the low mobility of phosphorus and restricted diffusion caused by the shrink–swell nature of these soils further limit its movement to plant roots. As a result, phosphorus availability to crops remains low despite the presence of soil P [38]. Reference [39] reported inconsistent rice yield response to applied P during the earlier years of application; however, there was a consistent increase in yield later on. Similarly, [40] reported that the application of P had only a little effect on grain yield despite increased P uptake by the plant. The high grain yield CV observed in this experiment may be attributed to differences in soil nutrient status among the study sites. This is further supported by the significant site × nitrogen interaction, suggesting that nitrogen responses varied across locations.

6) Straw Yield (kg ha^{-1}) The ANOVA result revealed that both nitrogen (N) and phosphorus (P) individually had highly significant effects ($p<0.01$) on rice straw yield, but their interaction (N×P) and Site × P and Site × N interaction was not significant. As shown in Table IV, higher application rates of N and P significantly increased straw yield. The maximum yield (9040.86 kg ha^{-1}) occurred with 138 kg N ha^{-1}, while the control plot (no fertilizer) produced the minimum yield (3894.81 kg ha^{-1}) (Table IV). This suggests that boosting nitrogen levels could increase rice straw output. The maximum straw yield was statistically similar to 8082.39 kg ha^{-1}, produced by applying 92 kg ha^{-1}, but significantly different from 0 and 46 kg N ha^{-1}. The increase in straw production caused by increased N fertilizer rates appears to be attributable to its influence on the rice plant's robust vegetative development. This finding is consistent with [30] [34], who found that the maximum straw production was

achieved with 138 kg ha^{-1} N fertilizer. Similarly, [41] showed that the maximum straw production was achieved with the highest amount of nitrogen fertilizer. Adding phosphorus significantly increased straw production ($p<0.05$). Increasing P levels from 0 to 46 kg ha^{-1} improved rice straw production by up to 7101.65 kg ha^{-1}. The maximum straw yield (7101.65 kg ha^{-1}) was achieved at 46 kg ha^{-1} P_2O_5, which is statistically equivalent to the values of 23 kg ha^{-1} P_2O_5, while the lowest (6127.54 kg ha^{-1}) was produced in the control plot. Reference [24] found that different N and P levels had a significant ($p < 0.05$) effect on rice straw yields.

D. Correlation Analysis

The correlation analysis revealed a strong and significant ($p < 0.01$) positive relationship between grain yield and several yield-related characteristics in rice. Specifically, grain yield showed significant positive correlations with straw yield (r = 0.67***), number of effective tillers (r = 0.46***), plant height (r = 0.72***), panicle length (r = 0.76***), thousand grain weight (r = 0.51***), and number of filled grains per spikelet (r = 0.39***) (Figure 4). Similar positive associations between grain yield and yield-related traits have been reported by other researchers, including [1]. Straw yield also displayed a strong positive correlation ($p < 0.01$) with plant height (r = 0.61***), panicle length (r = 0.71***), number of filled grains per spikelet (r = 0.2*), effective tillers (r = 0.32***), thousand grain weight (r = 0.26**), and biomass (r = 0.97***) (Figure 4). Moreover, biomass was significantly and positively associated with plant height (r = 0.7***), panicle length (r = 0.78***), grain yield (r = 0.84***), and straw yield (r = 0.97***) (Figure 4). These findings support the conclusions of [28] [42], who indicated that panicle length contributes indirectly to higher grain yield by increasing both panicle number and spikelets per panicle. In the present study, the number of filled grains per spikelet also showed positive correlations with plant height, panicle length, straw yield, biomass, and grain yield.

E. Regression analysis

The regression analysis examining the relationship between grain yield and nitrogen (N) application rate reveals a clear and statistically significant positive association. The regression model's intercept is estimated at 1.582, which provides a meaningful baseline value for grain yield when the nitrogen rate is zero. This intercept essentially serves as the starting point of the regression line on the yield scale. The slope coefficients of 0.03782 and 0.07217 indicate that for every one-unit increase in N and P application, the grain yield is expected to increase by approximately 0.03782 and 0.07217 units, respectively. This positive slope confirms that higher N and P levels consistently lead to greater grain yields. Importantly, this relationship is statistically supported by a p-value of 0.001, which is well below common significance thresholds (e.g., 0.05), indicating strong evidence that the slope differs from zero and is not due to random chance.

Furthermore, the regression model shows a strong fit to the observed data. The Pearson correlation coefficient between grain yield, phosphorus, and nitrogen rate is 0.86, reflecting a strong positive linear relationship. Additionally,

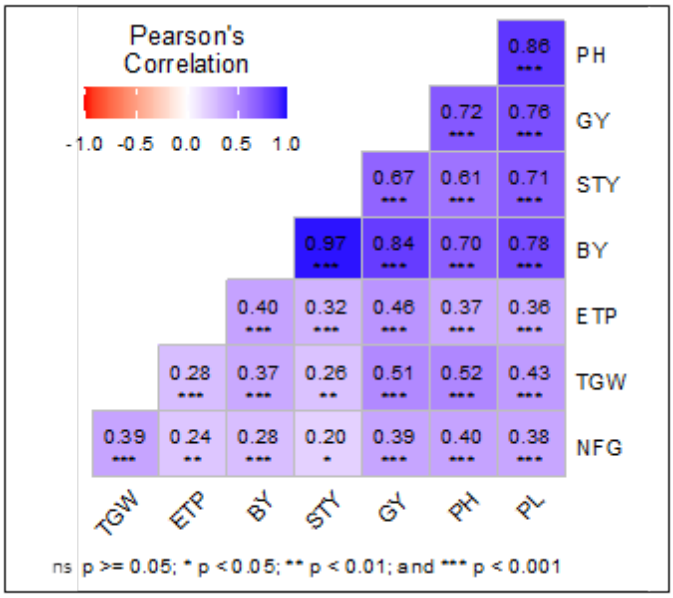


Fig. 4. Pearson correlation coefficients of the main characters of upland rice.
NB: Plant Height (PH), Number of Filled Grain per Spikelet (NFG), Effective Tillers per Plant (ETP), 1000 Seeds Weight (TSW), Biomass Yield (BY), Grain Yield (GY), Straw Yield (STY)

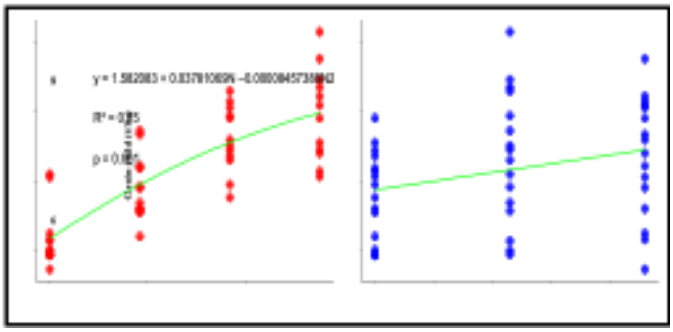


Fig. 5. Regression analysis of N and P rates on rice grain yield
NB; y= Grain yield (t/ha), N= nitrogen (kg/ha), P= phosphorus (kg/ha)

the coefficient of determination (R-squared) is 0.75, meaning that approximately 75 % of the variation in grain yield can be explained by the nitrogen and phosphorus rate. This suggests that N and P availability are major factors influencing rice grain yield, although other variables may also contribute to the remaining variability.

F. Partial budget analysis

Based on the principles of economic analysis as per [15], the minimum acceptable marginal rate of return (MRR %) should be 100%. The economic analysis was done on the basis of the prevailing prices of variable costs using the Ethiopian currency (Birr). The price of TSP and Urea fertilizer was 1430.00 and 1310.00 Birr per 100 kg, respectively. Moreover, the price of rice straw is valued at Birr 120.00 per 100 kg. In addition to this, the prices of seed for planting material during the cropping season were 1350.00 Birr per 100 kg. Grain and straw yield adjustments, calculations of total variable costs (TVC), gross benefits (GB), and net benefits (NB) were performed. Dominance analysis was performed after arranging

TABLE V. DOMINANCE ANALYSIS USING PARTIAL BUDGET ANALYSIS

N (kg ha-1)	P_2O_5 (kg ha-1)	AGY (kg ha-1)	GYB (ETB)	ASY (kg ha-1)	SYB (ETB)	GB (ETB)	TVC (ETB)	NB (ETB)	DA
0	0	2155	61869.8	3241	3889.2	65759	0	65759	
0	23	2330	67634.2	3924	4708.8	72343	1495	70848	
0	46	2345	69101.2	4519	5422.8	74524	2990	71534	
46	0	2936	86252	5510	6612	92864	4048	88816	
46	23	3546	103046	6035	7242	110288	5543	104745	
46	46	3772	109485.6	6342	7610.4	117096	7038	110058	
92	0	3824	112882	7480	8976	121858	8096	113762	
92	23	4953	144020.2	8469	10162.8	154183	9591	144592	
92	46	5244	151276.4	8298	9957.6	161234	11086	150148	
138	0	4353	128090.6	8278	9933.6	138024	12144	125880	D
138	23	6023	173882.8	9596	11515.2	185398	13639	171759	
138	46	5599	162213.4	9248	11097.6	173311	15134	158177	D

NB: Adjusted Grain Yield (AGY), Adjusted Straw Yield (ASY), Grain Yield Benefit (GYB), Straw yield Benefit (SYB), Gross Benefit (GB), Total Variable Cost (TVC), Net Benefit (NB), Dominance Analysis (DA)

TABLE VI. MARGINAL ANALYSIS USING PARTIAL BUDGET ANALYSIS.

N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	AGY (kg ha^{-1})	GYB (ETB	ASY (kg ha^{-1})	SYB (ETB)	GB (ETB)	TVC (ETB)	NB (ETB)	MR (%)
0	0	2155	61869.8	3241	3889.2	65759	0	65759	
0	23	2330	67634.2	3924	4708.8	72343	1495	70848	340
0	46	2345	69101.2	4519	5422.8	74524	2990	71534	46
46	0	2936	86252	5510	5510	92864	4048	88816	1633
46	23	3546	103046	6035	6035	110288	5543	104745	1065
46	46	3772	109485.6	6342	6342	117096	7038	110058	355
92	0	3824	112882	7480	7480	121858	8096	113762	350
92	23	4953	144020.2	8469	8469	154183	9591	144592	2062
92	46	5244	151276.4	8298	8298	161234	11086	150148	372
138	23	6023	173882.8	9596	11515.2	185398	13639	171759	846

NB: Adjusted Grain Yield (AGY), Adjusted Straw Yield (ASY), Grain Yield Benefit (GYB), Straw yield Benefit (SYB), Gross Benefit (GB), Total Variable Cost (TVC), Net Benefit (NB), Marginal Rate of Return (MRR)

the treatments in their order of TVC (Table 3). Treatments are considered as dominated if they have a higher TVC but a lower NB than a previous treatment with a lower TVC and a higher NB. Non-dominated treatments were taken out, and the marginal rate of return (MRR) was computed (Table V). The economic analysis of the result of this experiment revealed that the highest NB (Birr 171759 ha^{-1}) with an acceptable level of MRR (846) was observed at 184-23 N-P_2O_5 kg ha^{-1} (Table VI). In agreement with the present finding, [43] reported that rice genotypes performed efficiently at 120 kg N + 90 kg P_2O_5 ha^{-1}, where the highest paddy yield, net production value, and profit were obtained.

IV. CONCLUSSION AND RECOMMENDATION

The study showed that nitrogen and phosphorus fertilizers had a strong impact on the growth, yield, and related traits of upland rice grown on Vertisols in the Metema district of West Gondar. Applying nitrogen produced the most noticeable results. It increased plant height, panicle length, tiller production, filled grains per panicle, grain weight, biomass, grain yield, and straw yield. Phosphorus also helped improve yield components, especially when it was used with nitrogen, but its impact was smaller than that of nitrogen. The highest grain yield of 5916 kg ha^{-1} occurred with 138 kg N ha^{-1}, which was a 66.7% increase over the control. Likewise, using 138 kg N ha^{-1} along with 23 kg P_2O_5 ha^{-1} resulted in the heaviest thousand-grain weight of 40.7 g and the highest net economic benefit of 171,759 ETB ha^{-1}, with a reasonable marginal rate of return. The correlation analysis showed that grain yield was positively and significantly linked to other yield components such as plant height, panicle length, effective tillers, straw yield, biomass, thousand-grain weight, and the number of filled grains per spikelet. This highlights the important role of nutrient management in boosting rice productivity.

Therefore, based on agronomic performance and economic analysis, it is recommended to use 138 kg N ha^{-1} and 23 kg P_2O_5 ha^{-1} for upland rice production on Vertisols in Metema and similar areas in northwestern Ethiopia. However, more validation across different seasons and locations is needed before making broad recommendations for the region.

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