Advances in Crop Science and Technology

Tadesse, Adv Crop Sci Tech 2021, 9:5

Research Article Open Access

Determination of Nitrogen and Phosphorous Fertilizer Rates on Low Land Rice Production

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Received date: April 01, 2021; **Accepted date**: April 15, 2021; **Published date**: April 22, 2021

Abstract

Nitrogen and phosphorous fertilizers application experiment was conducted on rainfed lowland rice production at Fogera plain in two cropping seasons. The treatments were comprised of factorial combinations of five nitrogen (0,92,184, 276 and 368 kg/ha) and four phosphorous levels (0, 23, 46, and 69 P_2O_5 kg/ha). Data was collected on plant height. panicle length, number of total tillers/m, number of effective tillers/m, panicle length, number of fertile spiklets/panicle, thousand seeds weight, grain yield, straw yield and harvest index. All collected data were subjected to analysis of variance. Economic analysis was also carried out by following CIMMYT procedures. The results of the experiment indicated that the main effect of nitrogen application was significantly affecting plant height, panicle length, total tillers/m, effective tillers/m, filled spiklets/panicle, grain yield, straw yield, thousand seeds weight and harvest index while phosphorous was affecting only grain and straw yields. The interaction of nitrogen and phosphorous was affecting grain yield, straw yield and harvest index. With respect to the interaction effect, the highest grain yield (7.0 t ha-1) was obtained at 276-69 N- P2O5 kg ha-1. The economic analysis has exhibited that the combined application of 184-46 N-P2O5 kg ha-1 is the most profitable treatment. It is thus concluded that application of nitrogen and phosphorous fertilizers at rates of 184-46 N- P2O5 kg ha-1 is the best recommended for rainfed lowland rice production in Fogera plain and other similar agroecologies.

Keywords: Lowland rice; Nitrogen; Phosphorous; Profitable

Introduction

Rice (Oryza sativa L.) is an annual cereal grain and it is the most important food crops for the world's population, especially in South Asia, Middle East, Latin America and West India. Rice (*Oryza sativa L.)* is one of the most popular cereal crops in the world. It is the principal food for one third of the world's population. More than 90% of this rice is produced and consumed in Asia. It provides some 700 calories per person, mostly residing in developing countries. In Ethiopia, rice production was started three decades ago and the country has reasonable potential to grow various rice types mainly in rain fed lowland, upland and irrigated ecosystems. Though rice is a recent introduction to the country, its importance iswell recognized as the production area coverage of about 10,000 ha has increased to over 50,000 ha. The area coverage in domestic rice production has increased considerably linked with expansion of production in the wetland and upland areas with the introduction of suitable rice varieties for the agro-ecologies. In line with the area expansion, the production levels have been increasing consistently over years. CSA (Central Statistical Authority) data indicate that rice production increased from 71,316.07 tons in 2008 to 126,806.45 tons. The number of farmers engaged in rice production has also grown year after year. Rice production has brought a significant change in the livelihood of farmers and created job opportunities for a number of citizens in different areas of the country.Currently, Amhara, Southern Nations, Nationalities and Peoples Region (SNNPR), Oromiya, Somali, Gambella, BeniShangul Gumuz, and Tigray regions are the rice producing areas in Ethiopia. The Amhara region takes the lion's share of producing the crop and accounted for 74%-81% of the area coverage and 78%-85% of the production. The potential rice production area in Ethiopia is estimated to be about 39,354,190 hectares, of which 5,590,895 ha is highly suitable, 24,910,629 ha is suitable and 8,852,666 is moderately suitable. Most of Ethiopia's rice production potential area lies in the western part of the country.

The national average yield of rice is about 2.8t ha^{-1} which is lower compared to the world average productivity of 4.6 tones ha^{-1}. Weeds, pests, soil nutrient deficiencies and terminal moisture stress are the major causes of low rice productivity in Ethiopia. Poor soil fertility is among the major factors limiting rice production in Ethiopia. Nitrogen, phosphorus, and potassium are applied as fertilizers in large quantities to rice fields, and a deficiency of either of the nutrient leads to yield losses. Nitrogen and phosphorus are often cited as the most limiting nutrients in agricultural soils of Ethiopia. Appropriate fertilizer application is an important management practice to improve soil fertility and production of rice. Availability of plant nutrients, particularly nitrogen at various plant growth stages is of crucial importance in rice production. Therefore, a fertilizer experiment was conducted on the lowland rice production of Fogera Plain in order to recommend appropriate levels of nitrogen and phosphorous rates.

Materials and Methods

A rainfed lowland nitrogen and phosphorous rates experiment was conducted at Fogera plain in two cropping seasons. The experimental site is located between Latitude 11°49ˈ55 North and Longitude 37° 37′ 40 East at an altitude of 1815 meters above sea level. The study site receives averages mean annual, minimum and maximum temperature of 12.75°C and 27.37°C, respectively. The long-term rainfall data years indicated that much of the rainfall appear in July and August (Figure 1) [1].

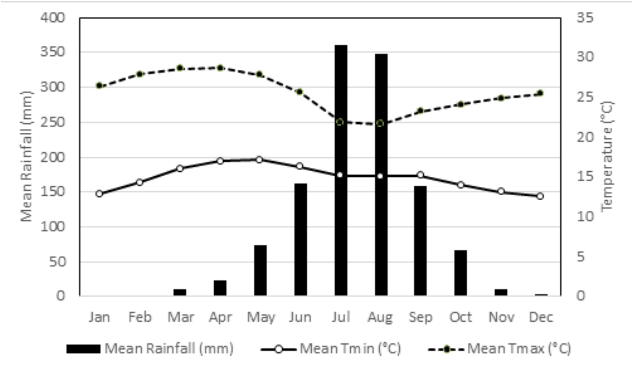

Figure 1: The rainfall and temperature condition of fogera plain for the period 1981-2017.

The experimental sites soil was found to be heavy clay with pH range of 5.87-6.63, which is slightly acidic and it is a preferred range for most crops (Table 1). Total nitrogen content was with range of 0.09-0.16y, which is within the range of low levels (0.02%-0.5%) for tropical soils. The organic matter content of the soil was between 2.13%-3.09%, which is within a range of medium (2-4%) for Ethiopian soils as per criteria developed. The available P content of the experimental sites soil was 11.4-25.13 ppm, which lies in a range of deficiency (<20 mg/kg-40 mg/kg) for most crops [2-4].

Soil properties	Units	Minimum Value	Maximum value
Textural class		**Heavy clay**	**Heavy clay**
Chemical properties			
pH (H2O) 1:2.5 g soil	-	5.87	6.63
Total nitrogen (TN)	%	0.09	0.16
Organic carbon (OC)	%	1.24	1.93
Organic matter (OM)	%	2.13	3.09
Available Phosphorus	Ppm	11.4	25.13

Table 1: Relevant soil physicochemical properties of the experimental rice field before planting in fogera plain of ethiopia.

The experimental treatments were comprised of factorial combinations of five nitrogen (0,92,184, 276 and 368 kg/ha) and four phosphorous levels (0,23,46 and 69 P_2O_5 kg/ha). The gross size of plots was 2 m × 4 m consisting of 10 rows planted at a spacing of 20 cm apart with seed rate of 100kg/ha. The net plot was made by excluding the left and right outer rows and a plot length of 0.5 m from the top and bottom sides of the plot. The final net plot size was thus 1.6 m × 3 m. Data was collected from the net plot area on plant height. number of total tillers/m, number of effective tillers/m, number of filled spiklets/panicle, thousand seeds weight, grain yield, straw yield and harvest index. The plant height was taken at physiological maturity of the crop by selecting five random tillers. Number of tillers were counted just before harvesting by random sampling using rulers. The total sundried biomass of the harvested rice was recorded before threshing. The harvest index was calculated as the ratio of grain yield to biological yield following the equation [5,6].

The rice grain yield and thousand seeds weight were adjusted at 14% standard moisture content. All collected data were subjected to analysis of variance (ANOVA) using SAS software version 9.2. Since the test of homogeneity of variances for each parameter was non-significant, combined analysis of variance was done over the years to determine the effects of application methods and N rates by year interaction. Wherever treatment differences are be found significant, mean separation of treatments would be calculated based on results of F-test and probability levels of 0.01 and 0.05 depending the results of the ANOVA [7-10].

Agronomic Efficiency (AE) was calculated to assess the efficiencies of the applied N rates as follows:

AE= (Gf - Gu / Na) kg rice grain/ kg N fertilizer applied

Where Gf is the grain yield of the fertilized plot (kg), Gu is the grain yield of the unfertilized plot (kg), and Na is the rate of applied N fertilizer (kg) [11-14].

Economic analysis was carried out by following CIMMYT procedures by taking all variable costs. The prevailing cost of inputs and out puts in year 2019 considered for the analysis. The cost of Urea and TSP fertilizers for the stated period at Fogera were Birr 13.1 and 14.3, respectively while the price of rice grain and straw were Birr 13.5 and 1.2, respectively.

Results and Discussion

The analysis of variance indicated that the main effect of nitrogen was highly significantly ($P<0.001$) affecting plant height, panicle length, total tillers/m, effective tillers/m, filled spiklets/panicle, grain yield, straw yield, thousand seeds weight and harvest index (Table 2). On the other hand, phosphorous was highly significantly ($P<0.001$) affecting grain and straw yields (Table 3). The interaction of nitrogen and phosphorous applications was highly significantly ($P<0.001$) affecting grain and straw yields and significantly ($P<0.005$) affecting harvest index (Table 3).

The comparison to the nitrogen rates indicated that the highest values of plant height (109.0 cm), panicle length (20.9 cm) number of total tillers/m (82.1), number of effective tillers/m (80.7), number of filled spiklets per panicle (102.9) (Table 3). In line with the present findings, Had reported that different level of N caused significant difference in plant height, the height of plant found to increase from 60 kg N^{-1} to 120 kg Nha^{-1}.

Concerning the yields, straw yield the highest (21.7 t ha^{-1}) were obtained at the highest rate of 368 kg N ha^{-1} while the rice highest grain yield (5.99 t ha^{-1}) was exhibited at the 276 kg N ha^{-1} rate, and the highest the thousand seeds weight (29.0 g) was at 184 kg N ha^{-1} (Table 3). Quite differently, the highest harvest index (34.51%) was observed at the no (0 kg N ha^{-1}) N rate (Table 3). The lower values for the respective parameters except for the harvest index were recorded at no (0kg N ha^{-1}). In the case of the harvest index the lowest score was at the maximum (368 kg N ha^{-1}) nitrogen rate (Table 3). Similar to the observations made at the study, reported for significant effect of N on straw yield mentioning that it was highest at N application of

180 kg/ha. Reporting significant responses of grain yield to N application, some authors observed highest rice grain yields at rates nearer to the current higher yielding rate (Nitrogen application increase the grain yield and largest values recorded at the nitrogen application treatment of 209 kg-220 kg N ha^{-1}. Highest mean grain yield of 10.5 t ha^{-1} at 300 kg ha^{-1} N treatment elaborating that as the N rates increased to 360 kg ha^{-1}, mean grain yield decreased to 9.4 t ha^{-1}. Optimum fertilizer level play an important role in achieving crops potential yield. Among the fertilizer, N is most important for proper growth and development of rice. The increase in grain yield might be due to nitrogen application enhancing the dry matter production, improving rice growth rate, promoting elongation of internodes and activity of growth hormones like gibberellins.

The only growth parameters which were significantly responding to the main effects of phosphorous application are grain and straw yields (Table 2). The highest grain (5.20 t ha^{-1}) and straw (15.2 t ha^{-1}) yields were obtained at the highest phosphorous (69 kg P_2O_5 ha^{-1}) rate (Table 4). The non-phosphorous application (0 kgP_2O_5 ha^{-1}) gave the lowest grain (4.00 t ha^{-1}) and straw yields (12.58 t ha^{-1}). The increase in P levels resulted in higher rice productivity (90>60−1>30>0 kg P ha^{-1}). The higher grain yield may be attributed due to better growth with higher nutrient availability and higher photosynthetic rate of the plants and more photosynthate partitioning into the reproductive parts. The response curve revealed that the grain yield of rice showed a declining trend after the application of 276 kg N ha^{-1} while the yield had a linear response to the phosphorous application and the maximum yield occurred at the maximum rate of 69 kg P_2O_5 ha^{-1} (Figure 2). This indicate that future rice fertilizer experiments in Fogera plain shall consider higher rates of phosphorous.

As revealed in the analysis of variance (Table 5), the grain yield, straw yield and harvest index responded significantly to the interaction effects of nitrogen and phosphorous (Table 2). The comparison to the grain yield indicated that the highest (7.00 t ha^{-1}) was gained at the combination of 276-69 N- P_2O_5 kg ha^{-1} which is statistically at par with the yields recoded at 368-69, 368-46, and 184-46 N- P_2O_5 kg ha^{-1} applications (Table 5). The lowest grain yield was at nill (0-0 N- P_2O_5 kg ha^{-1}) which is statistically equivalent with that of 0-23, 0-46, 0-69 N- P_2O_5 kg ha^{-1} applications (Table 5). Regarding the straw yield, the highest (23.16 t ha-1) was gained at the combination of 276-69 N-P_2O_5 kg ha^{-1} which is statistically at par with the straw yields shown at 368-69, 368-46, 184-46 and 368-23 N-P_2O_5 kg ha^{-1} applications (Table 5). The lowest straw yield of 4.11 t ha^{-1} was exhibited at no (0-0 N-P_2O_5 kg ha^{-1}) application which is statistically at par with that of 0-23, 0-46, 0-69 N- P_2O_5 kg ha^{-1} applications (Table 5). Management of soil fertility largely determines the availability of N and P for crop plants. Mineral nutrition in rice requires 16 essential elements of which nitrogen (N), phosphorus (P) and potassium (K) are applied to rice fields as chemical fertilizers in large quantities. Nitrogen and P are fundamental to crop development because they form the basic component of many organic molecules, nucleic acids and proteins.

The harvest index values comparison showed that the highest (23.16 t ha^{-1}) was gained at 0-0 N- P_2O_5 kg ha^{-1} which is statistically similar with the indices shown at 0-23, 0-46, 0-69 N- P_2O_5 kg ha^{-1} applications (Table 5). The lower harvest indices were associated with the combinations of the higher nitrogen and any of the phosphorous rates, the lowest (23.04 %) being at 276-69 N- P_2O_5 kg ha^{-1} (Table 5).

The analysis of the Agronomic Efficiency (AE) for the nitrogen indicate that the maximum AE of 15.43 was exhibited at 92 Kg ha^{-1} N (Table 6). As the N rate increased the AE was decreasing and finally a negative value of AE (-0.87) was recorded to the maximum (368 Kg ha^{-1}) n application. AE N is usually higher at low N rate than at high N rate. In tropical Asia, with proper crop and water management, AEN should be typically in the range of 20–25 kg kg^{-1}. Agronomic N use efficiency to be 15–25 kg rough rice per kg applied N in the tropics. Agronomic N use efficiency was 15 to 18 kg kg^{-1} N in the dry season in the farmers' fields in the Philippines. In China, agronomic N use efficiency was 15–20 kg kg^{-1} N from and declined to only 9.1 kg kg^{-1}. Since then, agronomic N use efficiency has further decreased in China because of the increase in N rate. Generally, fertilizer N use efficiency of lowland rice is relatively low due to loss of applied N through leaching, volatilization and denitrification in the soil-flood water system which necessitate the need for improved N fertilizer practices to reduce environmental impacts and increase economic benefits of N fertilization. The lower agronomic efficiency at the highest N rates in the current experiment indicate that emphasis should be given to efficient nitrogen application methods like the split applications, use of slow N releasing Fertilizer sources and real time N management so as to reduce the wastage of N in the rice production system of the Fogera plain.

Economic management of N fertilizer application is essential for improving crop productivity, N use efficiency, and environmental sustainability. Partial budget analysis method, grain and straw yield adjustments, calculations of Total Variable Costs (TVC), Gross Benefits (GB) and Net Benefits (NB) were performed (Table 7). Dominance analysis was carried after arranging the treatments in their order of TVC. A treatment will be considered as dominated if it has higher TVC but lower NB than a previous treatment with lower TVC and higher NB. Non dominated treatments were taken out and marginal rate of return (MRR) was computed (Table 8). According the to the CIMYYT partial budget analysis methodology, treatments exhibiting the minimum or more MRR (>100%) will be considered for the comparison of their NB. Highest NB (Birr 98,111.85/ha) with acceptable level of MRR (3499.15) was observed at 184-46 N-P2O5 kg/ha (Table 9). In agreement to the present finding reported that rice genotypes performed efficiently at 120 kg N+90 kg P_2O_5 ha^{-1} where highest paddy yield, net production value and profit were obtained. The combined application of nitrogen and phosphorous at 184-46 N-P_2O_5 kg/ha is the most profitable rate to be recommended for rice production in Fogera plain (Table 2).

N (kg/ha)	Plant height (cm)	Panicle length (cm)	Total tillers number/m	Effective tillers number/m	No of Fertile spiklets per panicle	Grain Yield (t/ha)	Straw Yield (t/ha)	TSW (G)	HI (%)
0	72.7D	17.0C	53.1D	51.6D	74.2C	2.14E	4.07E	30.45 BC	34.51 A
92	85.8C	19.5B	62.3C	60.7C	88.2B	3.56D	9.63D	30.99 AB	28.45 B
184	98.3B	20.2A B	71.4B	70.2B	98.6A	5.64C	17.28 C	31.65 A	25.64 C
276	107.2 A	20.6A	77.4A	75.7A	101.8 A	6.31A	20.67 B	30.30 BC	23.91 D

368	109.0A	20.9A	82.1A	80.7A	102.9A	5.99B	21.78A	29.83C	23.49D

Table 2: Main effect of nitrogen rates on rice yield and yield components.

P2O5 (kg/ha)	Grain Yield (t/ha)	Straw Yield (t/ha)
0	4.00C	12.58C
23	4.59B	14.41B
46	5.14A	16.5A
69	5.20A	15.26B

Table 3: Main effect of Phosphorous rates on rice grain and straw yields.

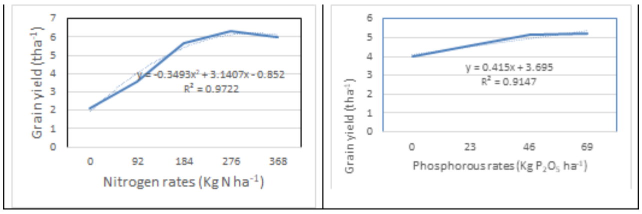

Figure 2: Response curves of rice grain yield (t ha^{-1}) to nitrogen and phosphorous application levels.

N	P		GY (t/ha)		SY (t/ha)		HI (%)
0	0		2.09H		4.11I		33.75A
92	0		3.03G		7.10H		30.50B
184	0		4.19E		13.77F		24.86D-G
276	0		5.31D		18.65D		22.60FG
368	0		5.36D		19.29D		22.03G
0	23		2.13H		3.74I		35.99A
92	23		3.76F		10.47G		27.58CD
184	23		5.53D		16.55E		25.46DEF
276	23		6.40BC		19.57CD		24.93D-G
368	23		5.15D		21.73AB		23.07FG
0	46		2.15H		4.16I		34.33A
92	46		3.79F		10.75G		26.49CDE
184	46		6.61ABC		22.33AB		24.81D-G
276	46		6.52BC		21.37BC		25.03D-G
368	46		6.63ABC		23.90A		24.82D-G
0	69		2.20H		4.25I		33.98A
92	69		3.76F		10.22G		29.24BC
184	69		6.22C		16.45E		27.40D
276	69		7.00A		23.16AB		23.04FG
368	69		6.83AB		22.21AB		24.03EFG
CV %			11.61		18.44		14.0

Table 4: Effects of N and P on lowland rice grain yield, straw yield and harvest index.

N (kg/ha)	Grain Yield (t/ha)	AE
0	2140	-
92	3560	15.43
184	5640	11.3
276	6310	2.43
368	5990	-0.87

Table 5: Agronomic Efficiency (AE) of rice.

N		P		TVC (Birr/ha)	GY (t/ha)	SY (t/ha)	AGY (t/ha)	ASY (t/ha)	GB (Birr/ha)	NB (Birr/ha)
0		0		0	2.09	4.11	1.881	3.699	29832.3	29832.3
92		0		2620	3.03	7.1	2.727	6.39	44482.5	41862.5
184		0		5240	4.19	13.77	3.771	12.393	65780.1	60540.1
276		0		7860	5.31	18.65	4.779	16.785	84658.5	76798.5
368		0		10480	5.36	19.29	4.824	17.361	85957.2	75477.2
0		23		865.52	2.13	3.74	1.917	3.366	29918.7	29053.2
92		23		3158.03	3.76	10.47	3.384	9.423	56991.6	53833.6
184		23		5778.03	5.53	16.55	4.977	14.895	85063.5	79285.5
276		23		8398.03	6.4	19.57	5.76	17.613	98895.6	90497.6
368		23		11018.03	5.15	21.73	4.635	19.557	86040.9	75022.9
0		46		1731.05	2.15	4.16	1.935	3.744	30615.3	28884.2

92		46		3696.05	3.79	10.75	3.411	9.675	57658.5	53962.4
184		46		6316.05	6.61	22.33	5.949	20.097	104427.9	98111.8
276		46		8936.05	6.52	21.37	5.868	19.233	102297.6	93361.5
368		46		11556.05	6.63	23.9	5.967	21.51	106366.5	94810.4
0		69		2596.58	2.2	4.25	1.98	3.825	31320	28723.4
92		69		4234.08	3.76	10.22	3.384	9.198	56721.6	52487.5
184		69		6854.08	6.22	16.45	5.598	14.805	93339	86484.9
276		69		9474.08	7	23.16	6.3	20.844	110062.8	100588.7
368		69		12094.08	6.83	22.21	6.147	19.989	106971.3	94877.2

Table 6: Grain and straw yield adjustments, total variable cost, gross and net benefit analysis.

N				TVC (Birr/ha)	NB (Birr/ha)	Dominance
0.0		0.0		0	29,832.30	
0.0		23.0		865.5263	29,053.17	D
0.0		46.0		1731.053	28,884.25	D
0.0		69.0		2596.579	28,723.42	D
92.0		0.0		2620	41,862.50	
92.0		23.0		3158.026	53,833.57	
92.0		46.0		3696.053	53,962.45	
92.0		69.0		4234.079	52,487.52	D
184.0		0.0		5240	60,540.10	
184.0		23.0		5778.026	79,285.47	
184.0		46.0		6316.053	98,111.85	
184.0		69.0		6854.079	86,484.92	D
276.0		0.0		7860	76,798.50	D
276.0		23.0		8398.026	90,497.57	D
276.0		46.0		8936.053	93,361.55	D
276.0		69.0		9474.079	100,588.72	
368.0		0.0		10480	75,477.20	D
368.0		23.0		11018.03	75,022.87	D
368.0		46.0		11556.05	94,810.45	D
368.0		69.0		12094.08	94,877.22	D

Table 7: Dominance analysis.

N		P		TVC (Birr/ha)	NB (Birr/ha)	MRR (%)
0.0		0.0		0	29,832.30	
92.0		0.0		2620	41,862.50	459.168
92.0		23.0		3158.026	53,833.57	2224.998
92.0		46.0		3696.053	53,962.45	23.953
184.0		0.0		5240	60,540.10	426.028
184.0		23.0		5778.026	79,285.47	3484.100
184.0		46.0		6316.053	98,111.85	3499.155
276.0		69.0		9474.079	100,588.72	78.431

Table 8: MRR analysis.

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