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Effect of Nitrogen Application on Grain Yield and Nitrogen Efficiency of Rice (*Oryza sativa* L.)

[1]Endris Yesuf and [2]Alemayehu Balcha

[1]Gambella Agricultural Research Institute, P.O. Box 62, Gambella, Ethiopia

[2]Department of Plant Science, College of Agriculture, Wolaita Sodo University, P.O. Box 138, Wolaita Sodo, Ethiopia

Corresponding Author: Alemayehu Balcha, Department of Plant Science, College of Agriculture, Wolaita Sodo University, P.O. Box 138, Wolaita Sodo, Ethiopia

ABSTRACT

In Ethiopia, rice (*Oryza sativa* L.) grain yield is low party due to low nitrogen fertility status of the soil. An experiment was conducted from August to November, during main rainy season of 2010, in Gambella, Ethiopia, to determine grain yield and yield components and N efficiency responses of rice to five N rates (0, 3.5, 7, 10.5, 14 g m^{-2}) in factorial combinations with three sowing methods (drilling, dibbling and broadcast) in a randomized complete block design with three replications using commonly grown rice variety, nerica-4. Grain yield increased from 302-469 g m^{-2}, total biomass 786-1268 g m^{-2}, tillers 477-661 m^{-2}, panicles 456-612 m^{-2} and filled grains/panicle 80-100 when N rate increased from 0-14 g m^{-2}. Maximum values for panicles (621 m^{-2}) and filled grains/panicle (110) and that for grain yield (510 g m^{-2}) were obtained at 7 and 10.5 g m^{-2} N rate, respectively. With the increase in N rate from 0-14 g m^{-2}, grain N concentration increased from 1.44-1.53%, straw N concentration 0.79-0.93%, total grain N 4.36-7.18 g m^{-2}, total straw N 3.82-7.45 g m^{-2} and total plant N 8.18-14.63 g m^{-2}. Maximum values for grain N concentration (1.58%) and total grain N (8.04 g m^{-2}) and total plant N (14.81 g m^{-2}) were obtained at 10.5 g m^{-2} N rate. Agronomic efficiency decreased from 29 -12, apparent recovery 0.76-0.46 and physiological efficiency 38-26 when N rate increased from 3.5-14 g m^{-2}. The present experiment suggests that soil nitrogen content should be considered in N fertilization recommendations.

Key words: Nitrogen, grain yield, agronomic efficiency, apparent recovery, rice (*Oryza sativa*)

INTRODUCTION

Rice (*Oryza sativa* L.) cultivation in Ethiopia occupies over 47,798 ha of land, producing over 103,128 tons of grain per year (CSA, 2010). However, its yield is low (less than 2.16 tons/ha) (CSA, 2010) partly due to low soil nitrogen fertility status of the country (MoARD, 2010). In Ethiopia, almost all soils are deficient in nitrogen (Woldeab *et al.*, 1991) indicating that adequate N fertilizer supply is necessary to maximize rice yield.

Nitrogen is a constituent of amino acids, proteins, nucleic acids and chlorophyll (Mengel and Kirkby, 1987). Thus, both vegetative and reproductive phases of growth are highly dependent on adequate N supply. Several studies have shown that grain yield of rice is responsive to N supply because N nutrition increases leaf area index (Salem, 2006; Salem *et al*., 2011), leaf chlorophyll content (Salem *et al*., 2011) and nutrient uptake (Hussaini *et al*., 2008) of the plants. However, application of excess N fertilizer beyond crop demand leads to environmental pollution because of N loss through leaching, volatilization, denitrification and soil erosion (Mengel and Kirkby, 1987).

N efficiency can be expressed as nitrogen use efficiency, the ratio of grain yield to the N supply and its components: uptake efficiency (the ratio of total plant N to N supply) and utilization efficiency (the ratio of grain yield to total plant N) (Moll *et al*., 1982). It can also be expressed in terms of agronomic efficiency and its components: apparent recovery and physiological efficiency by using the ratios of differences in grain yield, nitrogen uptake and N supplies between fertilized and unfertilized plots (Mengel and Kirkby, 1987). Agronomic efficiency for cereals is estimated to be 42 and 29% in developed and developing nations, respectively (Raun and Johnson, 1999) and that of apparent recovery of applied N is usually between 30-50% and at low rates of N or in well managed systems it reaches 50-80% (Dobermann, 2005). Because the information on rice response to N application is limited in Ethiopia, this experiment was conducted to determine grain yield and yield components and N efficiency of rice at different N rates.

MATERIALS AND METHODS

This experiment was conducted from August to November, during main rainy season of 2010, in Gambella, Ethiopia. Gambella is located at 8°15'N and 34°35'E at altitude of 526 m above sea level. It has the average annual rainfall of 1021 mm and average minimum and maximum temperature of 20.1 and 35.7°C, respectively. For the experimental period of August to November, 2010, mean monthly rainfall was 154 mm and the mean minimum and maximum temperature was 20.7 and 33.7°C, respectively. The analysis of soil at 0-30 cm depth for the experimental field gave pH 6.50 (in H_2O), total N 0.16%, organic carbon 1.79%, CEC 27.40 meq 100 g^{-1}, available P 20.0 ppm (Olsen) and clay texture (clay 43%, silt 36% and sand 21%).

Factorial combinations of five nitrogen rates (0, 3.5, 7, 10.5 and 14 g m^{-2} N) and three sowing methods (drilling, dibbling and broadcast) were laid out in a randomized complete block design with three replications. The commonly grown rice variety, nerica-4, was planted at recommended seeding rate of 70 kg ha^{-1} on August 1, 2010, on a plot of 2×2 m^2. Drilling and dibbling were done on 10 rows separated by 20 cm between rows while uniform seed distribution was maintained for broadcast plots. For dibbling eight seeds were planted at each hill separated by 12.5 cm between hills. The distance between replications was 1 m and that between plots was 50 cm. Half of nitrogen was applied at planting time and the remaining half was applied at panicle initiation stage in the form of urea and 46 kg ha^{-1} P_2O_5 in the form of triple superphosphate was applied at the time of planting. Weeds were controlled with frequent hand weeding throughout the experiment.

Days to flowering and maturity, plant height (average for five random plants at maturity), filled grains/panicle (average for five random panicles) and 1000 seed weight were recorded. Number of tillers and panicles m^{-2} were counted using 50×50 cm quadrant placed at the centre of the plot. The whole plot was harvested to determine grain yield, straw yield and total biomass at maturity. The grain yield was adjusted to 14% seed moisture and straw samples were sun-dried to constant weight before estimating straw yield and total biomass.

Determination of nitrogen efficiency: Grain and straw nitrogen concentration was determined by Kjeldahl method (Bremner, 1965) and was used to estimate nitrogen uptake in grain, straw and total biomass. Nitrogen efficiency was calculated according to Mengel and Kirkby (1987) as:

$$\text{Agronomic efficiency (AE)} = \frac{\text{GYf} - \text{GYc}}{\text{Ns}}$$

$$\text{Apparent recovery (AR)} = \frac{\text{Nf} - \text{Nc}}{\text{Ns}}$$

$$\text{Physiological efficiency (PE)} = \frac{\text{GYf} - \text{GYc}}{\text{Nf} - \text{Nc}}$$

where, GYf and GYc are grain yield of the fertilized and control plots, respectively; Nf and Nc are nitrogen uptake of the fertilized and control plots, respectively; Ns is the nitrogen fertilizer supply. All grain yield and yield components as well as N efficiency data were analyzed using SAS software (SAS, 1996).

RESULTS

Grain yield and yield components: The effect of N was significant for days to flowering and maturity, grain filling period, plant height, tillers m^{-2}, panicles m^{-2}, filled grains/panicle, 1000 seed weight, grain yield, straw yield, total biomass and harvest index except establishment count. The effect of sowing method except for establishment count and sowing method×N interaction effect except for plant height were not significant for the above parameters (Table 1).

The average establishment count (data were not shown) for drilling, dibbling and broadcast sowing was 209, 210 and 170, respectively. Grain yield increased from 302 - 469 g m^{-2}, straw yield 484 - 798 g m^{-2}, total biomass 786-1268 g m^{-2}, tillers 477-661 m^{-2}, panicles 456-612 m^{-2} and filled grains/panicle 80-100 when N rate was increased from 0-14 g m^{-2}. Maximum values for panicles (621 m^{-2}) and filled grains/panicle (110) and that for grain yield (510 g m^{-2}) were obtained at 7 and 10.5 g m^{-2} N rates, respectively. Similarly, the maximum increase in grain yield, straw yield and total biomass was obtained between 0 and 3.5 g m^{-2} N rates and that for tillers, panicles and filled grains/panicle was between 3.5 and 7 g m^{-2} N rates. The difference between 10.5 and 14 g m^{-2} N was not significant for days to flowering and maturity, grain

Table 1: Significance of F-ratios of 13 grain yield and yield components of rice across 5 N rates and 3 sowing methods

Sources of variation	d.f	DTF	DTM	GFP	EsC	PHT	NT	NP	FGP	SW	GY	SY	TB	HI
Replication	2	7.92**	1.44ns	5.30*	0.01ns	1.06ns	7.78**	4.97*	0.65ns	0.08ns	0.26ns	0.65ns	0.62ns	0.22ns
Sowing method (SM)	2	0.54ns	0.21ns	0.41ns	1524**	2.55ns	2.63ns	0.24ns	0.03ns	0.55ns	0.67ns	0.03ns	0.21ns	0.75ns
Nitrogen (N)	4	72.19**	134.41**	6.43**	1.01ns	39.73**	49.20**	14.64**	18.98**	14.90**	61.39**	47.31**	67.46**	10.67**
SM×N	8	0.25ns	1.15ns	0.88ns	0.45ns	5.29**	1.48ns	0.87ns	0.80ns	0.75ns	0.90ns	0.51ns	0.64ns	1.12ns
Error	28	0.29	0.32	0.71	5.04	3.60	1301	4630	68.68	0.82	1043	2989	5536	0.0004
CV(%)		0.85	0.59	2.52	1.14	1.57	6.12	12.28	8.50	3.25	7.44	8.35	6.83	4.76

DTF: Days to flowering, DTM: Days to maturity, GFP: Grain filling period, EsC: Establishment count, PHT: Plant height (cm), NT: No. of tillers m^{-2}, NP: No. of panicles m^{-2}, FGP: Filled grains/panicle, SW: 1000 seed weight (g), GY: Grain yield (g m^{-2}), SY: Straw yield (g m^{-2}), TB: Total biomass (g m^{-2}), HI: Harvest index (grain yield/total biomass), *,** = Signigicant at $p<0.05$ and $p<0.01$, respectively, ns: Not significant

Table 2: Mean values for 12 grain yield and yield components of rice at 5 N rates across 3 sowing methods

N rate (g m^{-2})	DTF	DTM	GFP	PHT	NT	NP	FGP	SW	GY	SY	TB	HI
0	62	94	32	115	477	456	80	27	302	484	786	0.38
3.5	62	95	33	119	522	462	92	27	402	582	983	0.41
7	62	96	33	121	634	621	110	29	487	667	1154	0.42
10.5	65	99	34	124	653	620	106	29	510	743	1253	0.41
14	65	99	34	125	661	612	100	27	469	798	1268	0.37
Mean	63	96	33	121	589	554	97	28	434	655	1089	0.40
$LSD_{0.05}$	0.52	0.55	0.81	1.83	35	66	8.00	0.87	31	53	72	0.02

DTF: Days to flowering, DTM: Days to maturity, GFP: Grain filling period, PHT: Plant height (cm), NT: No. of tillers m^{-2}, NP: No. of panicles m^{-2}, FGP: Filled grains/panicle, SW: 1000 seed weight (g), GY: Grain yield (g m^{-2}), SY: Straw yield (g m^{-2}), TB: Total biomass (g m^{-2}), HI: Harvest index (grain yield/total biomass)

Table 3: Significance of F-ratios for 9 N concentration, uptake and efficiency parameters of rice across 5 N rates and 3 sowing methods

Sources of variation	d.f	GN	SN	TGN	TSN	TN	NHI	d.f	AE	AR	PE
Replication	2	0.62ns	3.80*	0.64ns	3.42*	2.29ns	0.88ns	2	1.91ns	0.21ns	5.27*
Sowing method (SM)	2	0.46ns	0.22ns	1.00ns	0.16ns	0.75ns	0.74ns	2	0.27ns	0.48ns	2.14ns
Nitrogen (N)	4	10.39**	24.66**	67.96**	94.71**	107.61**	16.13**	3	30.07**	20.71**	11.00**
SM×N	8	0.44ns	0.14ns	0.68ns	0.59ns	0.68ns	1.08ns	6	0.60ns	0.77ns	0.47ns
Error	28	0.003	0.001	0.29	0.20	0.68	0.0004	22	16.77	0.010	22.13
CV (%)		3.34	4.21	8.16	7.82	6.65	3.84		18.85	14.77	14.60

GN: Grain N concentration (%), SN: Straw N concentration (%), TGN: Total grain N (g m^{-2}), TSN: Total straw N (g m^{-2}), TN: Total plant N (g m^{-2}), NHI: Nitrogen harvest index (total grain N/total plant N), AE: Agronomic efficiency, AR: Apparent recovery, PE: Physiological efficiency, *,** = Signigicant at $p<0.05$ and $p<0.01$, respectively, ns: Not significant

filling period, plant height, filled grains/panicle and total biomass whereas the difference between 7 and 14 g m^{-2} N was not significant for tillers and panicles m^{-2}. Moreover, the difference between 7 and 10.5 g m^{-2} N was not significant for filled grains/panicle, 1000 seed weight and harvest index. Grain yield, 1000 seed weight and harvest index decreased significantly with the increase in N rate from 10.5-14 g m^{-2} (Table 2).

N concentration, uptake and efficiency: The effect of N was significant for grain and straw N concentration and uptake and total plant N, nitrogen harvest index, agronomic efficiency, apparent recovery and physiological efficiency. However, the effect of sowing method and that of sowing method×N interaction were not significant for these parameters (Table 3).

Grain N concentration ranged from 1.44-1.53%, straw N 0.79-0.93%, total grain N 4.36-7.18 g m^{-2}, total straw N 3.82-7.45 g m^{-2} and total plant N 8.18-14.63 g m^{-2}. Maximum values for grain N concentration (1.58), total grain N (8.04) and total plant N (14.81) were obtained at 10.5 g m^{-2} N. Maximum increase in N concentration and uptake was obtained between 3.5 and 7 g m^{-2} N and the decline in total grain N and nitrogen harvest index with the increase in N rate from 10.5-14 g m^{-2} N was significant. Agronomic efficiency decreased from 29-12, apparent recovery 0.76-0.46 and physiological efficiency 38-26, with the increase in N rate from 3.5-14 g m^{-2}. Such decrease was significant for agronomic efficiency and apparent recovery when N rate increased from 7-14 g m^{-2} and for physiological efficiency when N rate increased from 10.5-14 g m^{-2} (Table 4).

Table 4: Mean values of N concentration, uptake and efficiency parameters of rice at 5 N rates across 3 sowing methods

N rate (g m^{-2})	GN	SN	TGN	TSN	TN	NHI	AE	AR	PE
0	1.44	0.79	4.36	3.82	8.18	0.53			
3.5	1.50	0.83	6.01	4.82	10.83	0.56	29	0.76	38
7	1.57	0.90	7.66	6.00	13.66	0.56	27	0.78	34
10.5	1.58	0.91	8.04	6.78	14.81	0.54	20	0.63	31
14	1.53	0.93	7.18	7.45	14.63	0.49	12	0.46	26
Mean	1.52	0.87	6.65	5.77	12.42	0.54	22	0.66	32
$LSD_{0.05}$	0.05	0.04	0.52	0.44	0.80	0.02	4.00	0.10	4.60

GN: Grain N concentration (%), SN: Straw N concentration(%), TGN: Total grain N (g m^{-2}), TSN: Total straw N (g m^{-2}), TN: Total plant N (g m^{-2}), NHI: Nitrogen harvest index (total grain N/total plant N), AE: Agronomic efficiency, AR: Apparent recovery, PE: Physiological efficiency

DISCUSSION

Seed germination requires good seed-soil contact to ensure water absorption. The low establishment count observed for broadcast sowing could be because it gives inadequate seed-soil contact for water absorption by the seed (Chapman and Carter, 1976). It has also been reported that inadequate burying of seeds in broadcast sowing makes them susceptible to damages from pests, diseases and other environmental factors (Chapman and Carter, 1976; Oyewole *et al.*, 2001, 2005). The high establishment count in drilling and dibbling methods could be because they provide optimum and uniform depth of planting (Tanveer *et al.*, 2003). Moreover, the non-significant effect of sowing method on grain yield and yield components except establishment count could be because of profuse tillering in broadcast sowing which compensated for low establishment in it. This also agrees with the previous studies on wheat (Oyewole *et al.*, 2001, 2005) and rice (Oyewole *et al.*, 2010) despite significant increase in grain yield, straw yield, number of tillers, plant height and 1000 seed weight in drilling compared to broadcast sowing has been reported for wheat (Soomro *et al.*, 2009).

In the present experiment, the increase in straw yield, tillers m^{-2}, panicles m^{-2} and filled grains/panicle with the increase in N rate could suggest that nitrogen nutrition is important for both source and sink development. Similarly, the increase in grain yield and total biomass could be because N supply increases leaf area index (Salem, 2006; Salem *et al.*, 2011), leaf chlorophyll content (Salem *et al.*, 2011) and nutrient uptake (Hussaini *et al.*, 2008). However, the less change or decline in grain yield and yield components at high N rates could be because with the increase in one nutrient, the availability of other nutrients or genetic potential of the crop becomes more important in determining crop yield (Marschner, 1995). The decline in grain yield, filled grains/panicle and 1000 seed weight at high N rate relative to the constant increase in straw yield with the increase in N supply could be because of low sink strength to translocate extra assimilates from source or due to increased vegetative growth competing for assimilates available for grain formation and grain filling (Hasegawa *et al.*, 1994; Marschner, 1995). Similar results have also been reported in previous studies on rice (Ahmed *et al.*, 2005) and barley (Shafi *et al.*, 2011) despite linear and significant increase in grain yield, number of tillers and 1000 seed weight with the increase in N supply has been reported for rice (Jamil and Hussain, 2000). The decrease in harvest index at high N rates could also suggest excessive increase in vegetative growth relative to the increase in the rate of translocation of carbohydrates to the grain filling. This is consistent with previous studies on rice (Ahmed *et al.*, 2005), wheat (Delogu *et al.*, 1998) and barley (Bulman and

Smith, 1993; Delogu *et al.*, 1998; Shafi *et al.*, 2011) even though non-significant effect of N supply on harvast index has been reported for rice (Jamil and Hussain, 2000).

As to the present experiment, the increase in N supply has been reported to increase grain and straw N concentration and uptake for wheat (Cassman *et al.*, 1992), barley (Bulman and Smith, 1993) and maize (Hussaini *et al.*, 2008). However, little change in straw N concentration despite significant change in straw yield at high N rates could also be due to dilution effect of dry matter because dry matter accumulation increased more than that of N accumulation. Similar results have also been reported for canola (Chamorro *et al.*, 2002).

Nitrogen harvest index indicates the level of efficiency of plants to use acquired nitrogen for grain formation (Fageria and Baligar, 2005). The decrease in nitrogen harvest index at high N rate observed in the present experiment could be because the increase in total plant N is greater than the increase in grain yield as well as the transfer of N to the grain (Lopez-Bellido and Lopez-Bellido, 2001). The significant effect of N supply on nitrogen harvest index for wheat (Cassman *et al.*, 1992; Delogu *et al.*, 1998) and barley (Bulman and Smith, 1993; Ponce *et al.*, 1993; Delogu *et al.*, 1998) as well as its non-significant effect on this parameter for barley (Ponce *et al.*, 1993) and rice (Singh *et al.*, 1998) has also been reported in previous studies.

As to the present experiment, the decline in agronomic efficiency for canola (Chamorro *et al.* 2002), rice (Baba *et al.*, 2010) and wheat (Haile *et al.*, 2012), apparent recovery for rice (Baba *et al.*, 2010) and wheat (Haile *et al.*, 2012) and physiological efficiency for wheat and barley (Delogu *et al.*, 1998) with the increase in N supply has also been reported. In contrary, the increase in apparent recovery with the increase in N supply for wheat and barely (Delogu *et al.*, 1998) as well as its non-significant effect on this parameter for barley (Ponce *et al.*, 1993) and rice (Singh *et al.*, 1998) has also been reported in previous studies. In the present expriment, the decline in agronomic efficiency and apparent recovery with the increase in N rate would indicate that the rate of increase in both grain yield and N uptake was less than the rate of increase in N supply. Thus, the excess N supply makes it susceptible for loss through leaching, volatilization, denitrification and soil erosion (Mengel and Kirkby, 1987). The present experiment suggests that soil nitrogen content should be considered in N fertilization recommendations.

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