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Effects of Sources, Rate and Application Times of Nitrogen Fertilizer on Yield and Yield Components of Upland Rice (*Oryza sativa* L.) in Northwest Ethiopia

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Abstract: Nitrogen nutrient losses through ammonia volatilization, denitrification, surface runoff, and leaching are causing low nutrient use efficiency in agricultural systems. Split application of N and use of slow N nutrient releasing fertilizers are among the known methods of increasing nitrogen use efficiency (NUE). A field experiment was conducted in Fogera plain to study the productivity response of upland rice to different sources of N fertilizer, rates, and time of application on a total of five farmers' fields during the main cropping seasons of 2018 and 2019. The experiment was conducted using a factorial arrangement of two sources of N fertilizer (conventional urea and slow-release urea), three N rates (69, 103.5, and 138 kg ha^{-1}), and three times of application (T1=1/3 at planting, 1/3 at tillering and 1/3 at panicle initiation (PI), T2 = 1/3 15 days after sowing (DAS), 1/3 at PI and 1/3 at heading, T3 = 1/3 15 DAS and 2/3 at PI laid out in a randomized complete block design with three replications. Phosphorous at rate of 46 kg P_2O_5 ha^{-1} was commonly applied at planting for all treatments. The commonly grown NERIC-4 variety was used as a test crop. The results of the experiment showed that the rates and time of N applications were significantly affecting most of the parameters. However, the different N source fertilizers as well as all interactions of the treatments did not bring statistically significant difference in all the growth and yield parameters. Regarding the rates, the highest plant height (77.35 cm), fertile tillers number (70.37 m^{-1} row), grain yield (5.3 t ha^{-1}) and straw yield (10.0 t ha^{-1} were obtained when 138 N kg ha^{-1} was applied. Concerning the N application timing, the highest plant height (77.5 cm), grain yield (4.9 t ha^{-1}), straw yield (9.6 t ha^{-1}) and thousand seeds weight (28.9 g) and the lowest number of infertile tillers (1.83 m^{-1} row) were observed when 1/3 of N was applied 15 DAS and the remaining 2/3 at PI. Therefore, 138 kg ha^{-1}, of commercially available urea with an application time of 1/3; 15 DAS and 2/3 at PI can be used to produce NERICA-4 upland rice in Fogera plain and similar Agro-ecologies in Ethiopia.

Keywords: Nitrogen, N Sources, Upland Rice

1. Introduction

Rice (*Oryza sativa*) is one of the most important cereal crops of the world, grown in wide range of climatic zones, to nourish the humankind. The crop is part of the diet of half the world population [3]. Rice is mostly grown in Asia under irrigation by flooding. However, the reduced availability of water for irrigation, due to increased industrial and human consumption, has demanded the search for alternatives that enable rice cultivation with greater water saving. As an alternative, there is the cultivation of rice in the upland ecosystem, which can be sprinkle irrigated or rain-fed, depending on rainwater distribution [3]. In Ethiopia, rice production was started three decades ago in the early 1970s and the country has reasonable potential to grow various rice types mainly in rain-fed lowland, upland, and irrigated ecosystems [18]. Although rice is a recent introduction to the country, its importance is well recognized as the production area coverage of about 10,000 ha in 2006 has increased to over 63,000 ha in 2018 [7]. Upland rice could suitably grow in many parts of the country, and the predominant potential areas include west central highlands of Amhara region (Fogera, Gondar Zuria, Dembia, Takusa and Achefer), Northwest lowlands of Amhara region (Metema) [2]. The national average yield of rice is about 2.8 t ha^{-1} [7] which is lower compared to the world average productivity of 4.6 t ha^{-1} [12]. Poor soil fertility is among the major factors limiting rice production in Ethiopia [14]. In the upland rice ecosystem, fertilization management, mainly with N, can provide significant increase in rice grain yield [3].

Nitrogen is one of the most dynamic nutrients in the soil [3]. The low efficiency of the agronomical use of this nutrient, observed in most agricultural systems, is due to rapid N losses from ammonia volatilization, denitrification, surface runoff, and leaching in the soil-flood water system [15, 3]. The efficiency of N use and loss processes in the soil plant system have not only economic consequences but also environmental ones [3]. Significant environmental problems (i.e., soil acidification, air pollution, water eutrophication) occurred due to N [15].

Worldwide, urea is the most used N fertilizer for rice (*Oryza sativa* L.) production [20, 3]. This fertilizer has several advantages, such as: lower price per unit of N; high concentration of N, which reduces the cost of transportation, and application; high solubility; lower corrosivity; compatibility with a large number of other fertilizers and pesticides; and high rate of foliar absorption [3]. However, the main disadvantage of urea is the high possibility of loss by volatilization of NH_3. When applied to the soil, urea suffers rapid enzymatic hydrolysis to NH_4^+; can lead to substantial NH_3 volatilization losses [20, 3].

Most upland rice growing farmers cannot flood their fields within a few days following urea fertilizer application. In a situation when the farmer cannot flood in a timely manner after the pre flood N application, it would seem prudent to use an N source less prone than urea to NH_3 volatilization loss. Various modifications have been made in fertilizers containing urea to produce losses by volatilization and to increase their use efficiency. To aid N management, cropping sensor-based technology such as soil plant analysis development or Device (SPAD) is one of the best strategies for efficient application of nutrients [6]. However, SPADS are mostly costly and are too technical to farmers and use of controlled nutrient releasing fertilizers is found feasible. Among the different sources of N fertilizers, slow-release urea, and urea supper granule (USG) have the potential to increase the productivity of rice [9, 17, 5]. Using appropriate N fertilizer sources is important for improving N use efficiency of crop plants [10]. Such practice increases not only yield, but also reduces cost of production and environmental pollution.

There are still few studies in the literature that demonstrate the effects of applying slow N nutrient releasing fertilizers for upland rice [3, 1]. Thus, the aim of this study was to determine appropriate N nutrient sources in relation to rates and time of Nitrogen application on yield and yield components of upland rice (NERICA-4) production in Fogera Plain.

2. Materials and Methods

The experiment was conducted for two consecutive cropping seasons in the years 2018 and 2019 at Fogera, Northwest Ethiopia, on five farmers' fields. The study at Fogera area is situated at 11° 54.4' 46.3" N to 11° 57' 03.3" N latitude and 37° 41' 23.9"E to 37° 42' 32.2"E longitude at elevation range of 1787-1812 m.a.s.l. The study site has minimum and maximum temperatures of 12.75°C and 27.37°C, respectively. The area receives average mean annual rainfall of 1219mm. The long-term rainfall data (1986 - 2019) years indicated that much of the rainfall appear in June and September. It has a heavy clay soil 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 the range of 0.09 - 0.16%, which is classified as low levels (0.02 - 0.5%) for tropical soils. The organic matter content of the soil was between 2.13 - 3.09%, which was within a range of medium (2 - 4%) for Ethiopian soils per criteria developed by [19]. The available P content of the experimental sites soil was 11.4 - 25.13 ppm, which lies in a range of deficiency (< 20 - 40 ppm) for most crops [16].

Table 1. *Relevant soil physio-chemical properties of the experimental field before planting in Fogera Plain of Northwest Ethiopia.*

Soil properties	Units	Minimum Value	Maximum Value
Textural class		Heavy clay	Heavy clay
Chemical properties			
pH (H_2O) 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

The experiment were comprised of factorial combinations of two N-source (UREA-stable and common-UREA), three level of N – rates (69, 103.5, and 138 kg ha^{-1}), and three times of N application (T1 = 1/3 at planting, 1/3 at tillering, and 1/3 at PI, T2 = 1/3 15 DAS, 1/3 at PI and 1/3 at heading, T3 = 1/3 15 DAS, 2/3 at PI) tested in randomized complete block design with three replications. Phosphorous at rate of 46 kg P_2O_5 ha^{-1} was applied at planting for all treatments. The rice was drill planted in row at a spacing of 20 cm with a seed rate of 100 kg ha^{-1}. The gross and net plot sizes were 3 m × 4 m and 2.2 m × 3 m, respectively. The commonly grown NERICA-4 variety was used as a test crop.

Data were collected for plant height, panicle length, number of total tillers/m^2, number of effective tillers/m^2, number of fertile spikes /panicles, thousand seeds weight, grain yield, straw yield, aboveground biological yield, and harvest index. The plant height was taken at physiological maturity of the crop by selecting five random tillers. Number of tillers was counted just before harvesting by random sampling using ruler. The total sundried biomass of the harvested rice was recorded before threshing. The harvested index was calculated as the ratio of grain yield to biological yield following the equation.

$$\text{Harvested index} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100 \qquad (1)$$

The paddy rice yield and thousand seeds weight were adjusted at 14 % moisture content.

3. Data Analysis

All collected data were subjected to analysis of variance (ANOVA) using SAS software version 9.2 (SAS-Institute, 2008). 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 N source and rates by year interaction. Wherever treatment differences are be found significant, mean separation of treatments was calculated based on results of F- test and probability levels of 0.01 and 0.05 depending on the results of the ANOVA.

4. Results and Discussion

The analysis of variance indicated that the rates and time of nitrogen applications were significantly affecting most of the parameters. However, the different nitrogen fertilizers source as well as all interactions of the treatments did not bring statistically significant difference in all the considered growth and yield parameters (Table 2). Though literatures [4, 20, 8, 1] stated significant effects of slow releasing N nutrient sources on yield and yield components, [3, 5] have reported non-significant effects in line with the present finding. The findings of [5] had reported that though there was non-significant difference between N sources, the ranking of treatments showed that ordinary urea fertilizer applied in splits (50% at pre plant and other 50% at the tillering stage) produced better grain and biomass yields compared to single dose application of controlled-release N fertilizer all at rate of 108 N kg ha^{-1}. Furthermore, the works of [3] which was done on upland rice concerning different nitrogen sources indicated that coated slow releasing urea did not provide increases in rice grain yield in relation to common urea. This fact shows that the coated urea sources behave similarly to common urea in some situations. A possible explanation for this lack of results could be the rains that occurred shortly after the application of the nitrogen fertilizers. This rain condition up to three days after nitrogen fertilization with urea is considered ideal to obtain better efficiency of N applied at topdressing, since N losses are minimal regardless of the source or form of the nitrogen fertilizer [3]. Thus, the conditions where rain incorporating urea, the choice of what source of N would be used will depend on the price. In this case, common urea is advantageous over the other nitrogenous fertilizers evaluated. Likewise, [11] found no differences in rice when using common urea and urea coated with polymer. Thus, according to these authors, the use of coated urea appears feasible only in places with risk of dry spells greater than nine days after the completion of nitrogen topdressing [3].

The variation in nitrogen rates brings highly ($p < 0.01$) significant differences in plant height, number of infertile tillers, grain yield and straw yield. Moreover, the nitrogen rate showed significant ($p < 0.05$) differences in the number of tillers. The time of application was highly significantly ($p < 0.01$) affecting plant height, number of infertile tillers, grain yield, straw yield and thousand seeds weight, while it was significantly ($p < 0.05$) affecting the harvesting index (Table 4). Plant height reveals the overall vegetative growth of the crop in response to various management practices. It was found that application of N fertilizers increased the plant height significantly, but maximum plant height (77.35 cm) was obtained when N was applied at maximum rate of 138 kg N ha^{-1} (Table 3). It was also reported increased level of leaf N with applied N bring an increase in plant height of rice [4]. The increase in plant height in response to application of N fertilizers is probably due to enhanced availability of nitrogen which enhanced more leaf area resulting in higher photo assimilates and thereby resulted in more dry matter accumulation.

Regarding the number of tillers, highest fertile tillers number (70.37 m^{-1} row); while the lowest number of infertile tillers (2.57 m^{-1} row) were observed with the application of the maximum N rate (Table 3). Number of tillers per unit area is the most key component of yield. More the number of tillers, especially fertile tillers, the more will be the yield. More number of tillers/m^2 in experiment might be due to the more availability of nitrogen that played a vital role in cell division. The current result is in accordance with the findings of [4, 3]. According to [4], as the amount of nitrogen absorbed by the crop increases, there is an increase in the number of tillers per square meter. Concerning the yield parameters, highest grain yield (5.3 t ha^{-1}) and straw yield (10.0 t ha^{-1}) were obtained from the highest rate (138 N kg ha^{-1}) (Table 3). In agreement with the current finding, [20] had reported that rice grain yields increased as N fertilizer rate increased for all the N sources. It had also reported an increase in grain and biomass yields with an increase in N rates irrespective of nitrogen sources [5]. Grain yield results for the different N rates reflect that the total N uptake is quite well [20].

Concerning the nitrogen application timing, highest plant height (77.5 cm), grain yield (4.9 t ha^{-1}), straw yield (9.6 t ha^{-1}) and thousand seeds weight (28.9 g) and lowest number of infertile tillers 1.83 m^{-1} row) were observed when 1/3 of the nitrogen was applied 15 days after sowing (DAS) and the remaining 2/3 at panicle initiation (PI) (Table 4). The highest harvested index (38.98%) was exhibited when nitrogen was applied 1/3 at planting + 1/3 at tillering + 1/3 at panicle initiation (PI) (Table 4). Similar to the current findings, [13] observed that highest plant, number of productive tillers and grain yield was obtained when nitrogen was applied 1/2 of the dose at planting time, and the rest administered 42 days after planting than applying the N full dose at planting. Corroborating these results, [5] also reported highest rice spikelets per panicle, grain yield, grain weight and total biomass when the ordinary urea fertilizer was applied as a split application at two rice developmental stages: one (50%) at planting and other (50%) at the tillering stage than the one-time application of ordinary urea and controlled - release fertilizers. [5] have further elaborated that there were no significant difference between N use efficiency indices of the common urea split applied and the single dose application of the controlled release fertilizers.

5. Conclusion and Recommendations

Low nitrogen use efficiency (NUE) is observed in most agricultural systems due to rapid nitrogen losses through ammonia volatilization, denitrification, surface runoff, and leaching. Split application of N and use of slow N nutrient releasing fertilizers are among the known methods of increasing NUE. The current experiment was conducted in Fogera plain to determine appropriate N nutrient sources in relation to rates and time of Nitrogen fertilizer application on yield and yield components of upland rice (NERICA-4) production. The results of the experiment indicated that the split application of common urea was better than the single dose application of slow releasing urea. It is finally recommended that the urea should be used at the rate of 138 kg N ha^{-1} with 1/3 of the N applied 15 days after sowing and the remaining 2/3 at panicle initiation to produce upland rice in the study area.

Table 2. *Mean square values of analysis of variance (ANOVA) for rice yield and yield components.*

VARIATION	DF	PH (CM)	PL (CM)	NT/MRL	NFT/MRL	NIT/MRL	NFG/P	NUG/P	GY	SY	TSW	HI
LOC	3	280.58**	197.22**	442.94*	316.94ns	3.617ns	13175.28**	88.82**	92.98**	1690.05**	320.82**	4327.68**
NR	2	412.51**	87.50ns	341.33ns	580.21*	18.143**	252.44ns	32.32ns	22.04**	42.16**	6.52ns	19.04ns
SN	1	0.819ns	55.30ns	263.46ns	591.25*	0.254ns	1.86ns	52.72ns	0.19ns	4.66ns	4.46ns	13.53ns
REP	2	44.405ns	35.35ns	120.60ns	230.49ns	14.889ns	364.51ns	2.01ns	0.67ns	5.16ns	9.38ns	27.41ns
TAN	2	623.59**	9.034ns	264.17ns	148.97ns	67.907**	244.62ns	19.85ns	6.28**	8.15**	44.98**	126.29*
LOC*NR	6	51.10*	30.71ns	113.37ns	101.88ns	3.636ns	159.12ns	31.37ns	0.59ns	6.15ns	2.89ns	19.88ns
LOC*SN	3	33.53ns	52.00ns	177.27ns	198.91ns	1.136ns	774.55ns	4.74ns	0.12ns	1.81ns	7.07ns	18.08ns
LOC*REP	4	187.52**	22.36ns	33.34ns	25.59ns	2.713ns	105.32ns	11.42ns	2.66ns	3.87ns	4.36ns	16.15ns
LOC*TNA	4	38.95ns	17.77ns	128.66ns	92.90ns	5.092ns	231.32ns	28.48ns	0.78ns	2.10ns	0.48ns	30.09ns
NS*NR	2	24.21ns	42.91ns	168.17ns	296.17ns	8.366ns	167.97ns	13.10ns	0.201ns	0.21ns	3.41ns	14.73ns
NR*REP	4	37.65ns	43.97ns	171.62ns	189.10ns	0.611ns	122.73ns	26.94ns	0.38ns	0.56ns	3.93ns	4.503ns
NR*TNA	4	26.47ns	59.52ns	334.69ns	296.75ns	0.880ns	282.56ns	23.68ns	0.233ns	1.61ns	5.45ns	11.82ns
NS*REP	2	3.922ns	25.21ns	1173.30ns	915.57**	2.296ns	628.06ns	11.70ns	0.025ns	1.01ns	3.13ns	7.63ns
NS*TNA	2	30.98ns	40.38ns	267.95ns	115.57ns	2.018ns	151.12ns	47.48ns	0.52ns	2.19ns	14.78ns	37.12ns
TNA*REP	4	4.451ns	50.89ns	188.85ns	201.13ns	4.852ns	657.99ns	21.96ns	0.17ns	0.55ns	1.7ns	4.27ns
LOC*SN*NR	6	68.90**	16.01ns	251.73ns	163.13ns	4.341ns	479.46ns	15.32ns	0.79ns	0.86ns	2.44ns	29.59ns
LOC*NR*REP	8	13.09ns	48.08ns	154.23ns	205.91ns	2.685ns	211.09ns	8.28ns	0.24ns	1.52ns	3.07ns	6.01ns
LOC*NR*TNA	8	23.22ns	61.45ns	46.14ns	58.06ns	2.065ns	185.08ns	7.75ns	0.40ns	1.23ns	5.48ns	14.80ns
LOC*SN*REP	4	21.78ns	25.50ns	404.69ns	553.12**	5.731ns	426.01ns	10.08ns	0.12ns	2.45ns	4.39ns	36.88ns
LOC*SN*TNA	4	6.19ns	21.44ns	218.92ns	362.17ns	2.592ns	125.75ns	16.63ns	0.59ns	0.83ns	4.00ns	21.16ns
LOC*TNA*REP	8	22.03ns	59.72ns	78.99ns	147.14ns	5.1759ns	416.08ns	25.68ns	0.25ns	0.90ns	8.10ns	18.61ns
SN*NR*REP	4	15.20ns	37.35ns	66.348ns	59.41ns	2.592ns	372.86ns	49.88ns	1.12ns	0.62ns	11.76ns	10.038ns
SN*NR*TNA	4	32.45ns	42.31ns	252.81ns	161.31ns	0.592ns	62.58ns	30.76ns	0.61ns	4.53ns	8.10ns	41.08ns
NR*TNA*REP	8	10.48ns	43.56ns	103.89ns	99.51ns	3.379ns	420.67ns	12.74s	0.27ns	2.28ns	6.43ns	18.70ns
SN*TNA*REP	4	31.33ns	40.53ns	81.66ns	88.26ns	0.815ns	336.42ns	3.72ns	0.45ns	1.33ns	6.76ns	7.34ns
ERROR	104	19.45	36.14	152.56	150.23	3.10	321.80	15.00	0.76	2.50	4.34	21.34
CV%		5.6	23.5	17.35	18.0	18.86	20.35	24.85	18.6	17.08	7.37	12.32
SE+		4.41	6.01	12.35	12.25	1.76	17.94	3.87	0.873	1.581	2.08	4.62

Note: DF = Degrees of Freedom, Nr = Nitrogen rate, SN = Source of Nitrogen, TNA = Time of nitrogen application, ** = significant at 1% probability level, * significant at 5% probability level, NS = non-significant.

Table 3. *Main effect of nitrogen rates on rice growth parameters.*

N rate (kg ha^{-1})	Plant height (cm)	Number of fertile tillers (m^{-1} row)	Number of infertile tillers (m^{-1} row)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
69	75.26^{b}	64.29^{b}	3.44^{a}	4.06^{c}	8.45^{c}
103.5	77.35^{c}	69.52^{a}	2.95b^{a}	4.70^{b}	9.28^{b}
138	77.35^{a}	70.37^{a}	2.56^{b}	5.28^{a}	10.02^{a}
CV (%)	5.6	18.0	18.86	18.6	17.08
SE+	4.41	12.25	1.76	0.87	1.58

Table 4. *Main effect of nitrogen application times on rice growth parameters.*

N application time	PH	NIT	GY	SY	TSW	HI
1/3 at planting + 1/3 at tillering + 1/3 at PI	72.05^{c}	3.486^{a}	4.7465^{a}	9.2618^{ab}	27.7903^{b}	38.98^{a}
1/3 15DAS + 1/3 at PI + 1/3 at heading	75.24^{b}	3.65^{a}	4.3724^{b}	8.8769^{b}	28.0069^{b}	36.83^{b}
1/3 15DAS + 2/3 at PI	77.54^{a}	1.83^{b}	4.9285^{a}	9.6261^{a}	28.8972^{a}	36.70^{b}
CV (%)	5.6	18.86	18.6	17.08	7.37	12.32
SE+	4.41	1.76	0.87	1.58	2.08	4.62

Note: PH = Plant height (cm), NIT = Number of infertile tillers (m^{-1} row), GY= Grain yield (t ha^{-1}), SY =Straw yield (t ha^{-1}), TSW = Thousand seeds weight (g), HI = Harvested Index (%).

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