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Economics of Nitrogen Fertiliser Application in Rice, Wheat and Maize Grown in the Indo-Gangetic Plains

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Nitrogen (N) is a key factor for cereal production in India. N is predominantly supplied to the plants through fertiliser application. The average response to applied fertiliser N has been declining steadily over the past decades. As a result, farmers are compelled to apply higher doses of fertiliser N to maintain the yields of the preceding years. Considering the increasing demand of N fertiliser in the coming years, wide variability in soil N supplying capacity and wide production gaps in the predominant cereals, the present on-farm study was undertaken in the Indo-Gangetic Plains (IGP). The objective was to estimate response of cereals (rice, wheat and maize) to N application, the economics and profitability of N application with changing fertiliser price scenario. On-farm results indicated yield loss due to N omission to the tune of 667-3337 kg ha^{-1}in rice, 500-4750 kg ha^{-1} in wheat and 400- 5160 kg ha^{-1} in maize. On the other hand, optimum use of N at observed N response levels, current and projected prices of N fertiliser and minimum support price of rice, wheat and maize had return on investment e" 3 indicating increasing significance of precise N management in cereals in the IGP. Results also suggest that advanced strategies of N management considering the indigenous N supplying capacity of soil, yield response, and agronomic efficiency of N at a given environment may become an important tool for improving farm profitability from N use in IGP.

Nitrogen plays a key role in increasing the foodgrain production of India. In the modern agro-ecosystems, it was estimated that removal of as much as 300 kg N ha^{-1} yr^{-1} in the above ground portions of the harvested produce necessitates substantial inputs of nitrogen either through fertilisers, manures or N-fixation via legumes to maintain the productivity (2). In India, N consumption was increased from 0.06 mt in 1951-52 to 15 mt in 2008-09 with a corresponding fourfold increase in foodgrain production from 50.8 to 233.9 mt during this period (6). Further, it was estimated that the majority of the crop requirement for N in the country is supplied primarily through fertilisers.

Soils of the Indo-Gangetic plains (IGP) are inherently low in soil organic matter and nitrogen is the major limiting plant nutrient, with N availability being routinely supplemented through application of fertilisers. Though the yield increase due to N fertilisation was substantial (47% in rice, 50% in wheat and 92% in maize), the average agronomic efficiency of N (kg grain kg^{-1} N) was only 11.4 in rice, 6.2 in wheat and 12.5 in maize (8) indicating low N use efficiency. A decline in N response in irrigated areas from 13.4 to 3.7 kg grain kg^{-1} N between 1970 and 2005 was also reported (1). Farmers in the IGP tend to apply high doses of fertiliser N in order to witness the same yields of the preceding years. This undermines the fact that managing N use efficiency is critical for improving crop productivity as indiscriminate and imbalanced application of N fertilisers will not only cause economic loss but will also lead to environmental hazards through leaching and volatilization.

Cereals constitute the staple food in India and about 61% of the protein requirement of Indian population is met through cereals. Cereals use 69% of the total fertiliser consumed in India of which rice, wheat and maize utilize 37, 24 and 2% of the total fertiliser (3), respectively. Rice is a major foodgrain crop predominantly grown during the *Kharif* season in the IGP. The average yield of rice in India during 1950-51 was 774 kg ha^{-1} which increased to 2125 kg ha^{-1} during 2010-11 (7), however, the productivity varies widely between major rice growing states in the country.

Table 1 – Characteristics of the experimental sites

State	Districts	Agro-climatic zone	Soil texture	Average annual precipitation (mm)	Cropping system	Crops studied	Ecology
Punjab	Ludhiana, Amritsar, Gurdaspur, Sangrur, Fatehgarh Sahib	Central Plain Zone to Sub-Mountain Undulating Zone	Sandy loam to silty loam	600-1020	Rice-Wheat, Cotton-Wheat	Rice and Wheat	Irrigated
Haryana	Karnal, Kurukashetra, Kaithal, Ambala, Yumnanagar	North Western Plain Zone	Sandy loam to clay loam	400-600	Rice-Wheat	Rice and Wheat	Irrigated
Uttar Pradesh	Agra	South Western Plain Zone	Sandy loam	650	Pearl millet-Wheat	Wheat	Irrigated
Bihar	Vaishali, Samastipur, Purnea, Katihar, Begusarai, Patna and Jamui	North West, North East and South Bihar Alluvial Plains	Sandy loam to silty clay loam	1100-1400	Rice-Maize	Rice and Maize	Irrigated
West Bengal	Uttar Dinajpur and Nadia	Old and New Alluvial Zone	Sandy loam to silty clay loam	1300-1500	Rice-Maize	Maize	Irrigated

Wheat is grown during the *Rabi* season in the IGP. India's current wheat production of 79 mt (2009-10) has to reach 105 mt by 2025, calling for an average growth rate of 4% per annum (8). The average productivity of wheat in the country is 2839 kg ha^{-1} with highest yield recorded in Punjab (4307 kg ha^{-1}) followed by Haryana (4213 kg ha^{-1}), Rajasthan (3133 kg ha^{-1}), Uttar Pradesh (2846 kg ha^{-1}), West Bengal (2680 kg ha^{-1}) and Bihar (2084 kg ha^{-1}) indicating wide yield differences between the major wheat growing states in the country (7). Currently declining profitability of wheat cultivation is causing unrest among the farmers (4).

Considering the huge stakes that these three crops carry in ensuring the food and energy security of the country, and also looking at the significant role of nitrogen input in the coming years, this study was undertaken to estimate: (a) response of cereals to N application in the IGP, (b) economic returns on application of N, and (c) profitability of N application with changing fertiliser price scenario.

MATERIALS AND METHOD

On-farm trials were carried out over a period of three years (2009-11) across the IGP covering the states of Punjab, Haryana, Uttar Pradesh, Bihar, Jharkhand and West Bengal in order to understand the soil characteristics and growing environments responsible for variable crop response to N application (**Table 1**). Locations with variable soil genesis and different crop management practices were selected to assess the effect of site variability on crop response to N application.

The experiment consisted of four treatments viz. T_1 - Ample NPK, T_2 - Omission of N with full P and K, T_3 - Omission of P with full N and K, and T_4 - Omission of K with full N and P. Nutrient application rates for rice were 125–175 kg N ha^{-1}, 50–80 kg P_2O_5 ha^{-1} and 60–90 kg K_2O ha^{-1} based on estimated yield target of 5–8 t ha^{-1}. In wheat, the estimated yield target of 5-6 t ha^{-1} was considered and N, P_2O_5 and K_2O were applied at 150–180, 90 and 100 kg ha^{-1}, respectively. Maize trials were concentrated only in Bihar and West Bengal and 150–180 kg N, 70–115 kg P_2O_5 and 120–160 kg K_2O ha^{-1} respectively were applied for 6-8 t ha^{-1} of yield target. Deficient secondary and micronutrients were also applied as per the blanket recommendation at each location to ensure that there is no limitation from these nutrients while determining the crop response to applied nutrients.

Computations and Economic Analysis

The yield response due to N (N response) and N application economics under rice, wheat and maize were estimated as follows:

$$N_R = GY_{NPK} - GY_{N0} \quad (1)$$

Where, N_R is the response to N application and GY_{NPK} and GY_{N0} are the grain yield in ample NPK plot and in N omission plot, respectively, expressed in kg ha^{-1}.

The economic significance of N use under rice, wheat and maize was assessed in terms of Rupees/Rupee invested on nitrogen (ROI_N) as:

$$ROI_N = (N_R \times MSP)/(N_U \times Nc) \quad (2)$$

Where MSP is the minimum support price of rice, wheat and maize, N_U and Nc are the amount of nitrogen (N) used (kg ha^{-1}) and cost of N (Rs kg^{-1}), respectively. The minimum support price of rice, wheat and maize was Rs 10, 11.7 and 8.80 kg^{-1} respectively while the cost of N was Rs. 11.54 kg^{-1}.

Return on investment (ROI) for N (i.e. rupees per rupee invested on N fertiliser) was estimated at four price levels of urea, Rs. 4830 (Rs 10.5 kg^{-1} N), Rs. 5310 (Rs 11.4 kg^{-1} N), Rs. 10000 (Rs 21.7 kg^{-1} N) and a further higher price of Rs. 15000 t^{-1} (Rs 32.6 kg^{-1} N), at five N response levels with N application based on three levels of agronomic efficiency of N (AEN, kg grain kg^{-1} N). Low nitrogen use efficiency in the cereals is a major concern as farmers often apply N in excess of actual requirement. Imbalanced application of other limiting nutrients along with N is one of the major reasons for such low AEN in India. The AEN levels used (16, 18 and 20 kg kg^{-1} N) for calculating ROI for the three cereal crops are attainable with good N management and average climatic conditions. Lower AEN can be expected with poor climatic conditions or poor N management. Higher AEN (>20 kg grain kg^{-1} N) are possible for these crops when climatic conditions are highly favourable and crop and nutrient management practices are optimal. In addition, the current and projected prices of N fertiliser and grain price (MSP) were used to estimate ROI for all the three crops. Calculations were based on the following criteria:

- Four price levels of N between Rs. 10.5 kg^{-1} N to Rs. 43.48 kg^{-1} N that correspond to urea price between Rs. 4830 and Rs. 20000 t^{-1} .
- Three N response levels corresponding to 25th, 50th and 75th percentile of the actual responses in each crop. The N response levels were: 1330, 1610 and 2080 kg ha^{-1} for rice; 2160, 2470 and 3080 kg ha^{-1} for wheat; and 1450, 1960 and 2590 kg ha^{-1} for maize.
- Fertiliser N rates assumed to be sufficient for the observed N responses:

• **Rice:** N response of 1000 kg ha^{-1} justifies application of 80 kg N ha^{-1} while N response of 1500 and 2000 kg ha^{-1} will require application of 100 and 120 kg N ha^{-1}, respectively.

• **Wheat:** Calculations were based on 120, 140 and 160 kg N ha^{-1}

applications rates at locations with 2000, 2500 and 3000 kg N ha^{-1} yield responses, respectively.

- **Maize:** Calculations were based on 120, 140 and 160 kg N ha^{-1} application rates at locations with yield response of 1500, 2000 and 2600 kg ha^{-1}, respectively.

♦ MSP levels of Rs 10 to Rs 15 per kg rice, Rs. 11 to Rs 16 per kg wheat, and Rs 9 to Rs 14 kg^{-1} maize.

RESULTS AND DISCUSSION

Yield Responses

On-farm studies revealed that application of 125-175 kg ha^{-1} N in the ample NPK treatment across 45 locations of the IGP recorded a significantly higher average grain yield of rice (4701 kg ha^{-1}) over the N omission treatment (2963 kg ha^{-1}), representing 59% higher grain yield. Yield response to application of N expressed as the difference in yield between ample NPK and N omission ranged between 667-3337 kg $ha^{-1}$with an average of 1739 kg ha^{-1} (**Figure 1**). The results are in agreement with the findings of Saha *et al* (10) who reported a yield response of 1510 kg ha^{-1} with application of N in the long term fertiliser experiments conducted at Raipur during 1999-2009.

Yield response studies conducted in the farmer fields at 141 locations across the Trans and Upper Gangetic Plains revealed that N application of 150-180 kg ha^{-1} showed a wheat yield response ranging from 500-4750 kg ha^{-1} with an average of 2566 kg ha^{-1} (**Figure 2**).

Omission plot trials conducted across 36 locations in Bihar and West Bengal (**Figure 3**) revealed that maize yield response due to application of 150-180 kg ha^{-1} N ranged from 400-5160 kg ha^{-1}, with an average of 2154 kg ha^{-1}. Singh (11) also reported 2815 kg ha^{-1} of maize yield response due to N application at Palampur.

Information on crop yield response to N fertiliser application paves the way to improve crop yields through use of nutrients at the right rate thus helping to manage the scenarios of escalating fertiliser prices. Also, wise decision on fertiliser application requires knowledge of the expected crop yield response to applied nutrient and is a function of nutrient removal by crop, supply of nutrients from indigenous sources and the short and long-term fate of the applied fertiliser (5). Further, application of N as per the crop yield response also helps to prevent indiscriminate and imbalanced use of N fertilisers by farmers by giving due consideration to the inherent soil fertility status and the nutrient requirement by crop thus minimizing the adverse effects on soil, climate and crop (9).

ECONOMIC RETURNS

Economic Returns based on Actual N Responses, N Fertiliser Rates and N Fertiliser Prices

N fertiliser cost along with the cost of other nutrients plays an important role in promoting the balanced use of plant nutrients. The increase in prices of fertilisers makes it important that the resource is used in a manner that ensures the profitability of N application in rice, wheat and maize under the scenario of limited hike in the Minimum Support Price (MSP).

Economic analysis of experiments carried out at farmers' fields across the IGP indicated that the return on investment (ROI) of N ranged from 3.9-19.5 (**Figure 4**) with an average of Rs. 10.04 per rupee invested on N. However, the significantly high ROI observed with application of N must not be seen in isolation as a complete N effect rather a resultant of the integration of P and K with N applied in balanced rates. Further, it is interesting to note that 19 out of 45 locations showed higher ROI over the average values indicating a better crop response and better returns with application of N. Singh (11) observed high rice

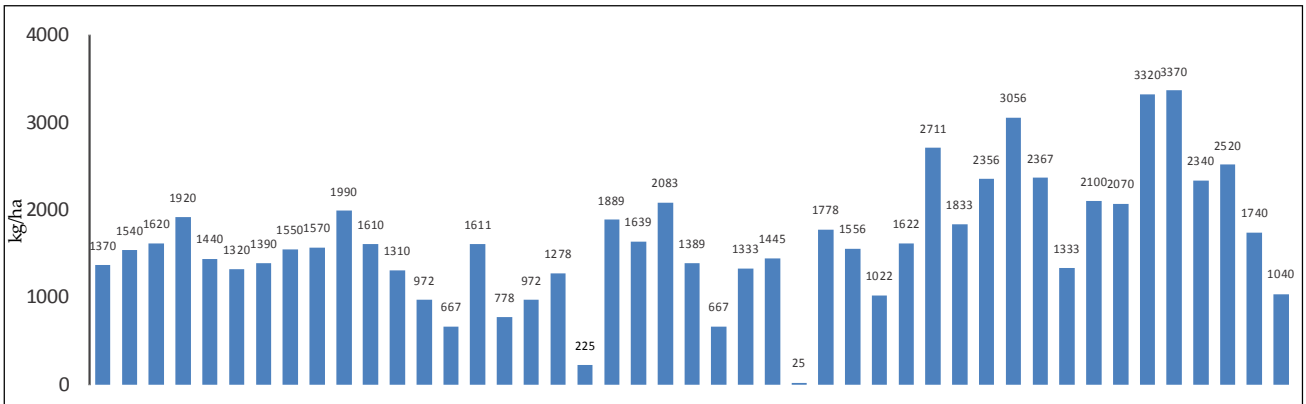

Figure 1 – N response in rice across 45 locations in the Indo-Gangetic Plains

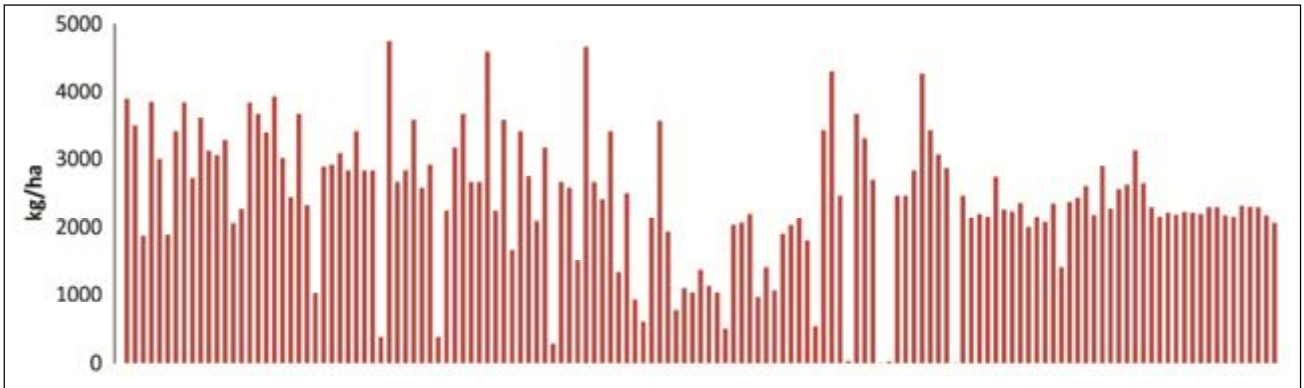

Figure 2 – N response in wheat across 141 locations in the Indo-Gangetic Plains

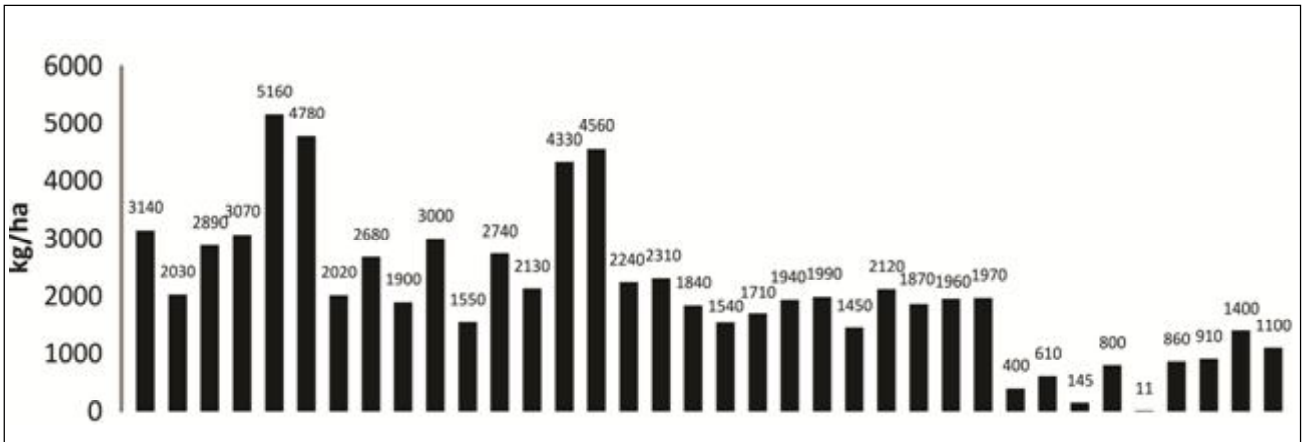

Figure 3 – N respone in maize across 36 locations in Bihar and West Bengal

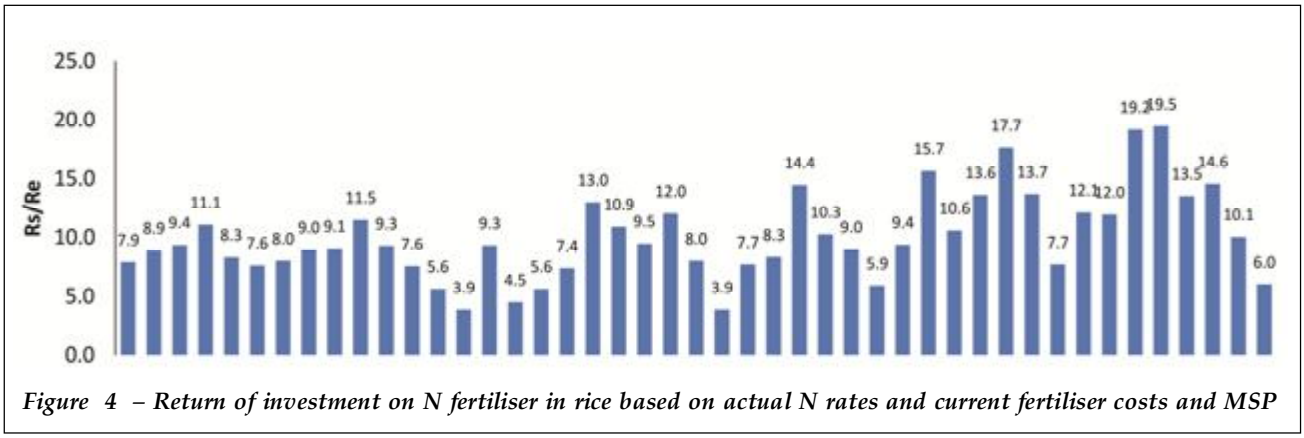

Figure 4 – Return of investment on N fertiliser in rice based on actual N rates and current fertiliser costs and MSP

yields and better net returns with integrated application of P and K along with N instead of applying 100% N alone. Therefore, better yield response with high ROI in rice depend upon the rate of fertiliser N applied and also on the balanced use of other fertilisers, particularly P and K.

Return on investment was calculated based on minimum support price of rice (Rs 10/kg) and current price of N (Rs. 11.54 kg^{-1}).

ROI on N fertiliser in the wheat experiments ranged from 2.4-22.9 with a mean return of Rs 12.4 per rupee invested **(Figure 5)**. Also, the returns from N application were higher than the mean ROI at 65 out of 141 locations implying 46% of the

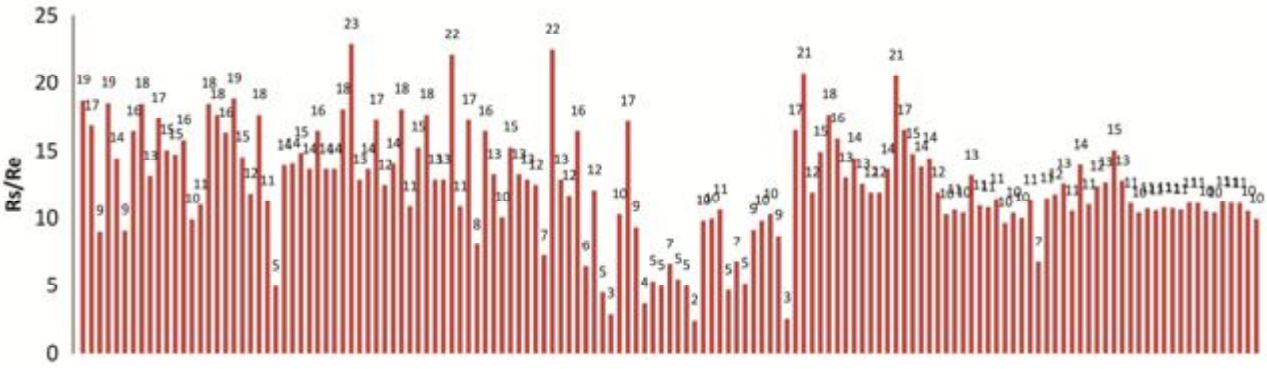

Figure 5 – Return of investment on N fertiliser in wheat based on actual N rates and current fertiliser costs and MSP

locations showing ROI higher than the mean returns.

Return on investment was calculated based on minimum support price of wheat (Rs 11.7 kg^{-1}) and current price of N (Rs. 11.54 kg^{-1}).

With ample application of N to maize, the ROI on N fertiliser in maize was 1.9-24.8 and the average ROI across the experimental sites was Rs. 10.4 **(Figure 6)**. Though maize had the lowest MSP among all the three cereals, none of the locations had ROI below Rs. 2 and it is interesting to note that 36% of experimental sites had ROI higher than the mean ROI of 10.4.

Return on investment was calculated based on minimum support price of maize (Rs 8.8 kg^{-1}) and current price of N (Rs. 11.54 kg^{-1}).

Economic Returns Based on Selected Levels of N Response, N Fertiliser Rates and N Fertiliser Prices

At the selected levels of AEN, N response, and urea prices, ROI for rice is at least 4.95 Rs Re^{-1} (**Table 2**). At the current price of urea (Rs 5310 t^{-1}), ROI for rice will be >13 Rs Re^{-1} if AEN is at least 16 kg grain kg^{-1} N (**Table 2**). An increase in fertiliser N use efficiency will also improve ROI, suggesting that improving fertiliser management practice will also improve the profitability of fertiliser application, especially fertiliser N.

Table 3 shows that application of N fertiliser in wheat at five levels of N response (500, 1000, 1500, 2000 and 2500 kg ha^{-1}), and at three levels of AEN (16, 18 and 21 kg grain kg^{-1} N) is profitable (ROI $\geq$ 5.7 Rs Re^{-1}) even at Rs 15000 t^{-1} of urea. At the current cost of urea and at AEN of 21 kg kg^{-1} N, ROI for wheat will be >21 Rs Re^{-1}, which is much higher than the average of the actual ROI (12.4 Rs Re^{-1}) in this study. In India, wheat is predominantly grown under irrigated conditions during winter-spring dry season with less incidence of diseases and pests (8), therefore yield increase in wheat was more pronounced and it is always profitable to apply N as per the yield response. Data from field trials have shown that AEN of 20 to 25 kg kg^{-1} N is possible with

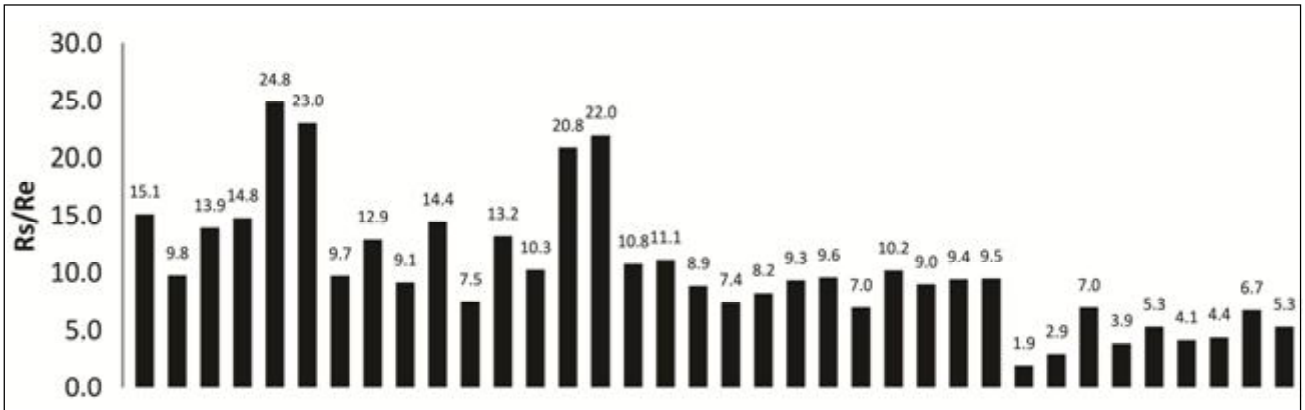

Figure 6 – Return of investment on N fertiliser in maize based on actual N rates and current fertiliser costs and MSP

Table 2 – Return of investment (ROI) on N fertiliser in rice at different crop response levels, cost of urea and application rates

Yield response to N (kg ha^{-1}) ⟶	500	1000	1500	2000	3000
	Nutrients to be applied at Agronomic Nitrogen Efficiency = 16 kg kg^{-1} N				
N kg ha^{-1} ⟶	**31**	**63**	**94**	**125**	**188**
Cost of urea = Rs. 4830 t^{-1}	15.36	15.12	15.20	15.24	15.20
Cost of urea = Rs. 5310 t^{-1}	13.97	13.75	13.82	13.86	13.82
Cost of urea = Rs. 10000 t^{-1}	7.42	7.30	7.34	7.36	7.34
Cost of urea = Rs. 15000 t^{-1}	4.95	4.87	4.89	4.91	4.89
	Nutrients to be applied at Agronomic Nitrogen Efficiency = 18 kg kg^{-1} N				
N kg ha^{-1} ⟶	**28**	**56**	**83**	**111**	**167**
Cost of urea = Rs. 4830 t^{-1}	17.01	17.01	17.21	17.16	17.11
Cost of urea = Rs. 5310 t^{-1}	15.47	15.47	15.66	15.61	15.56
Cost of urea = Rs. 10000 t^{-1}	8.21	8.21	8.31	8.29	8.26
Cost of urea = Rs. 15000 t^{-1}	5.48	5.48	5.54	5.53	5.51
	Nutrients to be applied at Agronomic Nitrogen Efficiency = 20 kg kg^{-1} N				
N kg ha^{-1} ⟶	**25**	**50**	**75**	**100**	**150**
Cost of urea = Rs. 4830 t^{-1}	19.05	19.05	19.05	19.05	19.05
Cost of urea = Rs. 5310 t^{-1}	17.33	17.33	17.33	17.33	17.33
Cost of urea = Rs. 10000 t^{-1}	9.20	9.20	9.20	9.20	9.20
Cost of urea = Rs. 15000 t^{-1}	6.13	6.13	6.13	6.13	6.13

Calculated based on minimum support price of rice (Rs 10 kg^{-1} of grain)

optimal N management in those growing conditions, suggesting that ROI for wheat can still go beyond 21 Rs Re^{-1} even at the current price of urea. This indicates that higher MSP of wheat coupled with optimal N management will provide more opportunity for higher economic return to the farmers.

The ROI on N fertiliser in maize in general, was lowest among the three cereals as the MSP of maize is the lowest among the three **(Table 4)**. Results revealed that N application in maize is economical even at high prices of urea (ROI ≥ 4.28 Rs. Re^{-1}) if N application is based on yield response and AEN is at least 16 kg kg^{-1} **(Table 4)**. At the current price of urea, ROI for maize will be at least 15 Rs. Re^{-1} if AEN is 20 kg kg^{-1}. Recent on-farm trials on hybrid maize in Asia have shown that AEN of up to 35 kg kg^{-1} is possible at high N response levels (>5 t ha^{-1}) (IPNI unpublished data).

From the results obtained in the current on-farm trials, it is interesting to note that only one out of 36 locations had an N response less than 500 kg ha^{-1}. The rest of the 35 sites had ≥ 500 kg ha^{-1} of N response and a few sites had N response of 3 to 5 t ha^{-1}, even when the attainable yield of maize was mostly below 9 t ha^{-1}. This suggests that N responses were already quite high at attainable yields below the highest acvhievable yields of maize in the country. And N responses of maize are likely to be further higher in areas where attainable yield approaches higher limits of ≥ 10 t ha^{-1}, particularly in states like Andhra Pradesh, Tamil Nadu and Bihar. Thus, aiming for high yields through improved fertiliser management (that is based on N response) will improve the profitability of fertiliser N application even with relatively low MSP.

Critical evaluation of the ROI data for the cereals **(Tables 2, 3 and 4)** revealed that ROI remained similar across increasing rates of N application corresponding to increasing yield response. This suggests that economic return from nitrogen application in cereals could be maintained at a relatively higher level than the current farmer scenarios when application rates are guided by location specific crop response and a targeted AEN. The ROI of maize at AEN 20 kg kg^{-1} N **(Table 4)** remained same across all application rates with increasing cost of urea. This indicates that farmers would be able to cope with the increasing fertiliser price when the application rates are based on AEN and N response. Besides economic benefit, this will also have off-farm environmental advantages.

FUTURE SCENARIOS

Rice

Figure 7 shows that N application,

Table 3 – Return of investment (ROI) of N fertiliser in wheat at different crop response levels cost of urea and application rates					
Yield response to N (kg ha^{-1}) ⟶	**500**	**1000**	**1500**	**2000**	**2500**
	Nutrients to be applied at Agronomic Nitrogen Efficiency = 16 kg kg^{-1} N				
N kg ha^{-1} ⟶	**31**	**63**	**94**	**125**	**156**
Cost of Urea = Rs. 4830 t^{-1}	17.97	17.69	17.78	17.83	17.86
Cost of Urea = Rs. 5310 t^{-1}	16.35	16.09	16.17	16.22	16.24
Cost of Urea = Rs. 10000 t^{-1}	8.68	8.54	8.59	8.61	8.63
Cost of Urea = Rs. 15000 t^{-1}	5.79	5.70	5.73	5.74	5.75
	Nutrients to be applied at Agronomic Nitrogen Efficiency = 18 kg kg^{-1} N				
N kg ha^{-1} ⟶	**28**	**56**	**83**	**111**	**139**
Cost of Urea = Rs. 4830 t^{-1}	19.90	19.90	20.14	20.08	20.04
Cost of Urea = Rs. 5310 t^{-1}	18.10	18.10	18.32	18.26	18.23
Cost of Urea = Rs. 10000 t^{-1}	9.61	9.61	9.73	9.70	9.68
Cost of Urea = Rs. 15000 t^{-1}	6.41	6.41	6.48	6.46	6.45
	Nutrients to be applied at Agronomic Nitrogen Efficiency = 21 kg kg^{-1} N				
N kg ha^{-1} ⟶	**24**	**48**	**71**	**95**	**119**
Cost of Urea = Rs. 4830 t^{-1}	23.21	23.21	23.54	23.46	23.41
Cost of Urea = Rs. 5310 t^{-1}	21.12	21.12	21.41	21.34	21.29
Cost of Urea = Rs. 10000 t^{-1}	11.21	11.21	11.37	11.33	11.31
Cost of Urea = Rs. 15000 t^{-1}	7.48	7.48	7.58	7.55	7.54
Calculated based on minimum support price of wheat (Rs 11.7 kg^{-1} of grain)					

Table 4 – Return on investment (ROI) on N in maize at different crop response levels, cost of urea and N application rates					
Yield response to N (kg ha^{-1}) ⟶	**500**	**1000**	**1500**	**2000**	**2500**
	Nutrients to be applied at Agronomic Nitrogen Efficiency = 16 kg kg^{-1} N				
N kg ha^{-1} ⟶	**31**	**63**	**94**	**125**	**188**
Cost of Urea = Rs. 4830 t^{-1}	13.52	13.30	13.37	13.41	13.37
Cost of Urea = Rs. 5310 t^{-1}	12.30	12.10	12.16	12.20	12.16
Cost of Urea = Rs. 10000 t^{-1}	6.53	6.43	6.46	6.48	6.46
Cost of Urea = Rs. 15000 t^{-1}	4.35	4.28	4.31	4.32	4.31
	Nutrients to be applied at Agronomic Nitrogen Efficiency = 18 kg kg^{-1} N				
N kg ha^{-1} ⟶	**28**	**56**	**83**	**111**	**167**
Cost of Urea = Rs. 4830 t^{-1}	14.97	14.97	15.15	15.10	15.06
Cost of Urea = Rs. 5310 t^{-1}	13.61	13.61	13.78	13.74	13.69
Cost of Urea = Rs. 10000 t^{-1}	7.23	7.23	7.32	7.29	7.27
Cost of Urea = Rs. 15000 t^{-1}	4.82	4.82	4.88	4.86	4.85
	Nutrients to be applied at Agronomic Nitrogen Efficiency = 20 kg kg^{-1} N				
N kg ha^{-1} ⟶	**25**	**50**	**75**	**100**	**150**
Cost of Urea = Rs. 4830 t^{-1}	16.76	16.76	16.76	16.76	16.76
Cost of Urea = Rs. 5310 t^{-1}	15.25	15.25	15.25	15.25	15.25
Cost of Urea = Rs. 10000 t^{-1}	8.10	8.10	8.10	8.10	8.10
Cost of Urea = Rs. 15000 t^{-1}	5.40	5.40	5.40	5.40	5.40
Calculated based on minimum support price of maize (Rs 8.80 kg^{-1} of grain)					

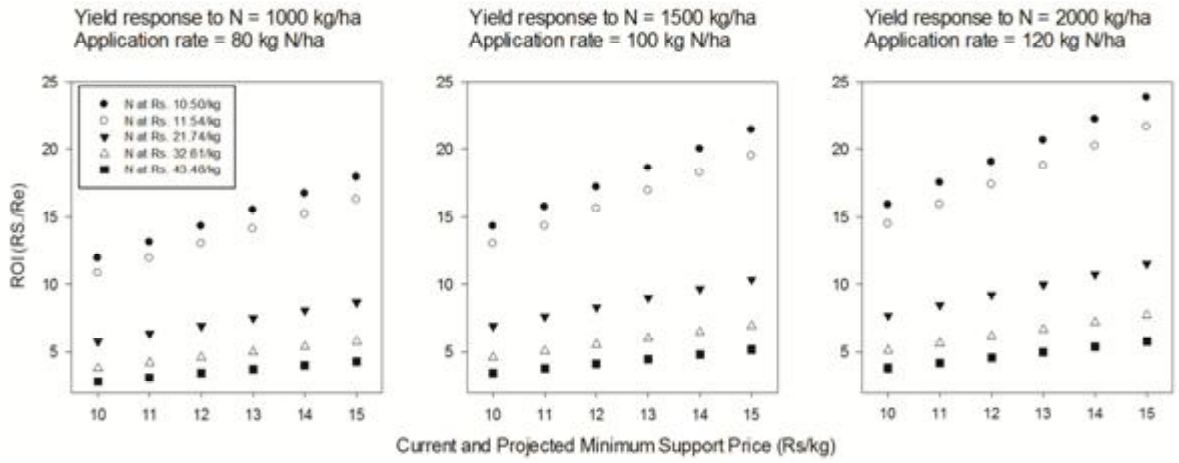

Figure 7 – Return on investment (ROI) on N fertiliser at different N response levels and projected cost of N fertiliser and minimum support price of rice

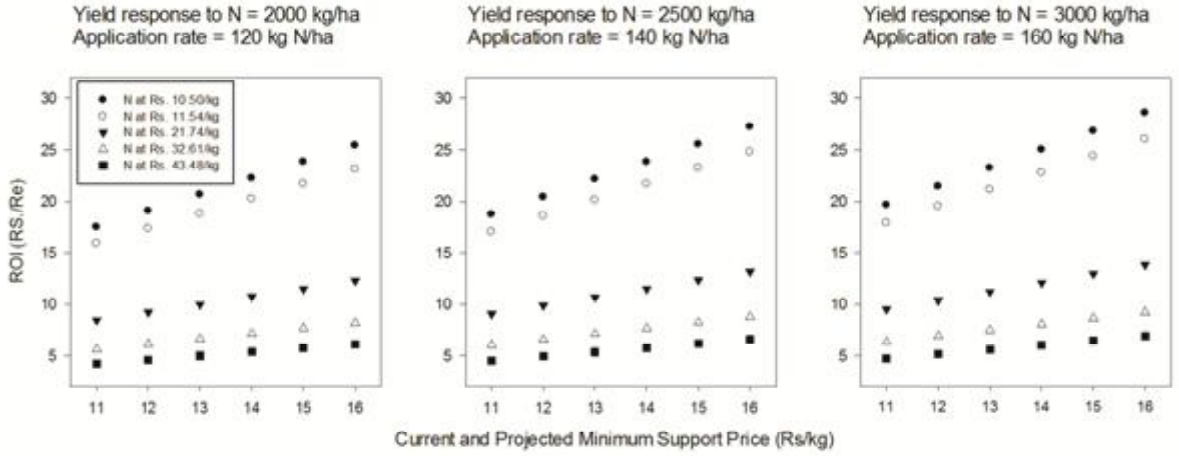

Figure 8 – Return on investment (ROI) on N fertiliser at different N response levels and projected cost of N fertiliser and minimum support price of wheat

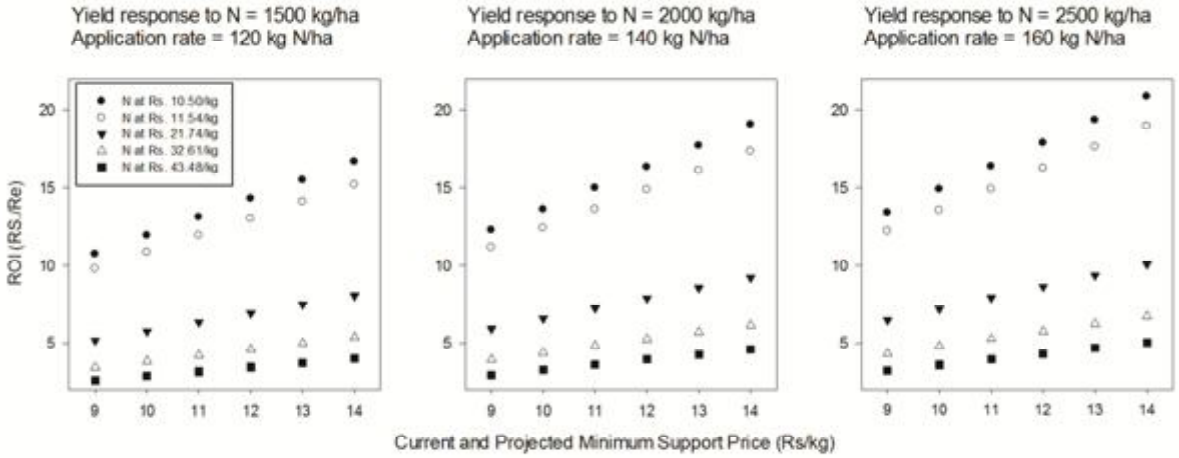

Figure 9 – Return on investment (ROI) on N fertiliser at different N response levels and projected cost of N fertiliser and minimum support price of maize

in general, is economically profitable even in areas where N response is ≤ 1000 kg ha^{-1}. At an application rate of 80 kg N ha^{-1} for a 1000 kg ha^{-1} response, the ROI at the highest price of N (Rs. 43.48 kg^{-1} of N) and the lowest MSP (Rs. 10 kg^{-1} rice) was 2.9, suggesting profitable return on nitrogen application. Further, the profitability increased with an increase in the MSP of the crop produce **(Figure 7)**. Again, considering higher crop response levels of 1500 and 2000 kg ha^{-1} at the lowest MSP of rice, application of 100 kg N ha^{-1} at highest price of N (Rs. 43.48 kg^{-1} N) resulted in a ROI between 3.4 and 5.2, respectively. In the on-farm experiments carried out at 45 locations, 125–175 kg N ha^{-1} was applied across the locations based on the yield targets of rice and a yield response of ≥ 1740 kg ha^{-1} of rice was observed in more than 40% of locations. This suggests that in such locations, application of at least 100 kg N ha^{-1} will provide ROI which is 50% of the mean ROI observed in these locations. It should be noted that maximum economic yields are obtained only with adequate (optimum) N fertilisation; therefore, providing adequate and balanced rates of N application considering the expected yield response in the rice growing soils of the Indo-Gangetic Plains will not only help in ensuring economic sustainability but also sustain the environmental efficiency.

Wheat

Profit analysis considering the projected cost of N fertiliser at varying MSPs of wheat (**Figure 8**) revealed that ROI decreased with increasing N fertiliser price from Rs. 10.5 kg^{-1} to a future forecasted price of Rs. 43.48 kg^{-1} of N but increased with increasing MSP of wheat irrespective of N fertiliser cost. ROI recorded at the current MSP and the projected maximum price of N fertiliser, across all N response levels, was ≥ 4.2 Rs. Re^{-1}, a return ratio of 1:4, making it a profitable option for the farmers.

Maize

MSP of maize is the lowest among the cereals. However, ROI at the current MSP and highest cost of N fertiliser were 2.6, 3.0 and 3.2 at the three N response levels of 1500, 2000 and 2500 kg ha^{-1}, respectively (**Figure 9**). This suggests that N application at the highest projected price of urea would provide reasonable economic returns to the farmers. The fertiliser N rates used for the three levels of N response correspond to AEN of 13, 14, and 16 kg grain kg^{-1} N **(Figure 9)**. This suggests that the ROI at these N response levels could still be improved if AEN is improved through better N management.

CONCLUSION

♦ Crop response to N fertiliser application is variable across sites and managing the location specific variability in indigenous N supply is a key to overcome the current mismatch of fertiliser rates and crop nutrient demand in cereals.

♦ N plays an important role in governing the yield of crops and is influenced by soil, crop, and management factors. Inadequate application or skipping the application of N fertiliser in all the three cereal crops will certainly cause variable yield and economic losses to farmers. This is evident from the yield loss of 1738, 2566 and 2154 kg ha^{-1} due to N omission in rice, wheat and maize, respectively.

♦ Economic assessment based on observed N response levels with current and projected prices of N fertiliser and MSP of the cereals showed ROI of ≥ 3 in all scenarios. Site-specific crop and fertiliser management practices that will improve the fertiliser N use efficiency are the key to higher profitability from fertiliser N application.

♦ Lack of awareness on improved strategies of N management coupled with relatively lower prices of N fertilisers (especially urea) encourages their imbalanced and indiscriminate use at majority of the locations in the IGP. Therefore, N management strategies that consider the yield response, AEN, coupled with appropriate timing and splitting may be used for increasing the yield and profitability from N use.

REFERENCES

1. Biswas P. P. and Sharma P. D. *Indian J. Fert.* 4(7), 59-62 (2008).

2. Cassman K. G., Dobermann A. and Walters D. *Ambio.* 31, 132-140 (2002).

3. Chanda T. K. *Indian J. Fert.* 4(5), 11-16 (2008).

4. Dhadli H. S., Singh, Y. and Singh, G. *Indian J. Fert.* 6(2), 31-34, (2010).

5. Dobermann A., Witt, C., Abdulrachman S., Gines, H. C., Nagarajan, R., Son, T. T., Tan, P. S., Wang, G. H., Chien, N. V., and Thoa, V. T. K.. *Agron. J.* 95, 924-935 (2003).

6. Fertiliser Statistics, The Fertiliser Association of India, New Delhi, India (2008-09).

7. Fertiliser Statistics, The Fertiliser Association of India, New Delhi, India (2010 -11).

8. Prasad, R. *Indian J. Fert.* 7(12), -66-76 (2011).

9. Ray, P. K., Jana, A. K., Maitra, D. N., Saha, M. N., Chaudhury, J., Saha, S., and Saha, A. R. *J. Indian Soc. Soil Sci.* 48, 79-84 (2000).

10. Saha, M. N., Singh, M., Wanjari, R. H., Majumder, A., Gorai, D., Saha, A. R., and Majumder, B., LTFE Project Report, Indian Inst. Soil Sci., Bhopal, 1-65 (2008).

11. Singh, M. *J. Indian Soc. Soil Sci.* 58(S), S47-S57 (2010).■