Effects of Nitrogen and Phosphorus Fertilizer Application on Yield Attributes, Grain Yield and Quality of Rain Fed Rice (NERICA-3) in Gambella, Southwestern Ethiopia

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Abstract: A field experiment was carried out during the 2008 and 2009 crop seasons at Imla, Gambella Zuria District, Gambella, southwestern Ethiopia, to establish the application rates of N and P fertilizers for rice variety NERICA-3 (*Oryza sativa x Oryza glaberrima*). The treatments consisted of factorial combinations of four rates each of N (0, 46, 92 and 138 kg N ha^{-1}) and P (0, 23, 46 and 69 kg P ha^{-1}) laid down in a randomized complete block design (RCBD) with three replications. The effects of year showed significant ($P \leq 0.05$ for some and $P \leq 0.01$ for most) differences for leaf area index (LAI), 1000-grain weight, plant height, panicle length and grain qualities. Similarly, the effects of N were significant ($P \leq 0.01$) for productive tillers plant^{-1}, grains panicle^{-1}, LAI, plant height, panicle length, grain yield, crude protein, ether extract and crude fiber. Growth, yield, and quality components did not differ significantly ($P > 0.05$) due to application of P except crude fiber. Conversely, the effects of year by N interaction were significant ($P \leq 0.05$ and/or $P \leq 0.01$) for LAI, panicle length, grains panicle^{-1}, crude fiber, plant height and ether extract. Effects of year by P interaction were significant only for crude fiber whereas the interaction effects of N by P and year by N by P on growth, yield and quality parameters were not statistically significant ($P > 0.05$). Rice grain yield increased from 3.54 to 5.90 tons per hectare (t ha^{-1}) with increase in level of N from the control to 92 kg N ha^{-1} but decreased with further increase of N. In conclusion, sensitivity analysis on coexisting changes in field prices of inputs and rice grain (±15%) showed that 92 kg N gave the highest (681.53%) marginal rate of return (MRR) followed by 23 kg P ha^{-1} (117.44%). Therefore, application of 92 kg N ha^{-1} to improve grain yield of rain fed NERICA-3 rice might be more profitable even under risky market situations in and around the study area.

Keywords: Economic Analysis; Grain Quality; Grain Yield; Nitrogen; Phosphorus; Yield Attributes

1. Introduction

Rice (*Oryza sativa* L.) is the most important food security crop for about half of the world's population (Brohi *et al*., 1998) and ranks third in area after wheat and second both in production and productivity after maize worldwide (FAOSTAT, 2012). It supplies more calories per 100 g portion than maize and wheat and provides more than one fifth of calories consumed worldwide by human (FAOSTAT, 2012; USDA, 2012). The total world rice production has risen steadily from about 200 million tons (t) of paddy rice in the 1960 to over 678 million tons in 2009. In the 2010/2011 and 2011/2012, the world paddy productions were estimated at 691.3 and 713.8 million tons, respectively. Globally, 158.9 million hectare (ha) of rice was harvested during the 2011/2012 (USDA, 2012).

In Ethiopia, the number of rice producing farmers, area under rice and its production and productivity rose from 53, 302, 18, 527 ha, 42, 825 tons and 2.31 t ha^{-1} in 2006 to 284, 868, 155, 886 ha 498, 332 tons and 3.2 t ha^{-1} in 2009, respectively. In the Gambella Region, although there is a 3,164, 230 ha of land of which 373, 848 ha is highly suitable, 2, 752, 345 ha is suitable and 38, 037 ha is moderately suitable for rice production, the crop occupied only 1, 314 ha with annual production of 4, 456 tons in the 2008 (MoARD, 2010). Owing to its recent introduction to the country, the research and development effort so far undertaken on rice in Ethiopia is of limited scale. However, its productivity, varied uses, existence of vast suitable conditions (swampy, waterlogged, rain fed and irrigable land) and possibilities of growing it where other food crops do not perform well make rice among the promising alternative crops available for cultivation in Ethiopia. As a result, rice is among the target commodities of the millennium development of the country that is named "Millennium crop" as it is expected to contribute greatly towards ensuring household as well as national food security in the country.

Rice can produce grain yield as high as 10-18 t ha^{-1} in countries advanced in its cultivation (Yuan, 2002). However, its productivity in Ethiopia in particular (2.31 t ha^{-1} of paddy rice) and in Africa at large is much below its world average (4.35 t ha^{-1} of paddy rice) due to improper crop management practices. The research and extension efforts made so far for promoting its production are also limited to certain areas. Fertilizer type, level and time of application are among the

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prioritized rice production input constraints set in Ethiopia (MoARD, 2010).

Daniel and Soloman (2008) from their soil nutrient variability study results of the Barro River basin plain, Gambella, reported that the amount of total nitrogen (N) ranged from 0.06 to 0.31%. Of the area surveyed, 44.4, 40.7 and 14.2% fall under very low, low and medium total N categories, respectively. They added that the amount of available phosphorus (P) ranged from absolutely deficit to excess levels. Furthermore, no information on recommended rates of N and P fertilizers for profitable rice production in the Region is available. Use of nutrients particularly N, P and potassium (K) in optimum quantities with appropriate sources, application methods and application time can markedly increase the yield and improve the quality of rice grain (Place *et al.*, 1970). Judicial use and management of nutrients improves and maintains soil fertility while sustaining an economically viable and environmentally friendly agriculture that will meet the requirements of the future (Moro *et al.*, 2008).

Nitrogen makes up 1-4% of the dry matter of plants and a good supply of N to the plant stimulates root growth and development as well as uptake of other nutrients (Brady and Weil, 2002), which in turn increases the grain yield by increasing the magnitude of yield attributes such as number of panicles m^{-2} and panicle length (Sewenet, 2005; Heluf and Mulugeta, 2006). Proper use of fertilizer increases crop yields significantly, particularly in cereals. Rice may benefit from the use of mineral and organic fertilizers to compensate exported nutrients. It is estimated that for every one ton of rice grain harvested, about 1.5-2.0% N, 0.2-0.3% P and 1.5-2.0% K are removed from the soil. With the introduction of new and high yielding rice varieties, soil nutrient mining will be on the increase when mineral fertilizer additions are absent or not in adequate amounts (Moro *et al.,* 2008). Bajwa and Rehman (1998) found that imbalanced ratio of NPK nutrients promoted excessive vegetative growth and led to reduced yield and productivity of the soil. In earlier studies, Malik *et al.* (1994) reported that the optimum nutrient requirement of fine rice is 84/41/49 kg N/P/K ha^{-1} and indicated that the response curve was of a quadratic trend to N and P and linear trend to K. At the Fogera plain, northwestern Ethiopia, the highest rice mean yield obtained due to the applications of 60/13.2 kg N/P ha^{-1}, representing an increase of 38.5% over the control (Heluf and Mulugeta, 2006). Rehman *et al.* (2006) studied the response of rice to different combinations of fertilizers in a farmer's field at Maghoki (Hafizabad) in a permanent field layout and found a significant improvement in paddy rice yield (3.30-4.35 t ha^{-1}) during the two experimental years with the application of recommended doses of N and P fertilizers. Panda *et al.* (1995) reported increased grain yield of rice due to increased N and P uptakes in response to external application of both N and P fertilizers. The present field experiment was conducted to evaluate the effects of inorganic N and P fertilizer application rates on growth, yield and grain quality of rice (NERICA-3) under rain fed conditions in the Gambella lowlands, and to determine the levels of N and P fertilizers required for obtaining maximum marginal rate of return on investment.

2. Materials and Methods

2.1. Description of the Study Site

The experiment was conducted at *Imla* (8^o 14' 46.36" N latitude; 34^o 35' 17.75" E longitude; altitude 450 meters above sea level) found in Gambella Zuria District, southwestern Ethiopia during the 2008 and 2009 main cropping seasons. The area is characterized by hot humid tropical lowland climate. The soil texture was clay, consisting of 4.08% organic carbon (OC), 0.51% total N and 65.00 mg kg^{-1} available P with a pH of 6.43 (Table 1). The weather data during the two experimental seasons (2008 and 2009) are presented in Figure 1.

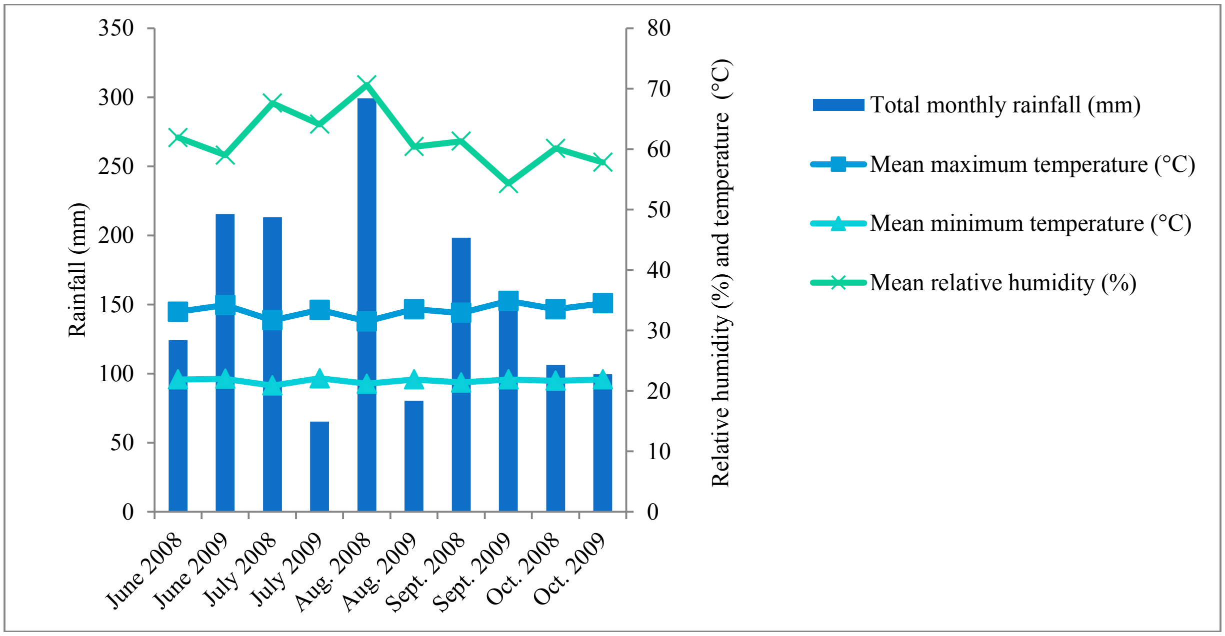

Figure 1. Monthly weather data for the 2008 and 2009 cropping seasons (Source: Gambella Meteorological Service Branch Office).

2.2. Treatments, Experimental Design and Procedures

The treatments consisted of factorial arrangement of 4 levels each of N (0, 46, 92 and 138 kg N ha^{-1}) and P (0, 23, 46 and 69 kg P ha^{-1}) in a randomized complete block design in three replications. To estimate the seeding rate, germination percentage of the rice seeds was determined through controlled test using newspaper (absorbent material), waterproof tray, randomly sampled mixed rice seed lot and tape water for 10 days before sowing on the field. Each day, the number of germinated seeds was recorded. Germination (%) was calculated as the ratio of number of seeds germinated to number of seeds on the tray and recorded as 96.1% in the 2008 and 94.8% in the 2009. The land was plowed by a tractor in April 2008. A suitable seedbed was prepared to get proper germination and root development. The plot size was 4 m x 4 m (16 m^2).

The rice variety NERICA- 3 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) and uniform dose of 20 kg K (KCl) ha^{-1} were 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 20 rows in each plot and two outer most rows and 0.5 m row length at both ends of each plot were considered as borders. The second, third and fourth rows on both sides of the plots were designated for destructive sampling, non-destructive sampling and guard rows, respectively. Of the 4 m x 4 m (16 m^2) gross plot size, 3.0 m x 2.4 m (7.2 m^2) was harvested when two-third of the length of panicle axis in 50% of the plant population attained yellow color.

2.3. Soil Sampling and Analysis

A composite surface soil (0-30 cm depth) sample was collected with a gauge auger in the 2008. Before plowing, the experimental field was blocked into three parts depending upon land uniformity. Plant residues on the sampling soil surface were removed. Eight soil sub-samples each for a composite surface soil and core (undisturbed) samples per block were collected for characterization of selected soil physicochemical properties. The sample was analyzed for soil texture using the hydrometer method (Jackson, 1967). Bulk density (Db) of the soil was measured from the undisturbed soil sample collected using core sampler, which was weighed at the field and after drying the pre-weighed core soil sample to a constant weight in an oven at 105 ^{o}C according to the procedure described by Okalebo *et al.* (2002). Particle density (Dp) was determined by the pycnometer method (Rowell, 1997) and total porosity (%) [(1-(Db/Dp) x 100] was calculated.

Soil pH was determined in a 1:2.5 soil-water suspension using a combination of glass electrode. Organic carbon was estimated by the wet digestion method (Okalebo *et al.*, 2002) 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 (Hesse, 1971). From the extract, exchangeable K was determined using a flame photometer while Ca and Mg were determined using an atomic absorption spectrophotometer. Further, sulfur (S) was extracted with $Ca(H_2PO_4)_2$ in $2NH_4OAc$ and measured turbidmetrically (Hoeft *et al.*, 1973). 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 (Hesse, 1971).

Total soil N was measured using the micro-Kjeldahl digestion, distillation and titration procedure as described by AOAC (1994). After extraction of the soil sample by sodium bicarbonate solution as per the procedure outlined by Olsen *et al.* (1954), available P was determined by measuring its absorbance using spectrophotometer. The investigated soil properties are shown in Table 1.

Table 1. Physiochemical properties of the experimental soil (0-30 cm depth) before sowing.

Soil property	Value	Rating	Source
Sand (%)	17.68	-	-
Silt (%)	32.72	-	-
Clay (%)	49.60	-	-
Textural class	Clay	-	-
Bulk density (g cm^{-3})	0.73	-	-
Particle density (g cm^{-3})	2.98	-	-
Porosity (%)	0.76	-	-
pH 1:2.5 (H_2O)	6.43	Slightly acidic	Tekalign (1991)
ECe (dS m^{-1})	2.42	-	-
Organic matter (%)	7.03	Very high	Tekalign (1991)
Total N (%)	0.51	Very high	Murphy (1968)
Available P (mg kg^{-1})	65.00	Adequate	DEFRA (2007)
S (mg kg^{-1})	63.00	-	-
Exchangeable Ca ($cmol_c$ kg^{-1})	2.14	Low	FAO (2006)
Exchangeable Mg ($cmol_c$ kg^{-1})	6.55	High	FAO (2006)
Exchangeable K ($cmol_c$ kg^{-1})	0.60	High	DEFRA (2007)
CEC ($cmol_c$ kg^{-1})	35.60	High	Landon (1991)

2.4. Crop Data Collection

Leaf area index (LAI) was determined using the length-width method (Reddy, 2006) during panicle initiation using 0.725 adjustment factor (Tsunoda, 1964). Number of hills m^{-2} was recorded using a 1 m x 1 m quadrat at physiological maturity. Plant height (cm) was obtained by measuring the length from the base to the tip of panicle at harvest from randomly sampled 20 plants. The productive tillers were counted during physiological maturity from 1.5 m row length of non-destructive rows of both sides of each harvestable net plot. Number of grains $panicle^{-1}$ was counted per plot from 20 randomly sampled panicles. Thousand-grain weight was recorded by weighing thousand grains per treatment using sensitive balance. Grain yield was obtained from the net plot area (7.2 m^2), and adjusted to 14% moisture using hygrometer and expressed as t ha^{-1}. Milled grain percentage was obtained from one kg of grain per plot by hand pounding with a mortar and pestle. Crude protein, ether extracts (fats) and crude fiber contents were determined from a grain sample to reveal their responses to N and P fertilizers were determined (AOAC, 1994). Grain N content of rice was analyzed from the respective sample collected using the micro-Kjeldahl digestion, distillation and titration procedure as described by AOAC (1994). Crude protein (N x 6.25), ether extract and crude fiber were also determined according to the AOAC (1994).

2.5. Economic Analysis

To assess the costs and benefits associated with different treatments (N and P fertilizer levels), the partial budget technique as described by CIMMYT (1988) was applied. Economic analysis was done using the prevailing market prices for inputs at planting and for outputs at the time the crop was harvested. All costs and benefits were calculated on ha basis of Ethiopian Birr (EtB). The inputs and/or concepts used in the partial budget analysis were the mean grain yield of each treatment in both years, the field price of NERICA-3 rice grain (sale price minus the costs of harvesting, threshing, winnowing, bagging and transportation), the gross field benefit (GFB) ha^{-1} (the product of field price and the mean yield for each treatment), the field price of N or P kg^{-1} (the nutrient cost plus the cost of transportation from the point of sale to the farm), the field cost of N or P (the product of the quantity required by each treatment and the field price of fertilizer), the total costs that varied (TCV) which included the sum of field cost of fertilizer, its application and the interest at 6% rate. The net benefit (NB) was calculated as the difference between the GFB and the TCV. Actual yield was adjusted downward by 30% to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment. There were optimum plant population density, timely labor availability and better management (e.g. weed control, better security) under the experimental conditions (CIMMYT, 1988; Moro *et al.*, 2008).

The dominance analysis procedure as detailed in CIMMYT (1998) was used to select potentially profitable treatments from the range that was tested. The discarded and selected treatments using this technique were referred to as dominated and undominated treatments, respectively. The undominated treatments were ranked from the lowest to the highest cost. For each pair of ranked treatments, the percent marginal rate of return (MRR) was calculated. The MRR (%) between any pair of undominated treatments was the return per unit of investment in fertilizer. To obtain an estimate of these returns the MRR (%) was calculated as changes in NB divided by changes in cost. Thus, a MRR of 100% was used indicating for every one EtB expended there is a return of one EtB for a given variable input.

Sensitivity analysis for different interventions was also carried out to test the recommendation made for its ability to withstand price changes. Sensitivity analysis simply implied redoing marginal analysis with the alternative prices. Through sensitivity analysis, maximum acceptable field price of an input was calculated with the minimum rate of return as described by Shah *et al.* (2009).

2.6. Statistical Analysis

The data were statistically analyzed using SAS statistical software version 9.10 (SAS Institute Inc., 2003). Treatment means were then compared using the Duncan's Multiple Range Test at 5% probability level.

3. Results and Discussion

3.1. Effects of N and P Fertilizers on Growth

3.1.1. Number of Hills

Analysis of variance (Table 2) showed no significant difference (P > 0.05) due to year, N and P application, as well as their interactions on the number of hills (rice main stem with its tillers) m^{-2}. This could be due to enough rainfall (Figure 1) for the establishment and growth of seedlings during both the cropping years. The availability of applied and reserve nutrients for the crop might have also been enhanced. Similarly, Singh and Khan (2000) reported no significant variation in the number of hills of rice with the application of N and P fertilizers.

3.1.2. Leaf Area Index

Leaf area index (LAI) of rice responded significantly to cropping year (P ≤ 0.05), N (P ≤ 0.01) and year by N interaction (P ≤ 0.05), but insignificant (P > 0.05) to the main effects of P, interactions of year by P, N by P and year by N by P (Table 2). The rice plant attained higher LAI (0.97) in 2008 than in 2009 (0.79) cropping year (Table 4).

Table 2. Mean square from combined analysis of the effects of N and P fertilizer rates on growth, yield attributes, yield and grain quality of rice during 2008 and 2009 cropping years, Gambella, southwestern Ethiopia.

	Mean square for source of variation							
Parameter	Year (1)	N (3)	P (3)	Y x N (3)	Y x P (3)	N x P (9)	Y x N x P(9)	Error (60)
Growth parameters								
Number of hills m^{-2}	277.81	402.28	213.81	80.99	655.05	1225.26	1198.97	764.76
Leaf area index	0.75*	0.88**	0.12	0.56*	0.01	0.12	0.11	0.08
Plant height (cm)	713.41**	940.94**	90.90	349.65**	77.22	45.64	57.27	40.75
Yield attributes and yield								
Productive tillers $plant^{-1}$	0.83	1.98*	0.48	1.48	0.21	0.24	0.49	0.60
Panicle length (cm)	39.58**	17.80**	0.28	7.29*	1.32	1.83	0.93	1.46
Grains $panicle^{-1}$	616.61	1276.42*	134.62	1497.73*	322.54	188.59	429.70	346.15
1000-grain weight (g)	27.46*	1.80	4.85	2.37	3.90	1.92	2.99	3.76
Grain yield (tons ha^{-1})	3.25	23.05**	2.95	0.77	1.09	1.00	0.57	1.38
Grain quality								
Milled grain (%)	1307.59**	17.00	1.92	3.90	6.67	5.15	3.69	6.99
Crude protein (%)	102.78**	36.70**	3.56	6.92	1.75	3.90	4.71	4.84
Ether extract (%)	55.82**	7.99**	0.08	5.47**	0.53	0.93	0.67	0.73
Crude fiber (%)	327.86**	1.83**	0.49*	0.49*	0.64**	0.15	0.15	0.13

*Figures in parenthesis = Degrees of freedom; ** = Significant at P ≤ 0.01; * = Significant at P ≤ 0.05; Y = Year; ha = Hectare.*

The interaction effect of year by N showed that the LAI increased linearly with an increase in N levels up to the highest N (138 kg ha^{-1}) in 2008 while it increased insignificantly up to 92 kg N ha^{-1} in 2009. Consequently, the application of 138 kg N ha^{-1} in the 2008 cropping season had significantly higher LAI (1.40) than any other N rates by cropping year treatment combination (Table 3). The application of 92 kg N ha^{-1} showed a significant increase in LAI over its lower rates of application while no significant variation was observed between 46 kg N ha-1 and the control in 2008. The increase in LAI due to the application of 138 and 92 kg N ha-1 was 105.9 and 52.9%, respectively, over the control. The increase in LAI with the increased N application might be due to the increased availability of N that increased number of functional leaves and production of higher tiller number per unit area (Tables 3 and 4). Xue *et al.* (2004) and Onasanya *et al.* (2009) also reported an increase in LAI with increasing rate of N application. In general, the increased tiller number at higher N application rates might have contributed to the increase in LAI.3.1.3. Plant Height

The rice plant height showed significant variation with cropping year, N and the interactions of cropping year by N ($P \leq 0.01$) while P, interactions of year by P, N by P and year by N by P had no significant effect on it (Table 2). Assefa *et al.* (2009) also reported a significant influence of N on plant height in upland rice in hot humid part of Northern Ethiopia. The interaction of cropping year with N showed insignificant difference in plant height between 92 kg (113.9 cm) and 138 kg (113.5 cm) N ha^{-1} in 2008, but had significant increase in height over other interactions (Table 3).

The increase in plant height in response to application of N fertilizer was also probably due to enhanced availability of N, which enhanced cell division and more leaf area resulting in higher photo assimilates and thereby resulted in more dry matter accumulation (Abd El-Rahman *et al.*, 2003). Sewenet (2005) observed a significant increase in plant height with the application of 46 and 69 kg N ha^{-1} over control. Haque *et al.* (2006) reported the tallest and the shortest plant height with 120 kg N ha^{-1} and without N application, respectively. In 2008 application of 46 kg N ha^{-1} was statistically in parity with the control, but revealed no significant difference in plant height among the N levels during 2009 (Table 3). However, while comparing the same level of N between 2008 and 2009 cropping years, unlike LAI application of 92 kg N ha^{-1} recorded significantly higher plant height in 2008 compared to 2009

Table 3. Interaction effect of cropping year and N application on leaf area index, plant height and panicle length of rice.

	Leaf area index		Plant height (cm)		Panicle length (cm)	
N (kg ha^{-1})	2008	2009	2008	2009	2008	2009
0	0.68^{c}	0.65^{c}	94.7^{c}	94.7^{c}	20.65^{d}	22.29^{c}
46	0.74^{c}	$0.83b^{c}$	99.9^{b}	102.0^{b}	20.78^{d}	23.46^{ab}
92	1.04^{b}	$0.89b^{c}$	113.9^{a}	100.7^{b}	22.60^{bc}	22.97^{abc}
138	1.40^{a}	$0.79b^{c}$	113.5^{a}	102.7^{b}	$23.25a^{bc}$	23.69^{a}

Means of the same parameter in a column followed by the same letter are not significantly different at $P > 0.05$ by Duncan's Multiple Range Test.

3.2. Effects of N and P Fertilizers on Rice Yield Attributes and Yield

3.2.1. Productive Tillers

Analysis of variance revealed that the number of productive tillers $plant^{-1}$ was significantly ($P \leq 0.05$) influenced by application of N whereas, effects of year, P, interactions of year by N, year by P, N by P and year by N by P were not ($P > 0.05$) (Table 2). The number of productive tillers $plant^{-1}$ increased with an increase in N application rates in which application of 138 kg N ha^{-1} resulted in a significant increase over the control and 46 kg N ha^{-1} (Table 4). Similarly, no significant difference existed among control, 46 and 92 kg N ha^{-1} treatments.

Enhanced tillering by increased N application might be attributed to more N supply to plant at active tillering stage (Ishizuka and Tanaka, 1963). Behera (1998) also reported that application of N increased the number of effective tillers per hill in rice. Whereas Haque *et al.* (2006) reported the highest number of tillers with 120 kg N ha^{-1} but was statistically similar to 60 kg N ha^{-1} application. Akinrinde and Gaizer (2006) showed no significant difference in number of tillers across six rice genotypes with P application. In contrast, Alam *et al.* (2009) reported 29% increase in effective tillers with the application of 72 kg P ha^{-1} over the control.

Table 4. Main effects of cropping year, N and P application on growth and yield attributes of rice, Gambella, southwestern Ethiopia.

Treatment	Growth parameters			Yield attributes	
	NH	LAI	Plant height (cm)	Productive tillers	Panicle length (cm)
			Year		
2008	94.9	0.97[a]	105.5[a]	2.45	21.82[b]
2009	98.3	0.79[b]	100.0[b]	2.27	23.10[a]
			N (kg ha^{-1})		
0	92.5	0.66[b]	95.7[b]	2.10[b]	21.47[c]
46	102.2	0.78[b]	100.0[b]	2.16[b]	22.12[bc]
92	96.3	0.97[a]	107.3[a]	2.43[ab]	22.78[ab]
138	95.3	1.10[a]	108.1[a]	2.73[a]	23.47[a]
			P (kg ha^{-1})		
0	99.7	0.83	100.8	2.22	22.54
23	92.6	0.82	105.1	2.31	22.40
46	97.7	0.98	101.5	2.35	22.34
69	96.2	0.88	103.6	2.55	22.56
CV (%)	28.64	31.14	6.21	32.94	5.39

Means of the same parameters in a column followed by the same letter are not significantly different at P > 0.05 by Duncan's Multiple Range Test. NH = Number of hills m^{-2}; LAI = Leaf area index; CV = Coefficient of variation

3.2.2. Panicle Length

There was a significant difference in rice panicle length due to cropping year, N ($P \leq 0.01$) and interaction of year by N ($P \leq 0.05$), while the effects of P, interactions of year by P, N by P and year by N by P had no significant ($P > 0.05$) influence on panicle length (Table 2). The interaction effect of cropping year with N showed that panicle length was significantly more with the application of 92 and 138 kg N ha^{-1} than the control and 46 kg N ha^{-1} in 2008 while in 2009 such difference was observed with 46 kg N ha^{-1} also. Consequently, the maximum panicle length (23.69 cm) was found with the application of 138 kg N ha^{-1} followed by 46 and 92 kg N ha^{-1} in 2009 which was statistically at par with panicle length recorded at 138 kg N ha^{-1} in 2008 (Table 3). The longer panicles obtained in treatments receiving higher N rates might probably be due to better N status of plant during panicle growth period. The increment in panicle length with increased N application is in agreement with the findings of Heluf and Mulugeta (2006) who noted increase in rice panicle length with increasing N supply up to 90 kg N ha^{-1}. Similarly, Salem (2006) reported a significant increase in panicle length with the increased N levels in two years of experimentation.

Table 5. Interaction effect of cropping year and N application on number of grains per panicle^{-1} of rice, Gambella, southwestern Ethiopia.

N (kg ha^{-1})	2008	2009
0	107.5[c]	124.8[b]
46	112.2[bc]	131.4[a]
92	129.0[ab]	126.0[ab]
138	139.6[a]	126.4[ab]

Means of the same parameter in a column followed by the same letter are not significantly different at P > 0.05 by Duncan's Multiple Range Test.

3.2.3. Grains Per Panicle

Effects of N fertilizer and its interaction with cropping year significantly influenced grain number panicle^{-1} ($P \leq 0.05$), while effects of cropping year, P, interactions of year by P, N by P and cropping year by N by P were not ($P > 0.05$) significant (Table 2). Application of 138 kg N ha^{-1} resulted in maximum (139.6) grains panicle^{-1} which significantly varied only with the control and 46 kg N ha^{-1} in 2008. Kamara *et al.* (2011) also reported that N application had a significant effect on number of grains panicle^{-1} in rice. During 2009, there was no significant difference in number of grains (124.8-131.4) due to N application. The data (Table 5) revealed that among 92 and 138 kg N ha^{-1} there was no significant difference between 2008 and 2009 years whereas, the control and 46 kg N ha^{-1} had significantly more grains panicle^{-1} in 2009 than that of 2008. The interaction effect indicated statistical parity among 92 and 138 kg N ha^{-1} in 2008 and with all the N application rates in 2009, while the control plots in 2008 recorded significant decrease in number of grains panicle^{-1} compared to other interaction effect except 46 kg N ha^{-1} in the same year. The more number of grains panicle^{-1} at higher N rates were probably due to better N status of plant during panicle growth period. Heluf and Mulugeta (2006), however, reported increased number of grains panicle^{-1} in the absence of both N and P fertilizers.

3.2.4. 1000-Grain Weight

Thousand grain weight of rice differed significantly due to cropping year ($P \leq 0.05$), whereas effects of N, P, interactions of year by N, year by P, N by P and year by N by P were not ($P > 0.05$) (Table 2). Significantly higher 1000-grain weight (27.46 g) was recorded in 2008 than in 2009 (26.39 g) which was higher than it by about 4.1%. Erratic rainfall, higher air temperature and inadequate rainfall during grain filling period in 2009 might have adversely affected the grain filling process resulting in lower 1000-grain weight. Grain weight is a genetically controlled trait, which is greatly influenced by environment during the process of grain filling, but it also appeared that the application of N increased the protein percentage, which in turn increased the grain weight (Kausar *et al.*, 1993).

3.2.5. Grain Yield of Rice

The analysis of variance (Table 2) showed significant ($P \leq 0.01$) difference in rice grain yield due to the effect of N application, whereas effects of cropping year, P, interactions of cropping year by N, cropping year by P, N by P and cropping year by N by P were not significant($P > 0.05$). The grain yield during 2008 was lower than in 2009 despite significantly higher 1000-grain weight. The increased grain yield in 2009 might have been contributed by higher panicle length (Table 4) and number of grains panicle^{-1} (Table 6).

Nitrogen supply directly or indirectly affects chlorophyll content, LAI, canopy coverage and other biophysical parameters (Daughtry *et al.*, 2000; Serrano *et al.*, 2000). The effect of N showed significant increase in grain yield from 3.54 to 5.9 t ha^{-1}with an increase in the level of N from the control (no N) to 92 kg ha^{-1}and significantly decreased with further increase of applied N rate to 138 kg N ha^{-1} (Table 6). The highest grain yield (5.90 t ha^{-1}) obtained with the application of 92 kg N ha^{-1} was 66.7% higher over the control. In spite of insignificantly higher number of grains panicle^{-1} in 138 kg N ha^{-1} treated plots, the more 1000-grain weight obtained from 92 kg N ha^{-1} treated plots might have contributed to significant increase in yield. In addition, the higher OC (4.08%) and native total N (0.51%) contents in the experimental field might have also negatively affected crop response and the increment in rice yield at higher application doses of applied N.

In line with this study, Singh *et al.* (2000) found the response of rice to N averaged over P levels was curvilinear with significant response up to 80 kg ha^{-1}. Spanu and Pruneddu (1997) also noted higher paddy yield with 150 and 250 kg N ha^{-1}, respectively. Similar results with higher N rates were also reported by Dixit and Patro (1994) and Meena *et al.* (2003). Further, Heluf and Mulugeta (2006) found significant increase in grain yield of rice up to 60 kg N ha^{-1}.

Fageria and Baligar (2001) found that the grain yield in rice is a function of panicle per unit area and 1000-grain weight. During the experimental period the plants in plots supplied with N were found to have longer and droopy leaves those might have collected more raindrops overloading the culm. Consequently, the two experimental years average lodging percentage of plants in the control, 46, 92 and 138 kg N ha^{-1} treated plots was 1.1, 6.6, 22.7 and 34.4%, respectively (data not shown). Thus, the plant supplied with higher N lodged even under the influence of light wind as a result of heavy panicles during milking stage. Finally, reduction of light-interception due to lodging and other mechanical effects produced depressed rice grain yield in 138 kg N ha^{-1} treated plots (1997; IAEA, 2008).

Application of P failed to bring significant difference in grain yield, which varied between 4.26 to 5.02 t ha^{-1}. This may be due to higher amount of inherent available P (65.00 mg kg^{-1} soil) in the soil (Table 1). In addition, P is generally most available to plants when the soil pH is between 6.0 and 6.5. Singh *et al.* (2000) 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, George *et al.* (2001) reported that the application of P had only little effect on grain yield in spite of increased P uptake by the plant.

3.3. Effects of N and P on Rice Grain Quality

3.3.1. Milled Grain

Analysis of variance (Table 2) showed significant ($P \leq 0.01$) differences in milled grain in the two cropping years/seasons. The milling percentage was significantly higher (78.2%) in 2009 than that of 2008 (70.8%). The result of milling percent was in agreement with the findings of Blumenthal *et al.* (2008), who reported the milling percentage of white rice was about 70% of the rough rice.

3.3.2. Crude Protein

The crude protein content varied significantly ($P \leq 0.01$) due to cropping years and N fertilizer, but not ($P > 0.05$) with P, interactions of year by N, year by P, N by P and year by N by P (Table 2). In variation to the percent milled grain, the protein content was significantly higher in 2008 (9.29%) than that of 2009 (7.22%) (Table 6). Differences in rainfall during the two cropping years (Figure 1) might have adversely affected the availability and uptake of N by the plants thereby reducing accumulation of N in the grain resulting in low protein content in 2009. The average crude protein content of milled rice in the two cropping years was 8.26%, which is in agreement with Dalia`s (2006) study results which showed milled rice flour had 7.95% protein content.

Table 6. Effects of cropping year, N and P application on yield attributes, yield and grain quality of rice at Gambella, southwestern Ethiopia.

Treatment	Yield attributes		Grain yield	Grain quality (%)			
	NG	TGW	(t ha^{-1})	MG	CP	EE	CF
Year							
2008	122.1	27.46^{a}	4.52	70.8^{b}	9.29^{a}	2.00^{b}	0.95^{b}
2009	127.1	26.39^{b}	4.89	78.2^{a}	7.22^{b}	3.53^{a}	4.64^{a}
N (kg ha^{-1})							
0	116.1^{b}	27.12	3.54^{c}	73.5	6.66^{c}	2.00^{c}	3.15^{a}
46	121.8^{ab}	26.72	4.49^{b}	75.3	8.03b^{c}	2.65^{b}	2.85^{b}
92	127.5^{a}	27.20	5.90^{a}	75.1	8.74^{ab}	3.30^{a}	2.69^{bc}
138	133.0^{a}	26.66	4.90^{b}	74.1	9.58^{a}	3.12^{ab}	2.49^{c}
P (kg ha^{-1})							
0	121.2	26.37	4.60	74.9	8.69	2.84	2.71^{b}
23	126.6	26.92	5.02	74.5	8.17	2.71	2.74^{b}
46	125.0	26.93	4.26	74.3	8.38	2.74	3.01^{a}
69	125.6	27.48	4.95	74.3	7.77	2.77	2.72^{b}
CV (%)	14.93	7.20	24.97	3.55	26.67	30.86	12.64

Means of the same parameter in a column followed by the same letter are not significantly different at P = 0.05 according to Duncan's Multiple Range Test. NG= Number of grains panicle^{-1}; TGW = 1000-grain weight (g); GY = Grain yield (t ha^{-1}); MG = Milled grain (%); CP = Crude protein (%); EE = Ether extract (%); CF = Crude fiber (%); CV = Coefficient of variation.

The perusal of the data (Table 6) further revealed that crude protein content increased with the increase in N application up to the highest N (138 kg ha^{-1}) level. Accordingly, the highest grain protein (9.58%) was obtained with the application of 138 kg N ha^{-1}, which was 43.8% more than that of the protein content found in control treatment. Salem (2006) also reported significant increase in grain protein content of rice up to 83.3 and 166.7 kg N ha^{-1} in first and second seasons, respectively. Whereas Kirrilov and Pavlov (1989) reported that applied N increased wheat grain protein content by 20.29% over the control treatment. The increase in grain protein content might be the enhancement of amino acid formation with the application of N, which is primarily reflected in greater amount of storage protein located in protein bodies with in starchy endosperm (Oo *et al*., 2010).

Rice protein content has earlier been found to be in the range of 7.63-10.30% (SD, 2005) and 13.0% (Ambreen *et al*., 2006) however, in most commercial varieties grain protein content has been reported below 10% (Blumenthal *et al.,* 2008). The lower percent of milled rice in 2008 might be due to higher protein content than in 2009 (Table 6) as the higher protein has been reported to make the grain more resistant to cracking and breakage during abrasive milling than the low protein grain (Blumenthal *et al.,* 2008). An erratic and poor distribution of rainfall with high temperature was observed in 2009 (Figure 1). This might have enhanced the loss of N through volatilization as ammonia gas and reduced nutrient availability and its uptake by rice.

3.3.3. Ether Extract

The cropping year, N and their interaction had significant (P ≤ 0.01) effect on ether extract of rice grain, but the effect of P, interactions of year by P, N by P and year by N by were insignificant (Table 2). The ether extract was comparatively high (3.53%) in 2009 compared to 2008 (2.01%) (Table 6).

Increasing N rates from control to 138 and from control to 92 kg N ha^{-1} increased the ether extracts of rice grain from 1.42 to 2.86 and 2.59 to 4.69% in 2008 and 2009, respectively. As a result applied 138 and 92 kg N ha^{-1} showed significantly highest ether extracts compared to other interactions of 2008 and 2009 year by N rates application, respectively.

Table 7. Rice grain ether extract (%) in response to N fertilizer rates in 2008 and 2009.

N (kg ha^{-1})	2008	2009
0	1.42^{e}	2.59^{cd}
46	1.83^{de}	3.47^{b}
92	1.91^{de}	4.69^{a}
138	2.86^{bc}	3.37^{b}

Means across columns followed by the same letter are not significantly different at P > 0.05 by Duncan's Multiple Range Test.

However, significantly highest ether extracts obtained with 92 kg N ha^{-1} over the other cropping years by N rates treatment combination. Cameron and Wang (2005) reported that milled rice flour had 0.34% ether extracts content while, Reddy (2006) reported that the rice ether extracts is low (around 2%) since much of it is lost during milling.

3.3.4. Crude Fiber

The crude fiber content of rice grain significantly varied due to effects of cropping year, N (P ≤ 0.01), P, interactions of cropping year by N (P ≤ 0.05) and cropping year by P (P ≤ 0.01) whereas, effects of N by P and cropping year by N by P were insignificant (P >

0.05) on this parameter. Also at both N and P rates, the crude fiber content was significantly higher in 2009 than in 2008 (Tables 6 and 8). These differences in the average rice grain crude fiber might have resulted due to meteorological data variation between the two years (Figure 1) that maintained better equilibrium of soil nutrients as well as applied N and P for better plant uptake. Interaction of year by N showed that the crude fiber decreased with the increase in N rates up to the highest (138 kg ha^{-1}) level in both years. Consequently, the control plots recorded the highest crude fiber compared to N applied plots in both cropping years. Likewise, the application of N at 138 kg ha^{-1} significantly decreased the crude fiber over the control in both years.

Oo *et al.* (2010) reported decreased amount of crude fiber content in rice grain with the increase in N levels. These findings were in harmony with the results of Shallan *et al.* (2010) and SD (2005) who reported that the brown rice (high amylase-24) had the highest value of crude fiber (1.33%) compared with brown rice (low amylase); and rice cultivars grain showed 4.45% crude fiber of which 1.15 and 2.15% was insoluble and soluble fiber, respectively.

Table 8. Interaction of N and cropping year, and P and cropping year on crude fiber of rice grain at Gambella, southwestern Ethiopia.

N (kg ha^{-1})	Crude fiber (%) 2008	Crude fiber (%) 2009	P (kg ha^{-1})	Crude fiber (%) 2008	Crude fiber (%) 2009
0	1.11^{d}	5.19^{a}	0	0.95^{c}	4.46^{b}
46	0.99d^{e}	4.70^{b}	23	1.01^{c}	4.48^{b}
92	0.88d^{e}	4.50^{b}	46	0.92^{c}	5.10^{a}
138	0.80^{e}	4.19^{c}	69	0.91^{c}	4.54^{b}

Means of the same parameter across columns followed by the same letter are not significantly different at P > 0.05 by Duncan's Multiple Range Test.

On the other hand, the response of rice grain crude fiber (0.91-1.01%) to rates of P fertilizer in 2008 was not significant, while it was significant during 2009 (Table 8). Increasing P rates up to46 kg ha^{-1}in 2009 cropping year significantly ($P \leq 0.05$) increased crude fiber.In this year, application of 46 kg P ha^{-1} had the maximum crude fiber content (5.1%) that was significantly higher than the other P levels by cropping year treatment combination. The application of 23 and 69 kg P ha^{-1} did not bring significant variation in crude fiber content compared to the control within a year while significant between the years.

3.4. Economic Viability of N and P Fertilizer Rates

Analysis of variance (Table 2) showed that N fertilizer had a significant ($P \leq 0.05$) effect on grain yield of rice, whereas response to P was not significant. An economic analysis on the combined results using the partial budget technique was thus appropriate (CIMMYT, 1988). The result of the partial budget analysis and the data used in the development of the partial budget are given in Tables 9 and 10.

Dominance analysis (Table 9) led to the selection of treatments 0/0, 0/23, 46/0, 138/0, 46/69 and 92/0 kg N/P ha^{-1} ranked in increasing order of total costs that vary. The treatments having MRR below 100% was considered low and unacceptable to farmers; thus, 46/0 and 138/0 kg N/P ha^{-1} were eliminated (CIMMYT, 1988). This was because such a return would not offset the cost of capital (interest) and other related deal costs while still giving an attractive profit margin to serve as an incentive. Therefore, this investigation remained with changes to 92/0, 46/69 and 0/23 kg N/P ha^{-1} as promising new practices for farmers under the prevailing price structure since they gave more than 100% MRR. This might suggest the use of inputs that result in maximum net benefits (Bekele, 2000).

Market prices are ever changing and as such a recalculation of the partial budget using a set of likely future prices *i.e.*, sensitivity analysis, was essential to identify treatments which may likely remain stable and sustain satisfactory returns for farmers despite price fluctuations. This study indicated that an increase in the field price of both N and P of Birr 0.51 per kg and a fall in the price of grain of Birr 0.6 per kg (Table 11) which represented a price variation of 15%.

These price changes are realistic under the liberal market conditions prevailing in Gambella among the lowland dwellers at the time of experimentation. Some of the considerations in projecting prices were increased rice supply due to aid for refugees' imports from abroad and a deteriorating business environment in Gambella. The new prices were thus used to obtain the sensitivity analysis (Table 11)

Table 9. Partial budget with dominance to estimate net benefit for application of N and P fertilizer rates at current prices.

	Partial budget with dominance				
N/P (kg ha-1)	Total grain yield (t ha-1)	Adjusted yield (t ha-1)	GFB (EtB ha-1)	TCV (EtB ha-1)	NB (EtB ha-1)
0/0	3.26	2.28	9128	2576	6552U
0/46	3.25	2.28	9100	3149	5951D
0/69	3.37	2.36	9436	3534	5902D
0/23	4.26	2.98	11928	3657	8271U
46/0	4.43	3.10	12404	3965	8439U
46/23	4.29	3.00	12012	4145	7867D
46/46	4.24	2.97	11872	4396	7476D
138/46	3.83	2.68	10724	4999	5725D
138/0	4.90	3.43	13720	5264	8456U
46/69	5.02	3.51	14056	5302	8754U
92/0	5.81	4.07	16268	5518	10750U
92/23	5.92	4.14	16576	5896	10680D
92/46	5.73	4.01	16044	6037	10007D
138/23	5.60	3.92	15680	6108	9572D
138/69	5.27	3.69	14756	6428	8328D
92/69	6.15	4.31	17220	6659	10561D

GFB = Gross field benefit; TCV = Total cost that varied; NB = Net benefit; Field price of N = Birr 3.38 per kg; Field price of P = Birr 4.38 per kg; FA = Fertilizer application; EtB = Ethiopian Birr; Wage rate = Birr 25 per day; Labor to apply fertilizer per ha = 2 man-day; L Retail price of grain = Birr 4000 per ton; HTW = Harvesting, threshing and winnowing cost = Birr 1000 per ton; BMT= Bagging, material and transport cost = Birr 65 per ton.

Table 10. Partial budget with estimated marginal rate of return (%) for application of N and P fertilizer rates at current prices.

Treatments	TCV (EtB ha-1)	NB (EtB ha-1)	Raised cost	Raised benefit	MRR (%)
N/P (kg ha-1)					
0/0	2576	6552	-	-	-
0/23	3657	8271	1081	1719	159.02
46/0	3965	8439	308	168	54.55
138/0	5264	8456	1299	17	1.31
46/69	5302	8754	38	298	784.21
92/0	5518	10750	216	1996	924.07

Field price of N = Birr 3.38 per kg; Field price of P =Birr 4.38 per kg; Retail price of grain = Birr 4000 per ton; TCV = Total cost that vary; NB = Net benefit; MRR = Marginal rate of return; EtB = Ethiopian Birr.

Changing from treatments 0/0 to 0/23 and 0/23 to 92/0 kg N/P ha-1 gave 117.44 and 681.53% MRR, respectively (Table 11) which were above the minimum acceptable MRR of 100% except 46/69 which was below the minimum acceptable MRR. These results agree with Saha *et al.* (1994) whose findings from coastal Kenya on maize showed that the application of 30 kg N ha-1 consistently gave acceptable economic returns.

Table 11. Sensitivity analysis of rice production after different practices based on a 15% rise in total cost and rice price of gross field benefit fall.

Treatment	TCV (EtB ha-1)	NB (EtB ha-1)	Increment cost	Increment benefit	MRR (%)
N/P (kg ha-1)					
0/0	2962	5569	-	-	-
0/23	4206	7030	1244	1461	117.44
46/69	6097	7441	1895	411	21.69
92/0	6346	9138	249	1697	681.53

Field price of N = Birr 3.89 per kg; Field price of P =Birr 5.04 per kg; Retail price of grain = Birr 3400 per ton; TCV = Total cost that vary; NB = Net benefit; MRR = Marginal rate of return; EtB = Ethiopian Birr.

Therefore, with 23 kg P and 92 kg N ha^{-1} give an economic yield response and also sustained acceptable even under a projected worsening trade conditions in Gambella. On a tentative basis farmers could thus choose any of the two new fertilizer rates depending on their resources. The results of this research can be used to make tentative recommendations, which can be refined through multi-location testing over a wider area.

4. Conclusions

The growth, yield components and yield of the rice variety NERICA-3 responded strongly to N fertilizer application. Accordingly, higher magnitudes of increase in almost all the parameters studied were obtained with applied N fertilizer. In this study, number of effective tillers $plant^{-1}$ and number of grains $panicle^{-1}$ were the most important yield forming attributes causing significant variation in grain yield of rice. From the range of treatments tested, 92 kg N ha^{-1} gave significantly higher grain yield. Crude protein and ether extract with N and crude fibre both with N and P application were significantly influenced. Application of 23 kg P or 92 kg N ha^{-1} gave an economic yield response. However, P application had no significant impact on rice growth, yield attributes and yield except crude protein. Hence, on a tentative basis, farmers at and around *Imla* site, Gambella Zuria District) could use either of the two rates of nutrients (23 P alone or 92 N kg ha^{-1}) in order to achieve economic grain yield of NERICA-3 rice grown on brown clay soils under rain fed conditions. Therefore, in the light of the significant response of rice to N fertilizer, further studies aimed at promoting integrated soil fertility management and formulation of fertilizer recommendation based on soil and plant tests over locations will be useful.

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