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Research Article

Fine Rice in Punjab: Response and Economics of Increasing Levels of Nitrogen

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ABSTRACT

With changing climate and introduction of new varieties over time, it is imperative to revisit the nitrogen fertilizer dose for optimum rice yields. Increasing prices of N has also necessitated the calculation of economics of N use. To achieve these objectives, a number of field studies were conducted on fine rice to determine its response to increasing nitrogen doses in Rice-Wheat and Central zones of Punjab Pakistan for four years from 2017 to 2020. During the first two years of study (2017 and 2018), seven doses of N (0, 28, 56, 84, 112, 140, 168 kg ha^{-1}) were tested at different locations. Half of nitrogen was applied to soil at transplanting and remaining half was applied about 30 to 35 days after transplanting. Phosphorus and potash were applied to soil at transplanting uniformly @ 90 and 60 kg ha^{-1} to all treatments except the check (No fertilizer). Increasing nitrogen levels upto 140 kg ha^{-1}, a significant increase in paddy yield was observed. However, further increase in N level did not result in any increase in yield; rather it decreased paddy yield. Agronomic efficiency and partial factor productivity of N decreased with increasing doses of N and it was reduced to 9.3 and 30 respectively at N level of 140 and 168 kg ha^{-1}. Economic analysis of N use on fine rice showed decreasing marginal rate of return (MRR) with increasing doses on N and it was 5.0 and 2.5 respectively for Rice-Wheat and Central zones at 140 kg N ha^{-1}. Above this level of N, the MRR became negative. Therefore, it was concluded that soil application of 140 kg N ha^{-1} was the most optimum dose for obtaining an economic yield for current scenario for fine varieties of rice. The outcome of this study will help formulating nitrogen fertilizer recommendation of fine rice.

Keywords: Economics, Fine rice, Nitrogen, Paddy, Yield.

INTRODUCTION

Among rice producing countries, Pakistan stands at 11th in rice production and 4th among exporters, as it counts 0.7% of GDP. In Pakistan, rice ranks second staple cereal crop and an important source of earning revenue through foreign exchange (Irshad *et al.*, 2018). To achieve the production level of rice and further increase the yield, application of essential nutrients required by crop plays a key role. Management of nutrients while applying them to crops is the main concern in order to achieve a profitable yield (Singh *et al.*, 2016). Nitrogen application also improved eating quality of rice (Ma *et al.*, 2024). Among all essential nutrients, N, P and K are the primary macronutrients important for optimum growth and yield of crop.

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Nitrogen plays a key role in plant growth by (i) influencing physiological attributes such as increases in plant heights and tiller numbers, (ii) synthesis of many components (growth hormones, hereditary material DNA, RNA, vitamins, enzyme proteins etc.) and their distribution to all plant parts (Noor, 2017). Maximum nitrogen use efficiency agronomic (ANUE) and economic (ENUE) was noted in Guard Lp-18 with 50 kg ha^{-1} of N. similarly, water use efficiency (WUE) was also maximum in same cultivar with 75 kg ha^{-1} of N. The highest gross income, net income, and benefit cost ratio (BCR) were noted at 75 kg N ha^{-1} among all cultivars (Wahab *et al.*, 2024).
For achieving optimum level of plant growth and yield, plants require all essential nutrients in balanced amount. Besides increasing plant growth and yield, balanced nutrition also maintains soil fertility and sustain the productivity level of crops (Saha *et al.*, 2017). Balanced fertilization means the dose of each required nutrient at which it gives profitable economic yield at minimum cost of production. Use of fertilizer above this dose does not give return, instead it is a burden on grower (Aslam *et al.*, 2015). In Pakistan, the main focus in fertilization is often limited to the sole application of nitrogen or imbalanced use of fertilizers with overuse of nitrogen-based fertilizers. Blind use of fertilizers without considering the benefit cost ratio and return obtained from applied inputs is a financial burden on today's farming community (Shahzad *et al.*, 2019). Excessive dose of N may also reduce grain filling resulting in decreased yield and grain quality (Zhao *et al.*, 2022). Moreover, excessive dose may also increase insect attack (Randhawa and Aulakh, 2014). Information on response of coarse varieties to N application is available but information on N response by fine rice varieties is limited since these varieties are only available in Pakistan and India. Therefore, this study was under-taken to evaluate the response of fine rice to increasing levels of nitrogen, its agronomic efficiency along with economics.

MATERIALS AND METHODS

Locations

This study was conducted on 31 plots at farmers' fields at fourteen locations (Table 1) in Rice and Central zones of Punjab to evaluate the response of increasing levels of nitrogen (N) on yield of fine rice varieties. In brief the Rice zone includes Lahore and Gujranwala divisions while the Central zone comprises of Faisalabad, Sargodha and Sahiwal Divisions. Rice zone is actually a Rice-Wheat dominant area whereas Central zone is a mixed cropping area.

Table 1. List of experimental location (2017 to 2020).

Sr. No	Zone	Locations	Latitude	Longitude
1	Rice-Wheat Zone	Narowal	32.100269°	74.725613°
2	-do-	Gujranwala	32.242752°	73.978344°
3	-do-	Gujrat	32.493345°	74.002451°
4	-do-	Hafizabad	32.022951°	73.556217°
5	-do-	Kala Shah Kaku	31.717607°	74.172543°
6	-do-	Shahkot	31.590372°	73.498027°
7	-do-	Safdarabad	31.715363°	73.569266°
8	-do-	Zafarwal	32.242004°	74.715898°
9	-do-	Sunder Lahore	31.345607°	74.124294°
10	Central Zone	Faisalabad	31.177175°	72.984906°
11	-do-	Khushab	32.324317°	72.280135°
12	-do-	Sargodha	32.106033°	72.478772°
13	-do-	Tandlianwala	31.053078°	73.161883°
14	-do-	Vehari	30.068433°	72.533760°

Climate

Experiments were conducted in Lahore, Gujranwala divisions commonly known a Rice zone. In Rice-Wheat zone, rice-wheat cropping system is most prevalent. Whereas, Faisalabad, Sargodha divisions including Vehari are commonly known as Central zone where mixed cropping system is prevalent. All these sites may be included in semi-arid climate. In Rice zone, during summers, maximum monthly temperatures from June to September generally reach a maximum monthly temperature of 35 to 40 ^{o}C. Whereas, temperature from November to January falls between 5.0 to 10 ^{o}C. In Gujranwala, maximum rainfall occurs in the months of July and August with 147 and 168 mm respectively which is 54 percent of total annual. Climate of Lahore is also similar to this. Central zone is relatively hotter in temperature. Mean maximum monthly temperatures range between 42 to 44 ^{0}C with average of 44 to 50 mm in July and August with frequent rainfalls.

Experimental conditions

During first two years, the doses of nitrogen were 0, 28, 56, 84, 112 and 140 kg ha^{-1}. All the fertilizer was added as soil application. However, during later two years, an additional treatment 168 kg N ha^{-1} was also added in the study in both the zones. The basal dose of phosphorus @ 90 kg ha^{-1} and potash @ 60 kg ha^{-1} was applied to all treatments as control (Table 2).

Table 2. Dose of nitrogen, phosphorous and potash used in the experiment.

Sr. No	kg ha^{-1}		
Nutrient	N	P_2O_5	K_2O
1	0	0	0
2	0	90	60
3	28	90	60
4	56	90	60
5	84	90	60
6	112	90	60
7	140	90	60
8*	168	90	60

*Included in 2019 and 2020 only.

Zinc was applied to all treatments @ 5 kg ha^{-1}. The experiments were carried out in randomized complete block design (RCBD) with three replications. All the treatments were applied to each sub plot uniformly according to treatment plan. Half N and all P, K and Zn was applied to soil through broadcast at transplanting. Remaining half N was applied to the field through broadcast at 30 to 35 days after transplanting. Transplanting of fine rice varieties was done manually in third week of July at all study locations. Fine varieties included Super Basmati, Basmati 515 and PK-1121. Plant population was maintained between 1,90,000 to 2,00,000 plants per hectare. All practices regarding pest and diseases control were adapted according to recommendations of the agriculture department. Subplots were harvested from experimental plots and threshing was done manually in mid of November.

Soil sampling and analysis

Soil samples were taken from all experimental sites (from 0-15 cm depth) in a zig zag pattern to make composite sample from each site for evaluation of soil chemical properties and fertility status. Samples were brought to the laboratory, air dried and ground and passed through 2mm sieve. Electrical conductivity and pH were analyzed according to method described by (Jackson, 1973). Organic matter of experimental sites was determined by using Walkley-Black method described in Nelson and Sommers (1996). Whereas, available P was determined by Olsen's method using sodium bicarbonate as extracting agent (Olsen *et al.*, 1982). Potassium was determined on flamephotometer after extraction by 1N ammonium acetate extractant.

Agronomy nutrient efficiency (ANE) and Partial factor productivity (PFP)

Agronomic nutrient efficiency (ANE) and partial factor productivity (PFP) of nitrogen was calculated by using the equation (i) and (ii).

$$\mathrm{ANE} = \frac{\mathrm{Yt-Yo}}{Nt} \quad \text{......................(i)}$$

$$\mathrm{PFP} = \frac{\mathrm{Yt}}{Nt} \quad \text{..........................(ii)}$$

Where Y_t and Y_0 are fine paddy yields for that particular N treatment and control T_2 (0) plot and Nt is the dose of N level.

Statistical Analysis

Statistical analysis of yield data was done through using analysis of variance (ANOVA) techniques. Regression analysis was also carried. Methods described by Gomez and Gomez (1984) were used for statistical analysis.

Economic Analysis

The economics of N was calculated. Marginal rate of return (MRR) techniques were employed to calculate the profitability with increasing level of N. The following equation was used to determine the MRR of nitrogen.

$$\mathrm{MRR} = \frac{\text{Marginal Revenue}}{\text{Marginal nutrient cost}} \quad \text{........................(iii)}$$

Where marginal revenue is the value of additional paddy yield above the previous N level and the marginal nutrient cost is the additional cost of N above the previous level.

RESULTS

Soil Characteristics of Experimental Sites

The experimental sites were free from salinity or sodicity problems (Tables 3, 4). The soil electrical conductivity less

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than 4.0 dS m^{-1} and pH less than 8.5 was classified as normal soil. The electrical conductivity (EC) of soils ranged between 0.9 to 2.84 dS m^{-1} in these two zones. Similarly, the soil reaction (pH) of these soils ranged between 7.8 to 8.4. Soil organic matter of these sites ranged between 0.25 to 0.84 percent which is classified as poor (<0.86%). Average available phosphorus contents in soils ranged between 5.5 and 6.8 ppm during these years. Again the soils were classified as poor. Generally, extractable soil potash varied from low to medium in Rice zone and medium to adequate in Central zone respectively.

Table 3. Pre sowing soil analysis of experimental sites (2017, 18).

Soil Parameters	2017				2018			
	Rice zone		Central zone		Rice zone		Central zone	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
EC (dS m^{-1})	2.18	1.03-3.8	2.01	1.35-2.95	0.90	0.90-0.90	2.01	1.80-2.19
pH	8.4	8.3-8.4	8.1	7.8-8.2	7.9	7.7-8.0	8.0	7.9-8.1
OM%	0.25	0.10-0.60	0.76	0.62-0.84	0.74	0.68-0.80	0.75	0.54-0.84
Available P (ppm)	7.0	6.0-8.0	6.4	5.7-7.3	7.0	6.0-8.0	5.5	4.5-6.6
Extractable K (ppm)	131	78-180	189	174-200	64	64-64	175	170-180

Table 4. Pre-sowing soil analyses of experiment sites (2019, 20).

Soil Parameters	2019				2020		
	Rice zone		Central zone		Rice zone		Central zone
	Mean	Range	Value	Range	Mean	Range	Mean
EC (dS m^{-1})	2.84	1.10-3.40	1.99	0.42-2.78	1.34	0.85-1.80	1.24
pH	8.0	7.6-8.4	7.8	7.0-8.3	8.0	7.5-8.4	8.4
OM%	0.79	0.56-1.05	0.84	0.63-1.04	0.77	0.63-1.05	0.98
Available P (ppm)	4.5	1.5-6.2	6.8	5.3-9.3	6.4	5.4-7.6	6.80
Extractable K (ppm)	101	62-121	196	148-312	82	42-126	180

Effect of nitrogen levels on paddy yield

In the Rice Zone, on an overall basis during four years (2017 to 2020), paddy yield was increased from 3.884 to 5.025 t ha^{-1} with increasing N application from 28 to 140 kg N ha^{-1} (Figure 1) showing the increase of 29 percent. However, increasing N dose beyond 140 kg ha^{-1} did not further increase paddy yield significantly rather it started decreasing (Tables 5, 6). A similar trend was observed in Central Zone application of N from 28 to 140 kg N ha^{-1} increased the paddy yield from 3.688 to 5.036 t ha^{-1}. On individual-year basis, the trend was also similar in both the Rice and Central Zones. Paddy yield equations for both zones are given below.

$y = 3.157 + 0.025x – 0.00009x^2$, $R^2 = 0.98$ (Rice zone)

$y = 2.919 + 0.029x – 0.0001x^2$, $R^2 = 0.99$ (Central zone)

Where y= paddy yield in t ha^{-1} and x= nitrogen dose in kg ha^{-1}

Similar results were obtained by Aslam et al (2015) who reported that paddy yield of rice increases with increased level of nitrogen fertilizer, however after a certain limit decline in yield started. In another study by Djaman *et al.* (2018) on the effect of nitrogen (N) fertilizer dose on yield and NUE (nitrogen use efficiency) of Rice, it was concluded that 150 kg ha^{-1} was more than enough for obtaining an optimum yield. In the same area, the yield of fine rice could not be increased with application of N above 135 kg ha^{-1} (Iqbal *et al.*, 2023). As in this reported study and the current study, P and K was added in recommended amounts, so climate or inherent yield potential could be the reason for lack of yield increase. The higher crop yield seemed to be the cumulative effect of growth parameters which were boosted by balanced nutrient application (Singh, 2017). All these findings are also supported in other studies as well (Pyngrope *et al.*, 2019).

Agronomic Nutrient Efficiency (ANE) and Partial Factor Productivity (PFP)

Yield data of both Rice and Central zones indicated that ANE and PFP of nitrogen decreased (table 7, figure 2) rapidly with increasing N levels. In both these zones, the agronomic efficiency was almost similar. The results showed that higher doses of N were less productive as compared to lower doses of N.

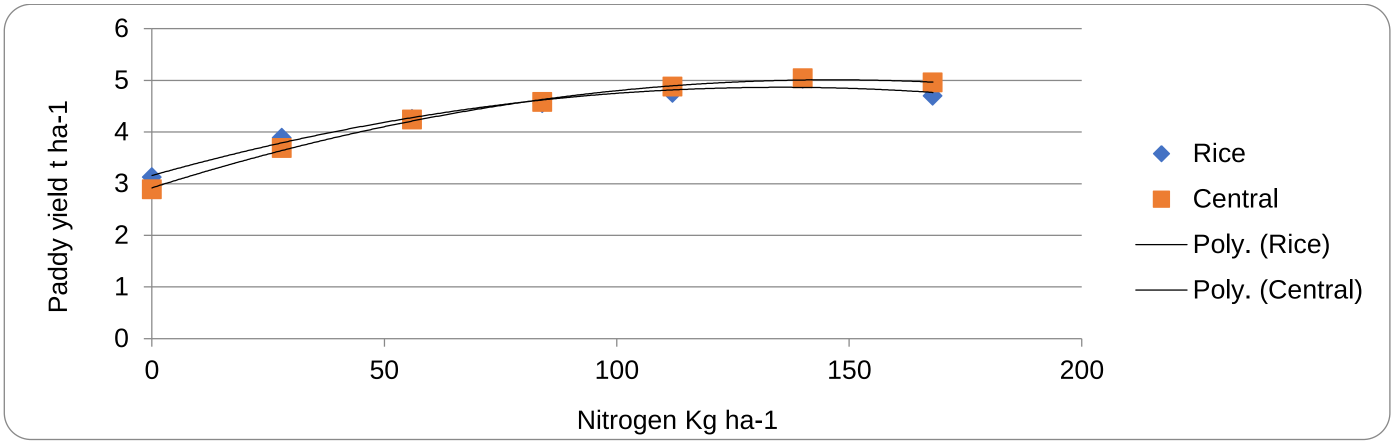

Figure 1. Effect of nitrogen levels on paddy yield in rice and central zones.

Table 5. Effect of NPK level on paddy yield (t ha^{-1}) in rice zone Punjab.

Treatments	$N-P_2O_5-K_2O$	2017	2018	2019	2020	Average
# of sites	Kg ha^{-1}	3	2	5	5	
T_1	0-0-0	2.608f	2.580f	2.063f	2.909e	2.523g
T_2	0-90-60	3.083e	3.637e	2.702e	3.362d	3.123f
T_3	28-90-60	3.853d	4.335d	3.506d	4.100c	3.884e
T_4	56-90-60	4.198cd	4.693c	3.906c	4.457bc	4.253d
T_5	84-90-60	4.546bc	5.147b	4.218bc	4.655ab	4.553c
T_6	112-90-60	4.916b	5.418b	4.447ab	4.705ab	4.756b
T_7	140-90-60	5.473a	5.752a	4.566a	4.923a	5.025a
T_8	168-90-60	-	-	4.601a	4.790ab	4.696b
Lsd 0.05		0.372	0.272	0.186	0.357	0.126

Table 6. Effect of N levels on paddy yield (t ha^{-1}) in central zone Punjab.

Treatments/ Year	$N-P_2O_5-K_2O$	2017	2018	2019	2020	Average
# of sites	Kg ha^{-1}	6	4	5	1	
T_1	0-0-0	2.139g	1.703f	1.895g	3.026g	2.009h
T_2	0-90-60	2.715f	2.774e	2.822f	4.722f	2.889g
T_3	28-90-60	3.618e	3.677d	3.492e	5.130e	3.688f
T_4	56-90-60	4.170d	4.314c	4.041d	5.333d	4.238e
T_5	84-90-60	4.499c	4.755b	4.348c	5.491c	4.578d
T_6	112-90-60	4.853b	5.120a	4.576b	5.593bc	4.879c
T_7	140-90-60	5.041a	5.187a	4.740ab	5.889a	5.036a
T_8	168-90-60	-	-	4.822a	5.648b	4.960b
		0.158	0.235	0.313	0.145	0.087

Economics Analysis

In the Rice zone, the highest marginal rate of return (MRR) was found in T_3, i.e. 15.99 (Table 8), with the minimum dose of N i.e. 28 kg ha^{-1}. In T_7 (N@140 kg ha^{-1}), MRR was 5.00 which means that N was still economical to apply. However, in T_8, with a further increase in N application to 168 kg ha^{-1}, MRR became negative. Therefore, the maximum dose of N which was economical was 140 kg ha^{-1}. N doses higher than 140 kg ha^{-1} may result in an economic loss in the first place due to more input cost of N and secondly due to disease and insects associated with higher doses of N owing to succulence. In the Central zone, the highest MRR was 16.83 observed with 28 kg ha^{-1} of N whereas with 140 kg ha^{-1} MRR was reduced to 2.50 which means still economical. However, 168 kg ha^{-1} of N had negative MRR showing it un-economical. Similar results were obtained in another study in Rice zone by Iqbal *et al.* (2023), where the use of N @180 kg ha^{-1} was not found economically viable (Table 9). Therefore, in present study, due to lower ANE and PFP of 168 kg ha^{-1} coupled with absence of yield increase over 140, the use of N above 140 kg ha^{-1} at current prices only increased the cost without increasing yield. T_7 (N@140 kg ha^{-1}) was found to have an MRR of 2.98 which means that it was still economical but N higher than that resulted in a negative MRR (-0.54).

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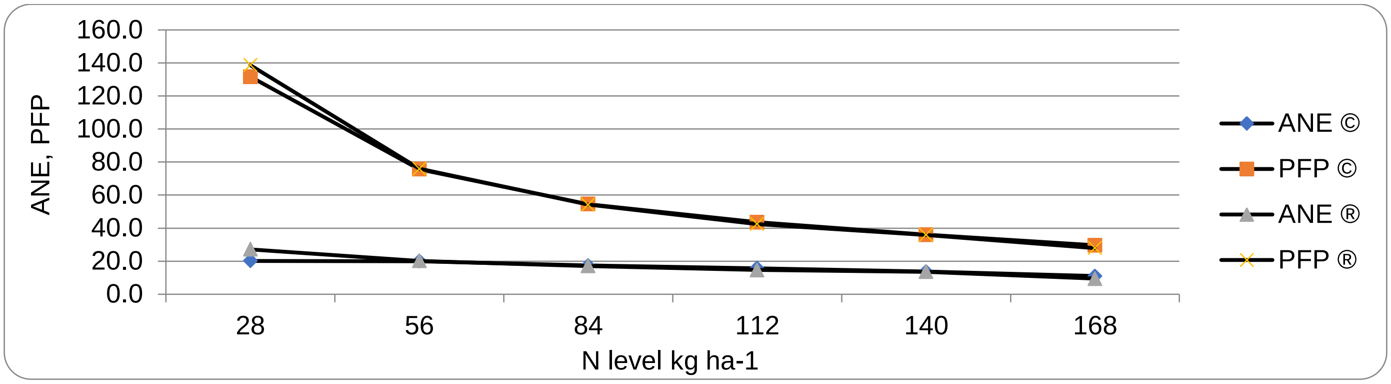

Figure 2. Agronomic efficiency and partial factor productivity of N at different levels of application; © Central zone, ® Rice zone.

Table 7. Agronomic efficiency and partial factor productivity of N (Rice and Central Zone).

T #	N kg / ha	Fertilizer N Cost (Rs ha^{-1})	Paddy Yield (t ha^{-1})	Agronomic N Efficiency	Partial Factor Productivity*	Paddy Yield (t ha^{-1})	Agronomic N Efficiency	Partial Factor Productivity*
			Rice Zone			Central Zone		
1	0	0	2.523	-	-	2.009		
2	0	0	3.123	-	-	2.889		
3	28	4,368	3.884	27.18	139	3.688	20.18	132
4	56	8,736	4.253	20.18	76	4.238	19.91	76
5	84	13,104	4.553	17.02	54	4.578	17.32	55
6	112	17,472	4.756	14.58	42	4.879	15.68	44
7	140	21,840	5.025	13.59	36	5.036	13.66	36
8	168	26,208	4.696	9.36	28	4.960	10.93	30

Table 8. MRR of N application on paddy yield (t ha^{-1}) in Rice Zone.

Sr No	N (kg ha^{-1})	Gross Return (Rs ha^{-1})	Net Return = (Gross Return-Nitrogen Cost) Rs ha^{-1}	Marginal Return (Rs ha^{-1})	Marginal Rate of Return (MRR)
1	2	3	4	5=(T_i-T_{i-1})	6=(T_i-T_{i-1}/T_{i-1})
T_1	0	2,45,993	2,45,993		
T_2	0	3,04,493	3,04,493		
T_3	28	3,78,690	3,74,322	69,830	15.99
T_4	56	4,14,668	4,05,932	31,610	7.24
T_5	84	4,43,918	4,30,814	24,882	5.70
T_6	112	4,63,710	4,46,238	15,425	3.53
T_7	140	4,89,938	4,68,098	21,860	5.00
T_8	168	4,57,811	4,31,603	-36,494	-8.35

Price of N used=N@ Rs 156 kg^{-1}, T_1=No fertilizer; in T_2 to T_8, P_2O_5 and K_2O added @ 90-60 kg ha^{-1}.

Table 9. MRR of N application on fine varieties paddy yield (t ha^{-1}) in Central Zone.

Sr. No	N (kg ha^{-1})	Gross Return (Rs ha^{-1})	Net Return = (Gross Return-Nitrogen Cost) Rs ha^{-1}	Marginal Return (Rs ha^{-1})	Marginal Rate of Return (MRR)
1	2	3	4	5=(T_i-T_{i-1})	6=(T_i-T_{i-1}/T_{i-1})
T_1	0	1,95,878	1,95,878		
T_2	0	2,81,678	2,81,678		
T_3	28	3,59,580	3,55,212	73,535	16.83
T_4	56	4,13,205	4,04,469	49,257	11.28
T_5	84	4,46,355	4,33,251	28,782	6.59
T_6	112	4,75,703	4,58,231	24,979	5.72
T_7	140	4,91,010	4,69,170	10,940	2.50
T_8	168	4,83,600	4,57,392	-11,778	-2.70

Price of N used=N@ Rs 156 kg^{-1}, T_1=No fertilizer, in T_2 to T_8 P and K added @ 90-60 kg ha^{-1}

These results were found similar to previous studies (Malik *et al.*, 2014) which reported an N dose of 120 kg ha^{-1} for improving yield components in Basmati varieties in India and economics in terms of MRR. Reduction of profitability with an excessive dose of N is a common phenomenon due to the increase of insect and disease attacks on rice and other crops. In another study by Sapkota *et al.* (2020) on the Indo-Gangetic Plain, it was observed that N application rates from 120 to 200 kg ha^{-1} have the most economic returns and are environmentally sustainable. Excessive use of nitrogen has also been reported as a critical factor in crop productivity from an economical and sustainability point of view (Shahzad *et al.*, 2019). In Northern India, similar results have been obtained for N between 120-150 kg ha^{-1} but on the basis of economics, the recommended dose was 120 kg ha^{-1} (Jehangir *et al.*, 2022).

CONCLUSION

It was concluded from above field studies that in both Rice and Central Zones, application of increasing levels of nitrogen upto 140 kg ha^{-1} increased paddy yield. Above this level, N application decreased the yield, decreased agronomic efficiency and economic benefit. Therefore, to get maximum financial benefit and agronomic efficiency N@140 kg ha^{-1} may be recommended for farmers. Moreover, research on application of N on soil analysis based is also needed to meet N needs of fine rice and improve fine paddy yield.

AUTHOR CONTRIBUTIONS

All the authors contributed equally in the manuscript.

COMPETING OF INTEREST

The authors have not declared any conflict of interest.

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