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WHEAT NITROGEN INDICES RESPONSE TO NITROGEN SOURCE AND APPLICATION TIME

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Abstract

The unnecessary inputs costs to farmers due to N losses can be optimized by developing a sound fertilizer strategy. The optimization for improved wheat productivity, N re-translocation, utilization and use efficiencies can be achieved through source and timing of N application. Thus, an experiment was carried out at the Research Farm of KPK Agricultural University Peshawar during 2005-06 to test the effects of sources and timing of N application on wheat biological yield and N indices. Nitrogen sources were ammonium (NH_4-N) and nitrate (NO_3-N) applied @ 100 kg ha^{-1} at three different stages i.e., at sowing (S1), tillering (S2) and boot stage (S3). Ammonium-N increased wheat biological yield and total N uptake whereas nitrogen utilization efficiency was increased with NO_3-N. Split N at sowing, tillering and boot stages had increased the biological yield and apparent N re-translocation, whereas total-N uptake and N harvest index was higher for full application of N at boot stage. Nitrogen application had almost double the N uptake compared to control and increased 27% N re-translocation regardless of sources and application time. It was concluded from the experiment that split application of N had higher wheat productivity and re-translocation, whereas full and delayed N dose increased N harvest index compared to other treatments. Thus, split N application is recommended for improved biological yield, whereas for improved quality of grains the delayed application of N at boot stage is preferable in agro-climatic conditions of Peshawar.

Introduction

The efficient utilization of nitrogen (N) helps in reducing the cost of cereal production. Nitrogen use efficiency (NUE) depends on source and timing of N fertilizer and other factors, thus NUE can be managed in cropping system components (Huggins & Pan, 1993) by adjusting a proper production technology for improving NUE. Improving NUE will be a way to produce high yields with low inputs of N (Limon-Ortega *et al.*, 2000).

The N application levels, types and times influenced N indices such as N uptake (Iqbal *et al*., 2005) and its translocations (Kichey *et al*., 2007). Fertilizers application timing had a significant role in determining uptake of fertilizer and its partitions to soil and plant (Limaux *et al*. 1999). Uptake, utilization efficiencies of N and its harvest index fell as N fertilizer rates increased, indicating poor N utilization, whereas N physiological efficiency had the opposite response (López-Bellido & López-Bellido 2001). López-Bellido *et al.,* (2003) recorded total uptake of N in the range of 50 to 127 kg N ha^{-1} while seed N uptake between 34 and 107 kg N ha^{-1}. Generally, the urea and NH_4NO_3 performed equally in neutral to slightly alkaline soil. Similarly, under warm soil or alkaline soil, urea performs equally to NH_4NO_3 by reducing N losses through volatilization (Mahler *et al*., 1994).

Timing of N application had a significant role on the N indices and can help in reducing N losses, e.g., Mossedaq & Smith (1994) reported that N losses could be minimized if N application is made before the onset of stem elongation. When N was applied at first node stage, the total N uptake was greater than at planting time (Limon-Ortega *et al*., 2000). Similarly, Tran & Tremblay (2000) reported that early application of N at planting and tillering had lower N fertilizer uptake than later application (shooting) in wheat. Split and latter application of N increased NUE through avoiding unnecessary vegetative growth and losses of N (Alcoz *et al*., 1993). Pan *et al.*, (2006) reported that during grain filling, N remobilization from the leaves, stem and chaff depended on the curvilinear or linear decreases of the N concentrations. Fertilizer recovery was higher when N was applied at anthesis compared to N applied during planting (Wuest & Cassman 1992). Delayed application of N increased the management flexibility by providing the N when soil moisture is low and root uptake is minimum and thus farmer can adjust fertilizer rates for improved N uptake and productivity (Ellen & Spiertz, 1980). Published studies have addressed the optimal N fertilization rates and timing for improved use and uptake efficiencies of N and information regarding sources of N and its combination with time of application is limited in this area. Thus, an experiment was designed to determine the effects of different sources of N fertilizer and its application timings for improved N indices, in addition to biomass productions under agro-climatic conditions of Peshawar.

Material and Methods

Experimental site: An experiment to determine the effects of sources and timing of application of N on different nitrogen indices was carried out at Agricultural Research Farm of KPK Agricultural University Peshawar during Fall 2005. The experimental site has warm to hot, semi-arid subtropical continental climate with a mean annual rainfall of about 360mm. The soil was silty clay loam, well drained and strongly calcareous, with a pH of 8.2. It was deficient in nitrogen and phosphorous but has adequate potassium.

Treatments and materials: The experimental treatments consisted of two types of N-fertilizer (NH_4-N & NO_3-N) and three-application time i.e., at sowing, tillering and boot stage. Urea was used as mineral-N source for NH_4-N and calcium nitrate ($CaNO_3$) for NO_3-N @ 100 kg ha^{-1}. Combinations of the treatments, including no fertilizer (control) were replicated four times in a Randomized Complete Block (RCB) design. Details of the experimental treatments are given in Table 1.

Table 1. Details of the experimental treatments and their levels.

	Type of fertilizer-N			Application time of fertilizer-N		
	----------- (% of N dose) $ ----------					
	(S1)	(S2)	(S3)	(S1)	(S2)	(S3)
T1	0	0	0	0	0	0
T2	NH_4	0	0	100	0	0
T3	NO_3	0	0	100	0	0
T4	0	NH_4	0	0	100	0
T5	0	NO_3	0	0	100	0
T6	0	0	NH_4	0	0	100
T7	0	0	NO_3	0	0	100
T8	NH_4	NH_4	0	50	50	0
T9	NH_4	0	NH_4	50	0	50
T10	0	NH_4	NH_4	0	50	50
T11	NO_3	NO_3	0	50	50	0
T12	NO_3	0	NO_3	50	0	50
T13	0	NO_3	NO_3	0	50	50
T14	NH_4	NH_4	NH_4	33	33	33
T15	NO_3	NO_3	NO_3	33	33	33

$ = 100 kg N ha^{-1}, S1 = at sowing, S2 = at tillering, S3 = at boot stage

Field operations: Field was thoroughly prepared using a common cultivator at field capacity stage. Sowing was done in October 2005 in a plot size of 5 x 3m having 10 rows with 30cm inter-row distance. A tractor-mounted planter equipped with row cleaner wheels adjusted for 120 kg ha^{-1} seed rate was used for sowing. Basel dose of phosphorus @ 60 kg ha^{-1} as single super phosphate (SSP) was used. Uniform agronomic practices for raising a successful crop were followed for all the treatment. The field was irrigated after 21 days when the germination was completed in all plots. The field was then irrigated as and when needed.

Observations and measurements: The six central rows were harvested, sun dried and weighed for the determination of biological yield. To determine the various N indices, plants were randomly sampled from a single position of 0.5m length from the rows located at the 3^{rd} row from the edges at pre-awns emergence and maturity stages i.e., at code 49, and 94, respectively (Zadoks *et al.*, 1974). The sampled plants were separated into chaffs and grain at maturity stage whereas no separation was practiced at pre-awns emergence stage. These components were dried for 36 hours in oven at 50°C. The dried samples chaffs and grains (12.7±0.2% moisture content) were ground by tissue grinder and sieved through 0.2mm sieve to get the fine powder for determination of N content. The grounded samples were stored until the completion of analyses following Kjeldahl procedure (Westerman, 1990).

The following calculations were made from the analyzed samples.

1. Total N uptake was recorded by using the formula:

$$\text{Total N uptake} = \text{Straw N} + \text{Grain N} \times \text{Biological yield}$$

2. Nitrogen use efficiency is the wheat grain yield (G_w) per unit of N supply (N_s), and was calculated by formula (G_w/ N_s). Nitrogen supply was calculated as N applied as fertilizer plus total nitrogen uptake in control plots (Huggins & Pan, 1993).

3. Nitrogen utilization efficiency was recorded by the formula (Fiez *et al.*, 1995)

$$\text{Nitrogen utilization efficiency} = \frac{\text{Grain yield}}{\text{Total N uptake (plant N)}}$$

4. Apparent N re-translocation was determined according to the procedure described by Cox *et al.*, (1986) using the formula:

$$\text{Apparent N re-translocation} = \text{N assimilation prior to anthesis} - \text{N yield at maturity (chaffs)}$$

5. Nitrogen harvest index was determined according to the procedure described by Cox *et al.*, (1986) by the formula:

$$\text{Nitrogen harvest index} = \frac{\text{Grain nitrogen}}{\text{Total N assimilation}} \times 100$$

Statistical analysis: The collected data was analyzed according to the procedure relevant to RCB design and the mean were separated using least significance difference (LSD) test. In addition to LSD, planned mean comparisons were also used to achieve the specific objectives of the research (Jan *et al*., 2009).

Results

Biological yield: Plots received NH_4-N had increased biological yield over NO_3-N (Table 2). Generally, the split application increased the biological yield when NO_3-N was used, whereas the full dose of NH_4-N application improved the biological yield. Average over sources of application time reflected maximum biological yield (7398 kg ha^{-1}) when N was used in split application compared to full dose. Control plots had produced minimum biological yield compared to fertilized plots (Fig. 1). Nitrogen applied as full dose increased the biological yield when applied later than to earlier sole dose application. The overall impact of full and split N application remained the same for biological yield. Similarly, within split N application (two or three split), no significant differences were observed for biological yield.

Total N uptake: Uptake of N by wheat from NH_4-N source of fertilizer was greater than NO_3-N. Split application of N increased the N uptake in NO_3-N compared to NH_4-N. Average over sources, total N uptake was higher (111 kg ha^{-1}) when full dose of N was used at boot stage compared to other earlier stages (Table 3). Nitrogen fertilization had increased the uptake of N compared to control plots (Fig. 2.). Delayed N application increased N uptake as compared to earlier application of N. Generally differences were noted for N uptakes between full or splits applications of N as well as within number of split applications.

Nitrogen use efficiency: Nitrogen use efficiency (NUE) was not affected by sources of N application. Within both sources, split applications of N had improved the NUE. Average over N sources, greater NUE (19.44%) was recorded when N was applied as split dose i.e., half at tillering and other half at boot stage (Table 4). Among planned mean comparisons (Fig. 3.), NUE was higher for control plots compared to fertilized plots. Early or delayed N application as a full dose had no effect on NUE. Nitrogen applied as split had increased the NUE compared to full dose; however, increasing the splitting of N had not affected the NUE.

Nitrogen utilization efficiency: Higher utilization efficiency of N (NUtE) was observed when NO_3-N was used as source of N compared to the NH_4-N source (Table 5). Average over sources, the maximum NUtE (29.31%) was observed when N was applied as split doses of 50 kg N ha^{-1} at planting time and other half at boot stages of the wheat. Among planned mean comparison, control plots had effectively utilized the N compared to the fertilized plots. Nitrogen applied either earlier or latter, as a full dose of 100 kg N ha^{-1} had no impact on NUtE (Fig. 4). Generally, the split application of N increased the NUtE compared to full dose application. More specifically, three split doses of N had improved the NUtE over two-split dose of N.

Table 2. Biological yield (kg ha^{-1}) of wheat as affected by source and timing of nitrogen application.

Application time (100 kg N ha^{-1})	Fertilizer source		Mean
	NH_4-N	NO_3-N	
Full S1	6556	6067	6311
Full S2	7022	6733	6878
Full S3	8111	6400	7256
1/2 S1 + 1/2 S2	7289	6733	7011
1/2 S1 + 1/2 S3	7156	6356	6756
1/2 S2 + 1/2 S3	7511	7267	7389
1/3 S1 + 1/3 S2 + 1/3 S3	7089	7411	7250
Mean	**7248**	**6710**	
LSD(0.05) for N sources			**
LSD(0.05) for N timing			575
Interaction (Sources x Timing)			*

S1= at sowing, S2= at tillering, S3= at boot stage, *, ** = Significant at 5% and 1% level of probability, respectively.

Table 3. Total nitrogen uptake by wheat (kg ha^{-1}) as affected by source and timing of nitrogen application.

Application time (100 kg N ha^{-1})	Fertilizer source		Mean
	NH_4-N	NO_3-N	
Full S1	99	93	96
Full S2	108	104	106
Full S3	126	95	111
1/2 S1 + 1/2 S2	108	101	105
1/2 S1 + 1/2 S3	103	93	98
1/2 S2 + 1/2 S3	112	109	110
1/3 S1 + 1/3 S2 + 1/3 S3	106	114	110
Mean	**109**	**101**	
LSD(0.05) for N sources			**
LSD(0.05) for N timing			9
Interaction (Sources x Timing)			**

S1= at sowing, S2= at tillering, S3= at boot stage, ** = Significant at 1% level of probability

Apparent nitrogen re-translocation: Sources of N had not affected the apparent N re-translocation. Higher apparent nitrogen re-translocation was observed for full dose of NH_4-N at sowing or splits applications of NO_3-N (Table 6). Average over sources, maximum apparent N re-translocation (7.94 g kg^{-1} DM) was observed when N was used in three equal splits application at sowing, tillering or boot stages. Planned mean comparisons revealed that control had lower apparent N re-translocation than fertilized plots (Fig. 5.). Full dose of N application either earlier or latter had not affected the apparent N re-translocation. Generally, the split application of N had higher apparent N re-translocation than full dose. More specifically, three splits application of N significantly increased the apparent N re-translocation over two splits.

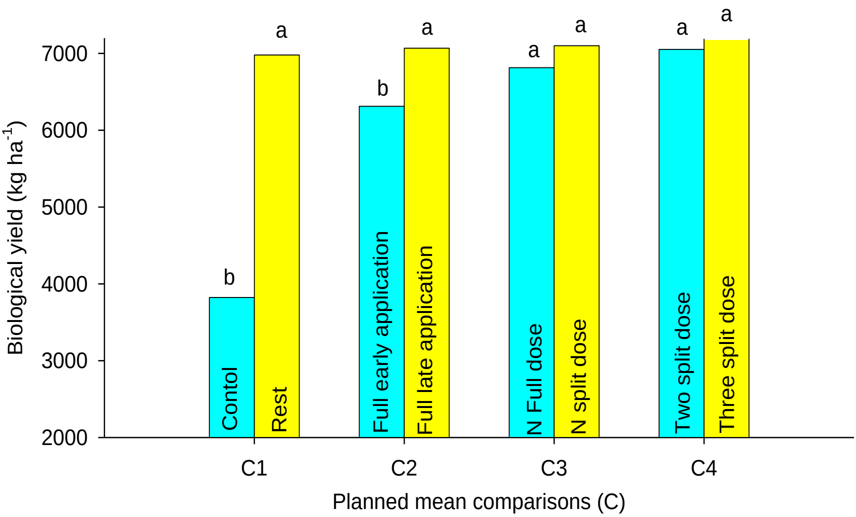

Fig. 1. Planned mean comparisons for biological yield (kg ha^{-1}) as affected by sources and timing of N. Bars having similar letter within each comparison are not significant.

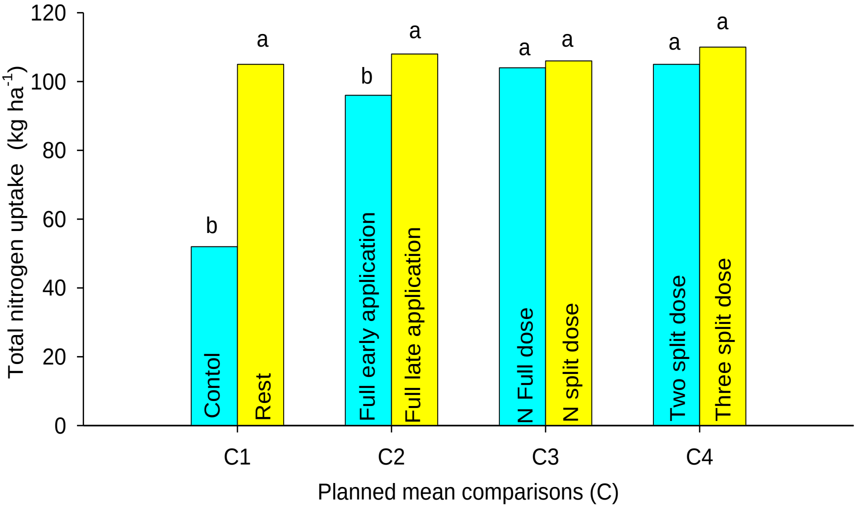

Fig. 2. Planned mean comparisons for wheat total nitrogen uptake (kg ha^{-1}) as affected by sources and timing of N. Bars having similar letter within each comparison are not significant.

Nitrogen harvest index: Nitrogen harvest index (NHI) was not affected by using NH_4-N or NO_3-N source (Table 7). Averaged over sources, NHI was higher (80.47%) when full dose of N was applied at boot stage compared to other treatments. Planned mean comparison (Fig. 6.) revealed that control had higher NHI than fertilized plots. Full dose (100 kg N ha^{-1}) application of N at either tillering or boot stages achieved higher NHI than at sowing. No differences for NHI were observed when N was applied as full dose or in split doses.

Table 4. Nitrogen use efficiency (%) of wheat as affected by source and timing of nitrogen application.

Application time (100 kg N ha^{-1})	Fertilizer source		Mean
	NH_4-N	NO_3-N	
Full S1	18.56	17.57	18.06
Full S2	17.63	17.16	17.39
Full S3	17.16	17.82	17.49
1/2 S1 + 1/2 S2	18.63	19.94	19.28
1/2 S1 + 1/2 S3	19.36	18.20	18.78
1/2 S2 + 1/2 S3	19.75	19.14	19.44
1/3 S1 + 1/3 S2 + 1/3 S3	18.21	18.21	18.21
Mean	**18.47**	**18.29**	
LSD(0.05) for N sources			NS
LSD(0.05) for N timing			1.38
Interaction (Sources x Timing)			NS

S1= at sowing, S2= at tillering, S3= at boot stage, NS= not significant

Table 5. Nitrogen utilization efficiency (%) of wheat as affected by source and timing of nitrogen application.

Application time (100 kg N ha^{-1})	Fertilizer source		Mean
	NH_4-N	NO_3-N	
Full S1	28.84	28.95	28.90
Full S2	24.96	25.66	25.31
Full S3	20.82	28.57	24.70
1/2 S1 + 1/2 S2	26.42	30.22	28.32
1/2 S1 + 1/2 S3	28.50	30.12	29.31
1/2 S2 + 1/2 S3	27.44	26.78	27.11
1/3 S1 + 1/3 S2 + 1/3 S3	26.24	24.63	25.44
Mean	**26.17**	**27.85**	
LSD(0.05) for N sources			*
LSD(0.05) for N timing			3.04
Interaction (Sources x Timing)			NS

S1= at sowing, S2= at tillering, S3= at boot stage, NS= not significant, * = Significant at 5% level of probability

Discussion

In the present study, the improved biomass with NH_4-N might be the consequences of larger available N (Malhi *et al*., 2006) or minimum N leaching (Habtegebrial *et al*., 2007) compared to NO_3-N. These results are in line with Brejda *et al*., (1995), who obtained greater wheat productivity from ammonium source of N than others. The increase in biomass with N application might be due to individual performance of the crop (Kibe *et al*., 2006), or might be due to efficient photosynthetic activity (Lopez-Bellido *et al*., 1998). Our results are in line with the findings of Shafiq *et al*., (1994) and Geleto *et al*., (1995) who reported that fertilizer application increased wheat productivity over control. Split applications of N might have decreased the losses of N and better synchronization with plant demand resulting in increased in wheat biomass.

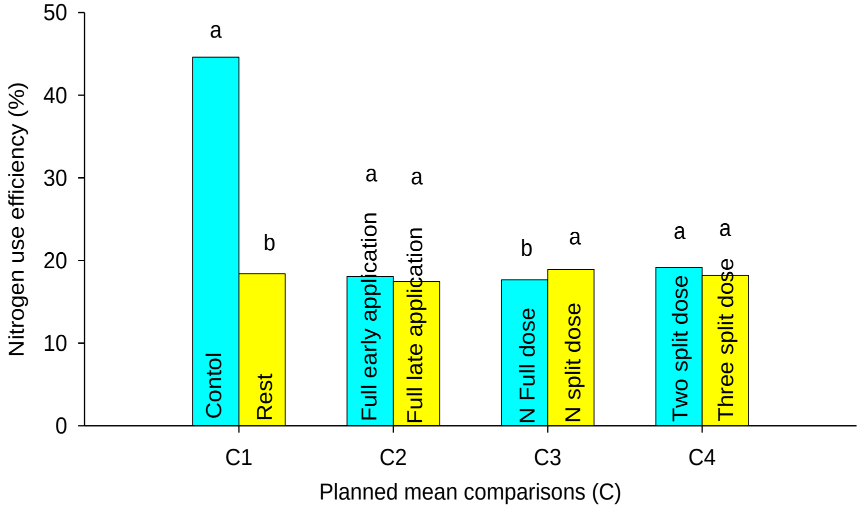

Fig. 3. Planned mean comparisons for nitrogen use efficiencies (%) in wheat as affected by sources and timing of N. Bars having similar letter within each comparison (C) are not significant.

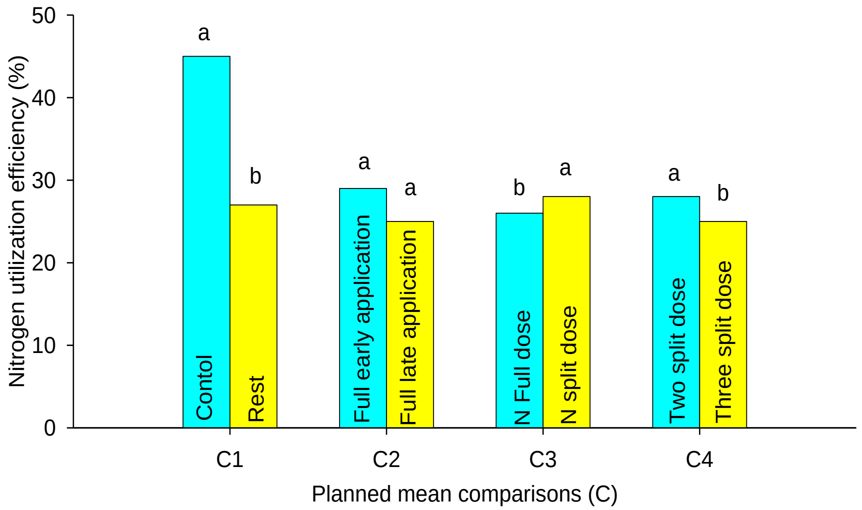

Fig. 4. Planned mean comparisons for nitrogen utilizations efficiencies (%) in wheat as affected by sources and timing of N. Bars having similar letter within each comparison are not significant.

Application of N had increased the uptake of N (Dhillon *et al.*, 1998), which might be attributed to higher N availability (Parmar & Sharma, 2001) for the crop. Split application of N had increased the availability of N for crop and thus more uptake was recorded from plots where N was applied in split application. Delayed application of N might have reduced the potential N losses from leaching or denitrification over winter (Ellen & Spiertz, 1980) and thus might have increased the N uptake. Our results are in agreement with findings of Mercedes *et al.*, (1993) who reported that split fertilizer N application improved N uptake in wheat.

Table 6. Apparent nitrogen re-translocation (g kg^{-1} DM) of wheat as affected by source and timing of nitrogen application.

Application time (100 kg N ha^{-1})	**Fertilizer source**		**Mean**
	NH_4-N	**NO_3-N**	
Full S1	7.77	6.53	7.15
Full S2	7.17	6.73	6.95
Full S3	7.27	6.42	6.85
1/2 S1 + 1/2 S2	6.57	7.04	6.80
1/2 S1 + 1/2 S3	7.24	7.63	7.44
1/2 S2 + 1/2 S3	6.25	8.06	7.15
1/3 S1 + 1/3 S2 + 1/3 S3	7.68	8.20	7.94
Mean	7.14	7.23	
LSD(0.05) for N sources			NS
LSD(0.05) for N timing			0.47
Interaction (Sources x Timing)			**

S1= at sowing, S2= at tillering, S3= at boot stage, NS= not significant, ** = Significant at 1% level of probability

Table 7. Nitrogen harvest index (%) of wheat as affected by source and timing of nitrogen application.

Application time (100 kg N ha^{-1})	**Fertilizer source**		**Mean**
	NH_4-N	**NO_3-N**	
Full S1	79.29	78.52	78.90
Full S2	79.13	80.05	79.59
Full S3	80.51	80.44	80.47
1/2 S1 + 1/2 S2	80.44	79.68	80.06
1/2 S1 + 1/2 S3	78.86	78.90	78.88
1/2 S2 + 1/2 S3	78.78	79.77	79.28
1/3 S1 + 1/3 S2 + 1/3 S3	78.92	79.13	79.02
Mean	**79.42**	**79.50**	
LSD(0.05) for N sources			NS
LSD(0.05) for N timing			0.80
Interaction (Sources x Timing)			NS

S1= at sowing, S2= at tillering, S3= at boot stage, NS= not significant

Control plots had efficiently utilized the available inherent N and thereby increased the NUE compared to fertilized plots. The full dose of N had resulted in less NUE than split applications, this might be attributed to the greater N losses as previously reported by many researchers. For example, Wuest & Cassman (1992) reported that pre-plant N applications might lead to losses or immobilization before uptakes by plant, thus greatly affecting NUE. Similarly, Rozas *et al.*, (2004) reported that the NUE was greater when N was applied at 6 leaf stages than when N was applied at planting time. The other possible explanation for improved NUE due to split N application might be the consequences of lower N losses through denitrification or leaching (Jokela & Randall, 1997) or lower N immobilization in organic forms (Wells & Bitzer., 1984) and greater plant N uptake due availability of N at the time of need.

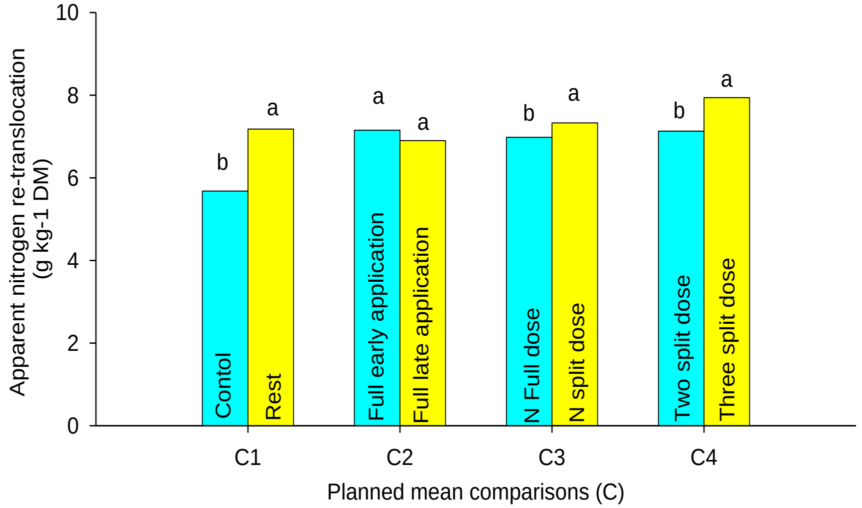

Fig. 5. Planned mean comparisons for Apparent nitrogen re-translocation (g kg^{-1} DM) in wheat as affected by sources and timing of N. Bars having similar letter within each comparison are not significant.

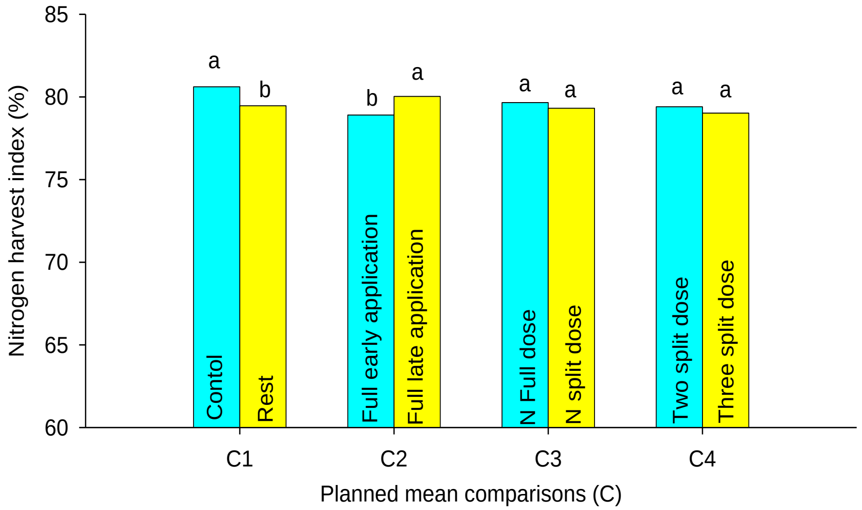

Fig. 6. Planned mean comparisons for Nitrogen harvest index (%) in wheat as affected by sources and timing of N. Bars having similar letter within each comparison are not significant.

Nitrogen fertilization had decreased the NUtE compared to control. Fertilization timings affect the NUtE by cereals (Ragheb *et al*., 1993), which might be the results of available N at the maximum plant demand (Bigiriego *et al*., 1979) or minimum N losses (Jokela & Randall, 1997). Split application of N had improved the photosynthetic capacity of the canopy (Frederick & Camberato, 1995) and thereby improved the NUtE compared to full dose of N. Our results are line with the findings of Rozas *et al*., (2004) who reported greater utilization of N with split application of N compared to full dose. The other possible explanations for improved NUtE due to split application might be the greater individual performance of the crop during early period (Khan *et al*., 2009) and/or efficiently utilizations of N when it was available at later stage of plant growth (Jung *et al*., 1972; Rozas *et al*., 2004).

Early N content in vegetative parts was higher in fertilized plots compared to control (Halvorson *et al*., 2000). The translocation of N to grain after grains filling (Cox *et al*., 1986) was not comparable to control plots and thus might have decreased the apparent N re-translocation (Gooding *et al*., 2007). Our results are supported by the findings of Kumar & Puri (2001). The continuous leaf activity plays a significant role in N assimilation that might be associated with re-translocation occurs through a process of protein degradation and remobilization of amino acids (Woodruff, 1972). The greater re-translocation of N from vegetative to reproductive parts due to split N applications might be due to greater source sink competitions (Lopez-Bellido *et al*., 2001) compared to control. In the same way, Vanderlip (1993) reported that N uptake in sorghum occur rapidly up to 35 days of emergence and thereafter re-translocation of N may occur.

Control had higher NHI than fertilized plots, which might be associated with lesser uptake of N in control plots. Application of full dose at later stage had increased the mineral N availability or N uptake at physiological maturity and a proportional increase in grain yield to the plant and thereby increased NHI (Rozas *et al*., 1999) compared to early application of N. The higher grain yield be obtained when N is applied at six leaf stages due to lesser gaseous N losses or NO_3 leaching (Rozas *et al*., 1999) and thereby increased the N content in grain and hence NHI. In the same way, Benziger *et al*., (1982) reported greater photosynthetic accumulation in wheat by late N application.

Conclusions and Recommendations

Ammonium N had increased the biological yield compared to NO_3-N, but has no effects on N indices. Increased N had increased the biological yield and total N uptake, whereas NUE, NUtE and NHI were decreased. Split application of N had increased the wheat productivity and N indices. Thus, for improved wheat productivity and efficient N utilization and uptakes the splits application of N at later stage of the crop should be practiced in agro-climatic conditions of Peshawar.

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