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Survey of nitrogen use pattern in rice in the irrigated rice-wheat cropping system of Haryana, India

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Abstract

Seeing the sustainability of rice-wheat cropping system (RWCS) of the Indo-Gangetic Plain, adequate crop nutrition in general and nitrogen (N) in particular holds the key to sound crop management. The excessive application or insufficient management of N means an economic loss to the farmer and may lead to yield penalties and environmental problems. Improving N management in consonance with other nutrients is much important to break yield plateaus as breeding for high yielding is not happening in recent years. Findings from farm survey are used to evaluate the on-farm N management practices in rice crop of the study area. The crop management practices (especially time of sowing/transplanting and irrigation requirement) and resource base of the farmers decided the N use pattern of the farmers. The $N_{\text{Physical optimum}}$ and $N_{\text{economic optimum}}$ exceeding the recommended levels revealed the apparent need for the revalidation of the existing recommendations. Paddy yield increased significantly within different rice types. This study generated comprehensive data on N use pattern in rice in the study area.

Key words

Rice-wheat cropping system, Nitrogen, Splits, Paddy yield

Introduction

Rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) grown sequentially in an annual rotation, constitute a rice-wheat cropping system (RWCS) and in a system occupy nearly 13.5 million hectares area in the Indo-Gangetic plains (IGP) of South Asia of which about 85% is concentrated in the IGP, encompassing Northern India, Pakistan, Nepal and Bangladesh (Timsina and Connor, 2001). These crops contribute more than 80% of the total cereal production and are critically important to employment and food security for hundreds of millions of rural families (Gupta and Seth, 2007). During 1960 to 1990, genetic improvements leading to development of highly fertilizer responsive varieties coupled with improved management strategies resulted in a dramatic rise in productivity and production from RWCS (Bijay-Singh *et al.*, 2003). The gains were particularly significant in the north-western region covered by the states of Punjab, Haryana and Western Uttar Pradesh although, of late, growth rates have slowed (Abrol, 1999). Now this system is showing the sign of fatigue and there is question mark on its ecological and economical sustainability (Garg *et al.*, 2006).

Intensive cultivation, growing of exhaustive crops, imbalanced and inadequate crop nutrition largely through chemical fertilizers has made the soils not only deficit in the nutrients but also deteriorated the soil health resulting in diminishing crop response to the recommended dose of nitrogenous fertilizer in the region. Non-judicious enhancement and its bias in favour of the N-fertilization further worsen the situation (Singh *et al.*, 2008). Evidence of declining partial or total factor productivity is already becoming available (Hobbs and Morris, 1996). Decreasing soil fertility has also been reported as one of the major reason for decline in crop yields.

Fertilizer use pattern for rice in RWCS in the IGP is region specific and diagnostic surveys have indicated that farmers are using more than the recommended levels of N (130 to 195 kg N ha^{-1}) to rice in Trans-Gangetic Plain and parts of upper Gangetic Plain representing Punjab, Haryana and Western Uttar Pradesh in India (Yadav *et al.*, 2000; Sheoran *et al.*, 2004). Recovery of fertilizer N applied seldom exceeds 50% due to heavy losses through various means and lack of synchronization of crop requirement resulting in lower physiological efficiency (Stalin *et al.*, 1999; Alam *et al.*, 2006). Food production is directly related to nutrient consumption, and N is the key element in the intensive cropping systems (Sharma and Masand, 2008). The grain productivity per kg N applied increased with the subsequent cropping cycles which exhibit that the yield level decreased with the control plot due to the decline in inherent fertility of the soil (Om *et al.*, 2008).

The recommendations regarding N application in rice crop were given long back. Most of the farmers are not aware of N recommendation and are happy with their present N management practices in rice which are traditional and location specific. Also the farmers have increased the fertilizer dose in their rice crop during last decade. Now the scenario has changed as lot of changes have occurred in terms of varietal basket, management options, yield realization and shift in crop residue management and use of organic manures, shift in soil status due to imbalanced use of fertilizers, micro-nutrient deficiencies, economic status of farmers, etc. As a result, the farmers themselves adjust their nutrient management practices on the basis of their experiences, but scientific revision of recommendation is yet to come. The present paper surveys the on-farm N management practices in different rice types of Haryana using a questionnaire.

Materials and Methods

Data sources: The study mainly interprets the fertilizer N use pattern management practices of rice crop in the RWCS. Although the recommendation of nutrients have been made but the farmers do not follow these recommendations for one reason or the other. The study area in Haryana covering nine districts was purposively chosen for this study as it comprises the locations where RWCS dominates (Erenstein *et al.*, 2008). The primary data source for this study was a formal roadmap survey of rice-wheat growers from the rice-wheat zone of Haryana state, India. The survey used a stratified sampling frame.

Each selected district was visited in 2006 using a predetermined route and 3 to 5 farmers were surveyed randomly after every 8-10 km halt to collect information using a structured questionnaire. The questionnaire covered the details of N management practices *viz.* type, source, dose, and method and time of application and paddy yield of rice [*kharif*/monsoon (June-October) 2006] of individual farmer. The survey yields are actually the farmer-reported yields. Overall, the survey covered 319 rice growing farmers which included the farmers growing one or more than one type of rice *i.e.* superfine, evolved basmati and traditional basmati, thus making total sample size of 468.

Analytical methods: For the subsequent analysis and reporting, the surveyed farmers were classified into three rice groups viz. superfine, evolved basmati and traditional basmati growers since recommendation for different rice groups is variable. Amongst the total 468 farmers being surveyed, 229 were classified as superfine, 186 as evolved basmati and 52 as traditional basmati growers.

Our hypothesis is that there are a number of differences between the three groups of rice, and that these may help explain the observed N management practices regarding time, dose, number of splits, *etc*. The groups were sufficiently large to allow for statistical comparisons between the rice groups at the farmer level. For the farmer level analysis, tables, therefore, typically includes the averages for each category as well as the overall sample, indicating statistically significant differences between rice groups where relevant.

When the farmers applied diammonium phosphate [$(NH_4)_2HPO_4$-46% P_2O_5 and 18% N] or other NPK complex fertilizers as a source of phosphorus and/or potassium, N was also applied and the quantity of N thus applied was also taken into account while calculating the total N applied to the crops. However, this dose of N applied through diammonium phosphate (DAP) or NPK fertilizer was not taken into account while analyzing the method and number of splits of N application and only N dose applied though straight N-fertilizers [Urea – $CO(NH_2)_2$ – 46% N] was taken into account. The significance between rice groups was calculated using the appropriate statistical tests (*e.g.* Chi^2, ANOVA with post-hoc test) using SPSS statistical software. Wherever not mentioned, sample size for source, method, dose, number of splits, time of N application and yield will be 468.

Results and Discussion

Extent of nitrogen use: Nitrogen (N) application in all the rice types was universal (Table 1) and prilled urea [$CO(NH_2)_2$] was its main source. In the IGPs of south Asia, urea (46% N) is the main source of fertilizer N for the RWCS. Lathwal *et al.* (2008) also reported urea as the major source of N and topdressing of N was the most common method of application in rice crop.

The extent of use of N varied widely and significantly in all the rice types. In superfine and evolved basmati, farmers used N more than 210 kg N ha^{-1} and in traditional basmati upto 180 kg N ha^{-1}. In Superfine rice, about 71.6% farmers used N above the recommendation *i.e.* >150 kg N ha^{-1} while in case of evolved basmati 92.0% farmers used more than the recommended dose of N *i.e.* 90 kg ha^{-1}. Similar was the condition in traditional basmati where only 9.6% farmers used the N upto recommended dose *i.e.* 60 kg N ha^{-1}. This shows a major deviation in N use from the recommendation given by state agriculture universities. The major reason of this change might be mainly due to availability and adoption of highly fertilizer-responsive hybrids/*varieties* of rice (Lathwal *et al.*, 2008),

Table - 1: Nitrogen (N) use pattern and paddy yield in different rice types

	Superfine (n = 229)	**Evolved Basmati (n = 187)**	**Traditional basmati (n = 52)**	**Sample mean (±SD) (n = 468)**	**Significance**
Use of N (% reporting)					
Yes	100.0 (n = 229)	99.5 (n = 186)	100.0 (n = 52)	99.8 (n = 467)	NS
No	-	0.5 (n = 1)	-	0.2 (*n* = 1)	
Extent of N use (% reporting)					
<60 kg N ha^{-1}	0.9 (n = 2)	3.7 (n = 7)	9.6 (n = 5)	3.0 (n = 14)	0.00
60-90 kg N ha^{-1}	0.4 (n = 1)	4.3 (n = 8)	34.6 (n = 18)	5.8 (n = 27)	
90-120 kg N ha^{-1}	4.8 (n = 11)	8.0 (n = 15)	30.8 (n = 16)	9.0 (n = 42)	
120-150 kg N ha^{-1}	23.3 (n = 51)	28.3 (n = 53)	23.1 (n = 12)	24.8 (n = 116)	
150-180 kg N ha^{-1}	23.1 (n = 23)	19.3 (n = 36)	1.9 (n = 1)	19.2 (n = 90)	
180-210 kg N ha^{-1}	41.9 (n = 96)	33.7 (n = 63)	-	34.0 (n = 159)	
>210 kg N ha^{-1}	6.6 (n = 15)	2.7 (n = 5)	-	4.3 (n = 20)	
Dose of N (kg N ha^{-1})	172.4 c	155.4 b	97.8 a	157.3 (±43.2)	0.00
Grain yield (t ha^{-1})	6.86 c	4.91 b	3.07 a	5.66 (±1.74)	0.00

Significance levels are from Chi^2 (% data) and one-way ANOVA (numerical data). Data followed by different lower-case letters differ significantly (Duncan's multiple range test, significance level = 0.10, within row comparison). Some of column sums may not add up to 100% due to rounding

Table - 2: Response function, optimum dose, yield and economics of nitrogen fertilization in different rice types

Particulars	**Superfine**	**Evolved basmati**	**Traditional basmati**
Response equation	$Y = 2192 + 45.79x - 0.104x^2$	$Y = 3181 + 21.67x - 0.063x^2$	$Y = 2472 + 16.61x - 0.098x^2$
Response coefficient (R^2)	0.10	0.04	0.06
N $_{\text{Physical optimum}}$ (kg N ha^{-1})	220.1	172.0	84.7
N $_{\text{Economic optimum}}$ (kg N ha^{-1})	212.4	164.4	81.5
Yield $_{\text{Physical optimum}}$ (kg N ha^{-1})	7232	5044	3176
Yield $_{\text{Economic optimum}}$ (kg N ha^{-1})	7226	5041	3175
N cost $_{\text{Physical optimum}}$ (INR ha^{-1})	2316	1810	892
N cost $_{\text{Economic optimum}}$ (INR ha^{-1})	2235	1730	858
Net profit N $_{\text{Physical optimum}}$ (INR ha^{-1})	44997	53919	52088
Net profit N $_{\text{Economic optimum}}$ (INR ha^{-1})	45038	53959	52105

Table - 3: Split application of Nitrogen (N) in different rice types

	Superfine (n = 229)	**Evolved basmati (n = 186)**	**Traditional basmati(n = 52)**	**Sample mean (±SD) (n = 467)**	**Significance**
Number of splits of N application	2.9 c	2.7 b	2.1 a	2.7 (±0.6)	0.00
Farmers applying (% reporting)					
1 split of N	-	2.7 (n = 5)	15.4 (n = 8)	2.8 (n = 13)	0.00
2 splits of N	17.0 (n = 39)	29.0 (n = 54)	57.7 (n = 30)	26.3 (n = 123)	
3 splits of N	72.9 (n = 167)	63.4 (n = 118)	26.9 (n = 14)	64.0 (n = 299)	
4 splits of N	10.0 (n = 23)	4.8 (n = 9)	-	6.9 (n = 32)	

Significance levels are from Chi^2 (% data) and one-way ANOVA (numerical data). Data followed by different lower-case letters differ significantly (Duncan's multiple range test, significance level = 0.10, within row comparison). Some of column sums may not add up to 100% due to rounding

declining soil fertility (Antil *et al.*, 2001) and much assured irrigation (especially groundwater). Low recovery (30-50%) of applied N to rice (Prasad, 1998) also leads to its immense application. Farmers have attributed this increase in N use to the role of fertilizers in the maintenance of soil health, yield advantage and improvement in economic condition.

The N use in terms of quantity varied significantly depending on rice type. On an average, farmers applied 172.4, 155.4 and 97.8 kg N ha^{-1} in superfine, evolved basmati and traditional basmati, respectively. The survey data revealed that farmers used 14.9, 72.9 and 63.0% higher dose of N than the recommended N level in superfine rice, evolved basmati and traditional basmati, respectively. In traditional basmati rice farmers used very high dose of N, about 101 kg N ha^{-1} (Lathwal *et al.*, 2008). Use of N fertilizer at higher dose as well as lack of synchronization with crop requirement makes plants succumb to lodging, and a paradise for insect pest and diseases complex (Islam *et al.*, 2007). Farmers tend to use more N-fertilizer

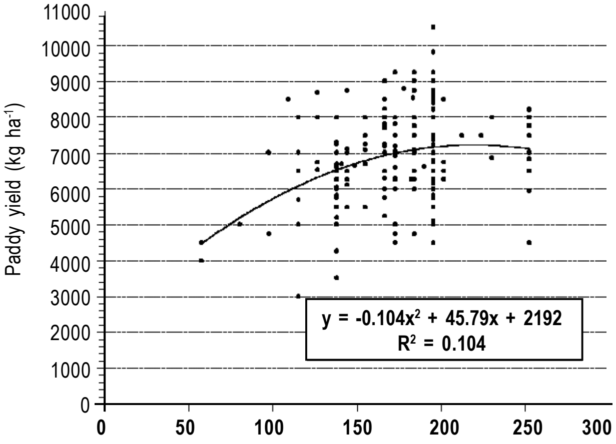

Fig. 1: Polynomial relationship between nitrogen dose and paddy yield in superfine rice (Significance level, p = 0.001)

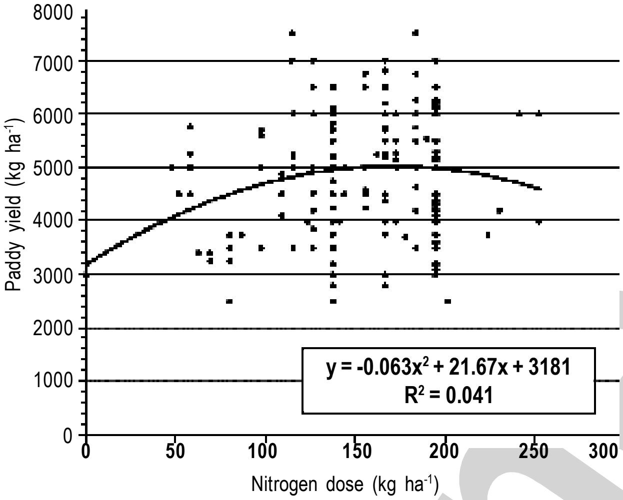

Fig. 2: Polynomial relationship between nitrogen dose and paddy yield in evolved basmati rice (Significance level, p = 0.02)

than needed mainly because of subsidized price and its immediate visible impact on plant growth and leaf colour without considering its ill effects on soil health and environmental pollution.

The trend is already evident for use of N more than 150 kg N ha^{-1} to rice which follows wheat in North-west Indian states of Punjab, Haryana and Western Uttar Pradesh, where grain yield of 10 to 12 t ha^{-1} annum^{-1} are being obtained for RWCS (Bijay-Singh and Yadvinder-Singh, 2003). Erenstein *et al.* (2007) also reported similar trend of N use (180, 159 and 103 kg N ha^{-1} in superfine, evolved basmati and Traditional basmati, respectively) in the rice-wheat zone of irrigated Haryana, India.

Yield, economics and N-use-efficiency: The paddy yield differed significantly across the rice types and was highest in superfine rice (6.86 t ha^{-1}) followed by evolved (4.91 t ha^{-1}) and traditional (3.07 t ha^{-1}) basmati rice (Table 1). The dose of N is directly related to the yield of rice crop as the N requirement of rice crop will depend upon the targeted yield (Prasad, 2006) as well as rice type and the farmers also use N in accordance to the yield potential of rice types.

The polynomial relationship between N dose and paddy yield in all the three types of rice was significant and showed that yield increased at increasing rate with increase in N dose up to a certain level and a constant rate with subsequent dose of N (Fig. 1 to 3). At a particular level *i.e.* at physical optimum dose of N ($N_{\text{Physical optimum}}$), yield approached a plateau and further increase in N dose decreased the yield. The regression coefficients of paddy yield on N dose indicate that with every unit increase in N dose, the paddy yield increased by 0.10, 0.04 and 0.06, respectively in superfine, evolved basmati and traditional basmati rice.

The $N_{\text{Physicaloptimum}}$ calculated from the response equations was found to be 220.1, 172.0 and 84.7 kg N ha^{-1}, respectively for superfine, evolved basmati and Traditional basmati (Table 2). The $N_{\text{Physical optimum}}$ for superfine and evolved basmati is still above the average dose of N being used by farmers in the region, indicating scope for further increase in N level. However, in the case of traditional basmati $N_{\text{Physical optimum}}$ is below the average dose of N being used by farmers, thus indicating unnecessary use of N. The paddy yields obtainable at the $N_{\text{Physical optimum}}$ are also higher than the average paddy yield obtained with current use of N in all the rice types. The economic optimum doses of N ($N_{\text{Economic optimum}}$) dose are even below the $N_{\text{Physical optimum}}$ giving almost similar yield and net returns, thus slightly cutting down the cost of N.

There are gapes between the current use and the $N_{\text{Physical optimum}}$/$N_{\text{Economic optimum}}$ which need to be bridged out. Thus, in general, N use in high yielding rice is inefficient (Alam *et al.*, 2006). basmati rice is prone to lodging and requires less N, particularly the relatively tall traditional basmati, explaining the observed differences in N use rate among different rice types (Erenstein *et al.*, 2007). Also the modern dwarf superfine varieties of rice respond well to higher doses of N.

N use efficiency was found to decrease with increasing doses of N. This was comparatively more in traditional basmati, followed by evolved basmati and superfine rice (Fig. 4). This is consistent with the diminishing law of returns. The superfine rice because of its dwarf nature and inherent high yield potential can respond to higher doses of N. However, the N fertilization beyond a level is counterproductive in evolved and traditional basmati (Islam *et al.*, 2007). The study further revealed yield gain even above the recommended levels of N. The fertilizer use can not be segregated from other elements of crop management. The underlying fact is that higher doses of N are even prompted by below optimum plant population. The application of prilled urea in lush green crop speaks otherwise and its translation in yield gain is doubtful (Garg *et al.*, 2006). The N use efficiency is an issue of whole strategy of crop management including N fertilization.

Table - 4: Amount of Nitrogen (kg N ha^{-1}) applied before transplanting and during different splits in different rice types

	Superfine (n = 229)	**Evolved basmati (n = 186)**	**Traditional basmati (n = 52)**	**Sample mean (±SD) (n = 467)**	**Significance**
A. Before transplanting*	16.3	17.3	15.1	16.5 (±8.8)	NS
B. After transplanting†					
1st split of N	55.4 b	54.7 b	43.7 a	53.7 (±10.0)	0.00
2nd split of N	54.9 c	50.5 b	31.8 a	50.6 (±14.3)	0.00
3rd split of N	41.2 c	30.6 b	7.2 a	33.2 (±24.9)	0.00
4th split of N	4.6 b	2.2 ab	0.0 a	3.1 (±12.0)	0.00
Total (A+B)	172.4 c	155.3 b	97.8 a	157.3 (±43.2)	0.00

Significance levels are from one-way ANOVA. Data followed by different lower-case letters differ significantly (Duncan's multiple range test, significance level = 0.10, within row comparison). *Main source of N (99.4%) was diammonium phosphate (DAP – 46% P_2O_5 and 18% N) or other NPK complex fertilizers which were applied as a source of phosphorus and/or potassium and use of urea was negligible (0.6%) before transplanting.
†Source of N was Urea

Table - 5: Time (days after transplanting) of Nitrogen (N) application in different splits in different rice types

	Superfine	**Evolved basmati**	**Traditional basmati**	**Sample mean (±SD)**	**Significance**
1st split of N (*n* = 467)	13.4 a	14.4 a	16.6 b	14.1 (±6.1)	0.00
2nd split of N (*n* = 454)	28.5 a	30.9 b	34.4 c	30.1 (±9.1)	0.00
3rd split of N (*n* = 328)	42.1	44.0	44.8	42.9 (±10.8)	NS
4th split of N (*n* = 32)	45.8	52.2	-	47.6 (±12.0)	*

*Post hoc tests are not performed because there are fewer than three groups.
Significance levels are from one-way ANOVA. Data followed by different lower-case letters differ significantly (Duncan's multiple range test, significance level = 0.10, within row comparison)

Table - 6: Paddy yield (t ha^{-1}) under different number of splits in different rice types

	1 split	**2 splits**	**3 splits**	**4 splits**	**Sample mean (±SD)**	**Significance**
Superfine (*n* = 229)	-	6.16 a	7.00 b	7.09 b	6.86 (±1.28)	0.00
Evolved basmati (*n* = 186)	3.64 a	4.87 b	5.00 b	4.85 b	4.92 (±1.11)	0.00
Traditional basmati (*n* = 52)	3.27	2.97	3.19	-	3.07 (±0.56)	NS

Significance levels are from one-way ANOVA. Data followed by different lower-case letters differ significantly (Duncan's multiple range test, significance level = 0.10, within row comparison)

Split application of nitrogen: The frequency of N application in rice crop varied significantly across its type. Farmers used N into 2.9, 2.7 and 2.1 splits in superfine, evolved basmati and Traditional basmati, respectively. In case of traditional basmati, farmers restricted the use of N upto 3 splits (73.1% within 2 splits); however, increase in number of splits corresponding to the increase in quantity was observed in evolved basmati and superfine rice. In superfine rice, no farmer applied his whole dose of N in one split; rather farmers went for even upto 4 splits (10.0% farmers). The frequency of N application in evolved basmati was in between traditional basmati and superfine rice (Table 3). Since adequate N supply is needed throughout the active growing period of rice, proper N management is very crucial for successful rice production (Stalin *et al.*, 2008). The split application reduces the chances of N loss through a number of N loss mechanisms operating in the fields, namely ammonia volatilization, leaching and denitrification (Prasad, 1998).

There was no significant difference in rice types regarding amount of N applied before transplanting with average amount of 16.5 kg N ha^{-1} (Table 4). This amount of N is mostly applied by diammonium phosphate (DAP – 46% P_2O_5 and 18% N) or other NPK complex fertilizers. However, the N topdressed into various splits after transplanting (urea) varied significantly among rice types with being highest in superfine and lowest in traditional basmati rice. Farmers applied 9.5, 11.1 and 15.4% of total applied N before the transplanting of crop in superfine, evolved basmati and traditional basmati rice, respectively. Higher percentage of N use after transplanting resulted into higher number of splits in superfine rice. The amount of N applied in a split decreased with increase in number of splits within rice types and trend was similar in all the three types of rice.

The time taken (days after transplanting – DAT) for N application varied significantly upto second split (Table 5). In general,

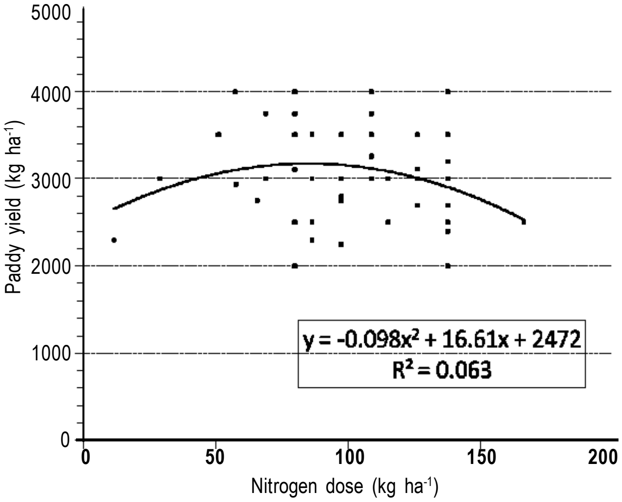

Fig. 3: Polynomial relationship between nitrogen dose and paddy yield in traditional basmati rice (Significance level, p = 0.19)

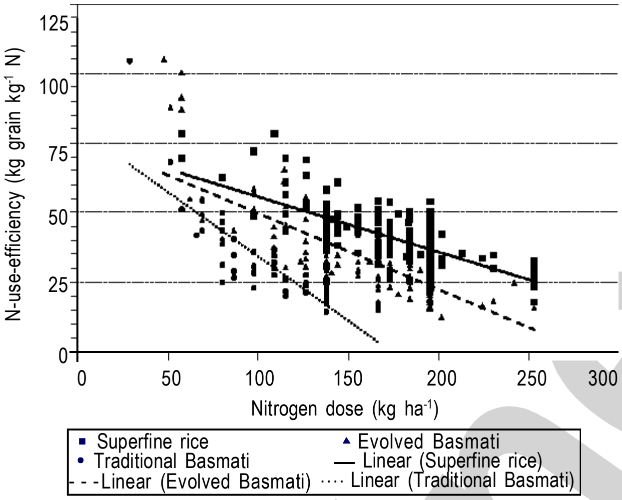

Fig. 4: Nitrogen use efficiency in different rice types (Significance level, p = 0.001)

the N was applied earlier in the superfine rice followed by evolved and traditional basmati in all the splits. The N application was completed within 46 DAT in superfine and in 52 DAT in evolved basmati rice. The crop duration (transplant to harvest) of basmati rice (123 days) being longer compared to the superfine rice (117 days) (Erenstein *et al.*, 2007), extended the time of N application in basmati rice. Farmers try to finish the N application within the active growing period and with this period being small in superfine rice, farmers completed 4 splits of N within 46 DAT. The average time per split application of N was 11, 13 and 15 days in superfine, evolved basmati and traditional basmati rice, respectively. The N concentration declines as the crop advances in age suggesting the need for adequate N fertilization at seedling/ transplanting so that rice plants have adequate N supply during active tillering stage when the protein synthesis is at the highest rate (De Datta, 1981). N accumulated at this stage is then transferred to other parts later *i.e.* from source to sink.

The paddy yield increased significantly with increase in number of splits of N application in superfine and evolved basmati, however there was no significant effect of number of splits on paddy yield in traditional basmati rice (Table 6). In superfine rice, the paddy yield increased even upto 4 splits while in evolved basmati it increased only upto 3 splits and decreased thereafter. Since superfine and evolved basmati rice also covered hybrids, which are highly responsive to N, response to split application of N was more abundant. The recommended application of N in three splits at the time of transplanting, 21 and 42 days of transplanting appears appropriate in evolved and traditional basmati.

The study established that on-farm use of nitrogen (N) exceeds the recommended levels and the increase corresponds to the increase in the number of splits. The increase in N use and thereby the number of splits is translating in yield gain in case of superfine and evolved Basmati. $N_{\text{Physical optimum}}$ and $N_{\text{economic optimum}}$ over and above the average doses of N in these two groups of rice indicates the further scope of N application. The use of N in the traditional Basmati rice is double edged sword where both dose and number of splits require high degree of precision and a gap of 60-70% is questionable since it is prone to biotic stresses. The insect-pest and disease complex in susceptible domains is directly correlated with the use of N-fertilizers. The findings of this study are quite explicit that the farmers targeting for higher yield tends to use higher doses of N but such doses not always add to the yield. The probability of yield penalty always remains. The optimization of N use may be higher than the recommended levels but in no way it will be the endorsement of the farmer's practice and needs synergy with other elements of crop management. The issue requires immediate action for safe environment by reducing N wastage. The number, time and amount of N into splits in all the rice types have proved beneficial in terms of yield.

This study provides necessary input to policy makers, researchers and developmental agencies and may be used for rationalization of fertilizer subsidy like crossing subsidies from N fertilizers to other fertilizers. The calculation of $N_{\text{economic optimum}}$ is on the basis of cost paid by the farmer. $N_{\text{economic optimum}}$ will slide down if the actual costing including the subsidy is taken into consideration. It is to be seen whether the inefficient and uneconomic yield gains in rice really required in the pursuit of food security. There is even scope of N economy through INM and thereby sound crop management. Thus, efficient N use is critical to produce enough food for the growing population and avoid large-scale degradation of ecosystems caused by excess N, thereby, requiring immediate correction of the existing recommendations.

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