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Nitrogen top dressing just before irrigation improves wheat growth, productivity and nitrogen use efficiency and profitability

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Abstract

A four year field study was conducted from 2010-11 to 2013-14 at the research farm of ICAR-Indian Institute of Wheat and Barley Research, Karnal, Haryana to evaluate the influence of timing and frequency of urea top dressing on wheat productivity. The 13 treatments consisted of three nitrogen levels (90, 120 and 150 kg N ha^{-1}), two time of application (just before applying irrigations and about a week after irrigations when it was possible to walk in the field) and two schedule of application (three equal splits as 1/3rd basal, 1/3rd at first irrigation and 1/3rd at second irrigation; and four equal splits as 1/4th basal, 1/4th at first irrigation, 1/4th at second irrigation and1/4th at third irrigation) along with one absolute control. The study revealed that urea top dressed just before irrigation and nitrogen splitted in three equal doses led to better crop growth, yield attributes and yield of wheat leading to improved agronomic NUE (22.5-29.8 kg grain kg^{-1} applied N) than urea top dressed after irrigation and nitrogen splitting in four equal doses at all levels of nitrogen application (90-150 Kg ha^{-1}). The highest wheat productivity was recorded with 150 kg N ha^{-1} applied in three splits with top dressing just before irrigation. Additional yield of 2.70-5.21q ha^{-1} (average 3.94 q ha^{-1}) was produced when urea was applied just before irrigation as compared to urea top dressed after irrigatin. This yield gain was 5.93 to 10.83 percent (average 8.36 %). This practice gave additional benefit of Rs. 4680 to 9043 ha^{-1} (average Rs. 6843 ha^{-1}).

Keywords: Agronomic NUE, grain protein, N splitting, urea top dressing, profitability

1. Introduction

Wheat (*Triticum aestivum* L.) is the second most important staple food crop of India after rice. It is cultivated on 29.58mha area with 99.7mt production having an average yield of 3371 kg ha^{-1} (4th advance estimates from the Agricultural Statistics Division, Directorate of Economics and Statistics, Department of Agriculture, Cooperation and Farmers Welfare, GOI, New Delhi). In India'snorthern plains, spring wheat is cultivated with the use of moderate level of N i.e. 150 kg ha^{-1} (Coventry *et al.,* 2011) and the fertilizer recommendation for wheat is also 150 kg N ha^{-1} (2-split schedule: 1/3 at sowing and 2/3 at the first node stage or half at sowing and half at first irrigation) and 60 kg P_2O_5 ha^{-1} and 40 kg K_2O ha^{-1} at sowing (Mishra *et al.,* 2005; Srivastava *et al.,* 2006). Most of the soils in Haryana and Punjab where wheat is grown in an irrigated double-cropping pattern, are deficient in N. In the rice–wheat rotation, farmers are applying more than the recommended N level (150 kgN ha^{-1}). A survey by Singh *et al.*(2010) indicated that farmers' in Haryana apply on an average 165.7 kg N ha^{-1} and 30 kg P_2O_5 ha^{-1} to wheat with only 9.2% of the farmers used K-fertilizer. The current understanding is that a 2-split application of N fertiliser is suited to the slightly heavier soils of eastern Haryana where the rice–wheat system dominates and in the west and south-west regions that have lighter soils and where rice is not grown apply N in 3 splits. Application of 150 kgN ha^{-1} in three splits i.e. 1/3 basal at sowing, 1/3 after first irrigation and 1/3 at spike initiation yielded significantly more grain yield than N applied as a single application in Hisar, Haryana, a non-rice region (Bhardwaj *et al.,* 2010).

Elsewhere in the world, N recoveries are higher in wheat when N is applied at targeted growth stages rather than all at planting, with such split applications often translating into higher yields, consistently higher grain protein and less lodging (Hobbs *et al.,* 1998). Low N use efficiency due to inefficient management of fertiliser N is reflected in low recovery of fertiliser N by the crop. Nitrogen use efficiency (NUE), which is expressed as the percentage of the N content of the grain to the N-fertiliser applied, illustrates how well a crop has recovered applied nitrogen fertiliser and highlight the pathways where nitrogen can be used more efficiently (Raun and Johnson, 1999; Woolfolk *et al.,* 2002). The optimum use of N fertiliser will come from matching N supply with crop demand for N (Bhardwaj *et al.,* 2010; Singh *et al.,* 2011) and losses of N can be large when the N application is not synchronised with crop growth and development. A Bangladesh study has shown considerable opportunity to increase farmers' yields through improved N management without any other change in fertiliser input or crop management practices (Alam *et al.,* 2006). Irrigation is also as important as fertiliser use, especially within the high cropping intensity areas of Haryana, in sustaining wheat productivity growth. To achieve high wheat yield, irrigation must be applied efficiently and on time. In Northern Haryana, the soils are irrigated by flooding with the water mainly drawn from underground water sources. However, many farmers also use sprinkler irrigation in SW Haryana. Irrigation is required to establish the crop and several subsequent irrigations are recommended at times corresponding to the specific growth stages (crown root initiation, early tillering, late jointing/boot, heading/flowering) of the wheat(Mishra *et al.,* 2005). Farmers of this region are facing the problem of exact timing of fertilizer application as top dressing of urea especially at tillering (20-25DAS) and jointing (40-45 DAS) stages of crop growth and number of splits of top dressed urea whether three application (1/3rd basal, 1/3rd at tillering and 1/3rd at jointing) or four split application (1/4th basal, 1/4th at tillering, 1/4th at jointing and 1/4th at late jointing generally coinciding with third irrigation at 60-65DAS) just before irrigation or after about a week when the field is suitable for walking. Hence, the present study was undertaken to examine the time, number of splits and rate of nitrogen in wheat crop for achieving higher productivity and nitrogen use efficiency in North Western Indian Plains.

2. Materials and methods

A field study was conducted to examine the time and frequency of nitrogen application especially urea top dressing on wheat productivity in Rabi season commencing from 2010-11 to 2013-14 at research farm of ICAR-Indian Institute of Wheat and Barley Research, Karnal, Haryana (Latitude 29^0 43' N, longitude 76^0 58' E and altitude 245 m). The experimental soil was sandy loam in texture (61.4% sand, 23.8% silt and 14.8% clay), low in organic carbon (0.30-0.35%) and available nitrogen (169.95-179.36 kg ha^{-1}), medium in available phosphorus (17.09-19.87 kg ha^{-1}) and medium to high in available

Table1. Nitrogen levels, number of splits and time of urea top dressing details

Treatment	Nitrogen Levels	Splits of Nitrogen	Time of Urea top dressing
T1	90 kg N ha^{-1}	3-1/3 Basal, 1/3 first irrigation, 1/3 second irrigation	After irrigation
T2	90 kg N ha^{-1}	4- ¼ Basal, ¼ first irrigation, ¼ second irrigation, ¼ third irrigation	After irrigation
T3	90 kg N ha^{-1}	3-1/3 Basal, 1/3 first irrigation, 1/3 second irrigation	Before irrigation
T4	90 kg N ha^{-1}	4- ¼ Basal, ¼ first irrigation, ¼ second irrigation, ¼ third irrigation	Before irrigation
T5	120 kg N ha^{-1}	3-1/3 Basal, 1/3 first irrigation, 1/3 second irrigation	After irrigation
T6	120 kg N ha^{-1}	4- ¼ Basal, ¼ first irrigation, ¼ second irrigation, ¼ third irrigation	After irrigation
T7	120 kg N ha^{-1}	3-1/3 Basal, 1/3 first irrigation, 1/3 second irrigation	Before irrigation
T8	120 kg N ha^{-1}	4- ¼ Basal, ¼ first irrigation, ¼ second irrigation, ¼ third irrigation	Before irrigation
T9	150 kg N ha^{-1}	3-1/3 Basal, 1/3 first irrigation, 1/3 second irrigation	After irrigation
T10	150 kg N ha^{-1}	4- ¼ Basal, ¼ first irrigation, ¼ second irrigation, ¼ third irrigation	After irrigation
T11	150 kg N ha^{-1}	3-1/3 Basal, 1/3 first irrigation, 1/3 second irrigation	Before irrigation
T12	150 kg N ha^{-1}	4- ¼ Basal, ¼ first irrigation, ¼ second irrigation, ¼ third irrigation	Before irrigation
T13	0 kg N ha^{-1}	Absolute Control	

potash (251.68-287.52 kg ha^{-1}) content. The experiment was laid out in a randomized complete block design with three replications. The treatments consisted of three nitrogen levels (90,120 and 150 kg N ha^{-1}), two time of application (just before first and second irrigations and about a week after first and second irrigations depending upon the soil conditions ready to enter in the field) and two schedule of application (three equal splits as $1/3^{rd}$ basal, $1/3^{rd}$ at first irrigation at 21-25 DAS and 1/3rd at second irrigation at 40-45DAS; and four equal splits as $1/4^{th}$ basal, $1/4^{th}$ at first irrigation at 21-25 DAS, $1/4^{th}$ at second irrigation at 40-45 DAS and $1/4^{th}$ at third irrigation at 60-65 DAS) along with one absolute control (no nitrogen) thus making total thirteen treatments (Table 1). The wheat was fertilized with 60 Kg P_2O_5 and 40 kg K_2O ha^{-1} as basal (at sowing) and nitrogen as per treatments. The wheat variety DBW 17 was grown at row spacing of 20cm and using seed rate of 100 Kg ha^{-1} during all the four seasons. Every year the preceding crop taken was coarse rice cultivar HKR 147. The plot size for each treatment was 8.0 m x1.8 m. All other agronomic practices were kept uniform for all the treatments. Data on growth and yield attributes and yield were recorded at maturity of the crop. Plant height and earhead length of five plants from each plot were measured by meter scale from the net plot area. Earhead density was recorded one meter deep from both ends in penultimate row on both sides of the every plot for one running meter, averaged and then multiplied by five to have earheads/square meter. Biomass was recorded after harvesting above ground part of matured wheat plants from net plot area after air drying. The pre-weighed bundles of wheat biomass from each plot were threshed separately by plot thresher, produce stored in cloth bags and then cleaned thoroughly before taking the final weight of grains from each plot and correcting the yield for 12% moisture. Thousand grains weight and protein content of the grains were recorded from the samples taken from each treatment at the time of final weighing of grain yield from each plot. Grains per earheads were calculated by using formula: Grains/earhead= Yield, q/ha X 10,000/ (Earheads/sq.m. x 1000 grains weight, g). Grain protein content was estimated by using NIR (Near Infra Red Reflectance) machine of FOSS make. Agronomic nitrogen use efficiency was calculated by deducting the grain yield (kg ha^{-1}) of control treatment from the grain yield of respective treatment (kg ha^{-1}) and dividing it by the amount of N applied in respective treatment (kg ha^{-1}). Yield gain at various nitrogen levels due to pre -irrigation urea top dressing was calculated by deducting the yield of respective nitrogen level after irrigation top dressing treatment. For calculating net returns, the minimum support price of wheat was taken as Rs 1735/q.

3. Result and discussion

Results presented in Table 2 revealed that application of nitrogen as urea at different time and splits (3 or 4) influenced the plant height significantly during all the years as well as on pooled basis. The plant height significantly increased with nitrogen levels from 90 to 150kg N ha^{-1} as compared to control (no nitrogen). On pooled basis, the plant height was significantly higher in treatments where N was applied in three splits after irrigation as compared to respective four splits up to 120 kg N ha^{-1}.

Earhead length was also significantly affected by nitrogen levels and all the nitrogen levels recorded significantly higher earhead length than control (no nitrogen) but

Table 2. Effect of pre and post irrigation and split application of urea nitrogen on growth and earheads density of wheat

Treatment equal splits	Plant Height, cm					Earhead length, cm					Earheads/sq. m.				
	2010-11	2011-12	2012-13	2013-14	Pooled	2010-11	2011-12	2012-13	2013-14	Pooled	2010-11	2011-12	2012-13	2013-14	Pooled
T1-90N, 3 after irrigation	78.9	81.1	83.2	77.33	80.1	8.0	9.0	7.2	8.8	8.3	454	361	409	341	391
T2-90N, 4 after irrigation	70.9	**74.9**	80.9	75.07	75.5	7.7	9.2	7.3	8.3	8.1	461	358	400	345	391
T3-90N, 3 before irrigation	78.7	84.3	79.6	78.47	80.3	7.8	8.9	7.7	8.1	8.1	483	368	422	394	416
T4-90N, 4 before irrigation	76.5	83.3	81.9	80.33	80.5	7.9	9.3	7.9	7.9	8.2	473	362	428	359	405
T5-120N, 3 after irrigation	77.3	84.6	82.7	85.27	82.5	7.5	8.9	7.7	8.8	8.2	470	423	458	375	432
T6-120N, 4 after irrigation	74.2	79.5	82.8	75.07	77.9	7.5	9.2	7.4	8.1	8.1	450	385	461	354	413
T7-120N, 3 before irrigation	80.0	85.0	85.8	77.47	82.1	8.3	9.1	7.5	8.5	8.4	533	433	480	437	470
T8-120N, 4 before irrigation	78.1	86.7	84.1	81.47	82.6	7.4	9.0	7.5	8.4	8.1	495	375	483	405	439
T9-150N, 3 after irrigation	77.9	85.9	85.2	83.33	83.1	8.1	9.3	7.5	8.5	8.3	496	455	474	415	460
T10-150N, 4 after irrigation	74.8	85.5	84.5	86.60	82.9	7.5	9.3	8.1	8.5	8.4	483	375	490	421	442
T11-150N, 3 before irrigation	80.8	90.4	84.3	82.87	84.6	7.7	9.3	7.5	8.3	8.2	516	473	489	476	488
T12-150N, 4 before irrigation	79.0	91.5	83.6	82.93	84.3	8.1	9.2	7.9	8.6	8.5	509	450	495	443	474
T13-Control (no nitrogen)	60.1	59.6	63.0	49.57	58.1	6.2	7.5	6.4	7.2	6.8	319	303	291	297	303

among different levels, time of application of urea and number of splits of nitrogen were found at par among themselves (Table 2) indicting no effect of timing and split application on earhead length.

Earhead density was also significantly affected by the application of nitrogen levels and all the nitrogen levels recorded significantly higher earhead density than control (no nitrogen).On pooled basis, highest earhead density (488/ sq. m.) was recorded in treatment where 150 kg N ha^{-1} was applied in three splits just before irrigation and it was significantly higher than the 90 kg N ha^{-1} applied in three or four splits just before or after irrigation (Table 2). Three split application of N as urea top dressed just before irrigation recorded more earhead density at all the levels of nitrogen and it was numerically better than four splits and urea top dressed after irrigation during all the years as well as on pooled basis (Table 2).

Perusal of the data presented in Table 3 revealed that levels, time and splits of nitrogen did not influence the boldness of the wheat grain (1000 grains weight,) during all the years of study as well as on pooled basis except during the year 2010-11 where all the nitrogen levels, times and splits produced significantly bolder grains than control.

Number of grains/earhead was also significantly influenced by levels, time of N application as well as number of splits as compared to control (no nitrogen). The highest numbers of grains/earhead (31.42 grains/earhead) on pooled basis were recorded in treatment where 150kg N was applied

Table 3. Effect of pre and post irrigation and split application of urea nitrogen on yield attributes and biomass of wheat

Treatment equal splits,	1000 grains weight, g					Number of grains/ Earhead					Biomass, q ha-1				
	2010-11	2011-12	2012-13	2013-14	Pooled	2010-11	2011-12	2012-13	2013-14	Pooled	2010-11	2011-12	2012-13	2013-14	Pooled
T1-90N, 3 after irrigation	41.37	38.11	37.23	37.12	38.46	26.07	33.71	29.54	33.06	30.59	114.29	108.33	107.14	96.83	106.65
T2-90N, 4 after irrigation	40.55	37.39	37.65	36.56	38.04	22.55	27.25	29.03	30.06	27.22	94.44	91.27	103.97	85.71	93.85
T3-90N, 3 before irrigation	39.60	38.42	37.35	37.31	38.17	28.66	34.13	30.16	29.06	30.50	116.27	114.68	113.49	101.59	111.51
T4-90N, 4 before irrigation	40.26	38.10	36.73	36.59	37.92	24.05	32.55	29.48	31.11	29.30	101.59	107.54	112.30	92.46	103.47
T5-120N, 3 after irrigation	40.10	39.49	37.80	37.97	38.84	27.98	27.46	27.30	32.33	28.77	114.29	114.68	114.29	103.57	111.71
T6-120N, 4 after irrigation	40.77	38.12	36.45	37.05	38.10	27.11	28.78	28.71	32.20	29.20	105.16	104.76	115.48	92.46	104.46
T7-120N, 3 before irrigation	39.25	38.31	37.39	37.25	38.05	26.88	31.88	28.06	29.00	28.95	127.78	124.21	119.44	109.52	120.24
T8-120N, 4 before irrigation	39.71	39.11	37.07	36.80	38.17	25.27	34.30	28.10	29.14	29.20	117.06	125.79	118.65	98.02	114.88
T9-150N, 3 after irrigation	39.12	38.55	37.07	36.94	37.92	29.34	30.48	29.92	32.72	30.62	124.21	126.59	123.02	113.10	121.73
T10-150N, 4 after irrigation	40.97	38.03	36.58	37.36	38.24	26.71	35.68	28.86	29.93	30.30	113.89	122.22	123.81	100.79	115.18
T11-150N, 3 before irrigation	39.12	38.36	37.24	36.99	37.93	30.90	33.64	29.92	31.22	31.42	141.67	142.06	126.98	123.41	133.53
T12-150N, 4 before irrigation	40.11	37.93	36.99	37.26	38.07	29.19	34.48	29.42	30.87	30.99	134.92	136.51	128.17	111.90	127.88
T13-Control (no nitrogen)	37.36	37.43	37.09	36.25	37.03	17.38	18.85	23.32	17.26	19.20	47.22	45.24	57.54	44.05	48.51
CD (0.05)	1.52	NS	NS	NS	NS	2.78	2.83	2.53	2.44	3.04	4.80	4.90	5.84	4.83	4.99

Table 4. Effect of pre and post irrigation and split application of urea nitrogen on yield and quality of wheat

Treatment equal splits,	Grain yield, q ha-1					Straw yield, q ha-1					Grain protein content, %				
	2010-11	2011-12	2012-13	2013-14	Pooled	2010-11	2011-12	2012-13	2013-14	Pooled	2010-11	2011-12	2012-13	2013-14	Pooled
T1-90N, 3 after irrigation	49.00	46.36	44.92	41.81	45.52	65.29	61.97	62.22	55.02	61.13	10.34	9.20	10.57	11.63	10.44
T2-90N, 4 after irrigation	42.12	36.52	43.69	37.90	40.06	52.32	54.75	60.27	47.82	53.79	10.14	9.37	10.07	10.30	9.97
T3-90N, 3 before irrigation	54.67	48.05	47.42	42.73	48.22	61.60	66.63	66.07	58.86	63.29	9.90	9.30	10.03	11.37	10.15
T4-90N, 4 before irrigation	45.64	44.77	46.28	40.88	44.39	55.94	62.77	66.02	51.58	59.08	10.07	9.67	10.30	10.60	10.16
T5-120N, 3 after irrigation	52.71	45.85	47.28	46.00	47.96	61.58	68.83	67.00	57.58	63.75	10.03	9.10	10.73	12.23	10.52
T6-120N, 4 after irrigation	49.25	42.18	48.15	42.25	45.46	55.91	62.58	67.33	50.21	59.01	10.19	9.33	10.80	11.40	10.43
T7-120N, 3 before irrigation	56.07	52.79	50.31	47.17	51.59	71.71	71.41	69.13	62.35	68.65	9.81	9.23	10.67	12.07	10.45
T8-120N, 4 before irrigation	49.67	50.17	50.17	43.43	48.36	67.40	75.63	68.48	54.59	66.52	9.93	9.37	10.83	10.73	10.22
T9-150N, 3 after irrigation	56.83	53.46	52.61	50.15	53.26	67.38	73.13	70.40	62.95	68.47	9.78	9.67	10.77	12.00	10.55
T10-150N, 4 after irrigation	52.75	50.76	51.73	46.97	50.55	61.14	71.46	72.08	53.82	64.63	10.24	9.50	11.73	11.47	10.74
T11- 150N, 3 before irrigation	62.25	60.94	54.50	54.92	58.15	79.42	81.13	72.49	68.50	75.38	9.78	9.53	11.63	12.73	10.92
T12-150N, 4 before irrigation	59.63	58.81	53.81	50.82	55.77	75.29	77.70	74.37	61.08	72.11	10.03	9.97	11.73	11.50	10.81
T13-Control (no nitrogen)	20.69	21.38	25.08	18.50	21.41	26.53	23.86	32.46	25.55	27.10	9.34	9.37	9.90	9.92	9.63
CD (0.05)	2.40	2.61	1.51	2.54	2.09	4.64	4.28	7.58	3.58	5.01	0.38	NS	0.86	0.83	0.67

in three splits just before irrigation indicating the positive effect of nitrogen top dressed just before irrigation (Table 3). The significantly lowest numbers of grains/earhead (19.20 grains/earhead) on pooled basis were recorded in treatment where no nitrogen was applied.

The results revealed that the biomass production was influenced significantly by time, level and split application of urea top dressing (Table 3). Biomass was significantly higher in all the levels of nitrogen from 90 to 150 kg ha-1 than control treatment. Biomass was also significantly higher where urea was top dressed just before irrigation than urea top dressed after irrigation at all the levels of nitrogen in three split application as compared to four split application on yearly as well as on pooled basis.

Grain yield of wheat was significantly affected by levels of nitrogen, split application and time of urea top dressing. The significantly higher (58.15 q ha-1) grain yield was observed in treatment where N at 150 kg ha-1 was top dressed just before irrigation with three split application during all the years as well as on pooled basis (Table 4). As expected, the lowest grain was recorded in absolute control treatment. It was reported (Coventry *et al.,* 2011) earlier also that three spit application of 150 kg N ha^{-1} (three equal splits as $1/3^{rd}$ basal, $1/3^{rd}$ at first irrigation at 25 DAS and $1/3^{rd}$ at second irrigation at 45 DAS) were better than two split application in Haryana conditions.

The application of urea just before irrigation recorded higher grain yield at all the levels of nitrogen application than corresponding level where urea was top dressed after irrigation (about a week) indicating the positive impact of before irrigation urea top dressing and a yield gain of 2.70-5.21 q ha^{-1} was observed on pooled basis (Table 5). It indicates greater recovery of applied nitrogen due to top dressing just before irrigation which was reflected in consistently higher productivity.

Straw yield of wheat was significantly affected by levels of nitrogen, split application and time of urea top dressing. The highest (75.38 q ha^{-1}) and significantly higher straw yield was observed in treatment where urea was top dressed just before irrigation with three split application of N at 150kg ha-1 during all the years and on pooled basis. The lowest straw yield (27.10 q ha^{-1}) was recorded in absolute control treatment (Table 4).

Wheat quality measured in the form of grain protein content was also significantly influenced by nitrogen levels and time of application (Table 4). All the levels of nitrogen recorded significantly higher grain protein content than absolute control indicating the positive effect of Nitrogen for achieving better quality of wheat. On pooled basis, it was observed that three split application of nitrogen and urea top dressing just before irrigation had higher grain protein content than four split application and urea top dressed after irrigation but the increase was numerical only (Table 4).

Agronomic nitrogen use efficiency (NUE) was also influenced by levels of N, number of splits and time of urea top dressing. The highest agronomic NUE (29.8 kg grain kg^{-1} N applied) was recorded where 90 kg ha^{-1} N was applied in three splits and urea was top dressed just before irrigation (Table 5). Urea top dressing just before irrigation brought about higher agronomic NUE than urea top dressed after irrigation in three split application (three equal splits as $1/3^{rd}$ basal, $1/3^{rd}$ at first irrigation at 20-25 DAS and $1/3^{rd}$ at second irrigation at 40-45 DAS) than four split application (as $1/4^{th}$ basal, $1/4^{th}$ at first irrigation at 20-25 DAS, 1/4th at second irrigation at 40-45 DAS and$1/4^{th}$ at third irrigation at 60-65 DAS) at all the levels

Table 5. Effect of pre and post irrigation urea split application on agronomic NUE, yield gain and economic returns

Treatment	Agronomic NUE, kg grain per kg nitrogen applied	Yield gain with pre irrigation over corresponding post irrigation urea application	Percent yield gain with pre irrigation over corresponding post irrigation urea application	Net economic returns by applying pre irrigation urea over post irrigation (Rs. ha-1)
T1- 90N, 3 equal splits, after irrigation	26.79	-	-	-
T2- 90N, 4 equal splits, after irrigation	20.72	-	-	-
T3- 90N, 3 equal splits, before irrigation	29.78	2.70	5.93	4680*
T4- 90N, 4 equal splits, before irrigation	25.53	4.34	10.82	7522
T5- 120N, 3 equal splits, after irrigation	22.12	-	-	-
T6- 120N, 4 equal splits, after irrigation	20.04	-	-	-
T7- 120N, 3 equal splits, before irrigation	25.14	3.63	7.56	6295
T8- 120N, 4 equal splits, before irrigation	22.45	2.90	6.38	5035
T9- 150N, 3 equal splits, after irrigation	21.23	-	-	-
T10- 150N, 4 equal splits, after irrigation	19.43	-	-	-
T11- 150N, 3 equal splits, before irrigation	24.49	4.89	9.18	8481
T12- 150N, 4 equal splits, before irrigation	22.90	5.21	10.31	9043

of nitrogen i.e. 90 to 150kg ha^{-1}. It clearly indicates that three split application of N and top dressing of urea just before irrigation is the best nitrogen management strategy for irrigated wheat under North Indian conditions. The practice of urea top dressing just before irrigation resulted in 2.70-5.21q ha^{-1} (average 3.94 q ha^{-1}) additional yield compared to respective treatment of urea top dressing after irrigation (Table 5). This yield gain was 5.93 to 10.83 percent (average 8.36 %) higher yield than urea top dressed after irrigation which resulted in additional benefit of Rs. 4680 to 9043 ha^{-1} (average Rs. 6843 ha^{-1}) at the wheat MSP of Rs. 1735/q^{-1} (Table 5).

Three split application of N and urea top dressed just before irrigation treatments were found better than four split application of N and urea top dressed after irrigation at all the levels of N in improving the growth, yield attributes, yield and quality of wheat crop as well as in improving agronomic NUE which might be due the reason that N applied through urea top dressed just before irrigation was efficiently dissolved in the irrigation water and stored in the root zone of the wheat crop and thus reduced the volatilization losses of N. Earlier, Katyal *et al.* (1987) also reported that the apparent recovery N through urea applied just before irrigation was higher (62%) than the apparent recovery of N through urea applied after irrigation. Similarly,Fernando Viero *et al.* (2015) also reported that sprinkler irrigation immediately after N fertilization is effective in reducing ammonia losses by volatilization, particularly from urea.

Conclusion

On the basis of this four year study it can be concluded that 150 kg N ha^{-1} applied in three equal splits (as 1/3rd basal, 1/3rd at first irrigation at 20-25 DAS and 1/3rd at second irrigation at 40-45 DAS) with top dressing using urea just before irrigation was the most efficient practice of nitrogen management for better growth, yield and quality of wheat as well as better recovery of applied N along with greater profitability to farmers.

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