Indian J. Plant Physiol., Vol. 9, No. 3, (N.S.) pp. 239-246 (July-Sept., 2004)

NITROGEN ASSIMILATION, GRAIN PROTEIN AND YIELD OF WHEAT IN RESPONSE TO IRRIGATION AND METHOD OF FERTILIZER N APPLICATION

N.K. SEKHON* AND K.S. SANDHU

Department of Soils, Punjab Agricultural University, Ludhiana-141004, India

Received on 29 May, 2003, Revised on 22 July, 2004

SUMMARY

A field experiment was conducted with wheat (*Triticum aestivum* L. cv PBW 343) during 1999-2000, to assess the interactive effects of timings of irrigation and fertilizer N on nitrogen assimilation, grain yield and protein content on a sandy loam soil. The experiment consisted of nine irrigation treatments ranging from nil to four in the main plots and three N treatments viz. no fertilizer N and 120 kg N ha^{-1} (a) drilled at the time of sowing and (b) broadcast before presowing irrigation (BPSI) applied one week before sowing in the sub-plots. Mineral N distribution in the soil profile, determined at the time of sowing, showed that presowing irrigation transported 63 percent of the applied N to the sub-soil.

Nitrate reductase activity (NRA) of the flag leaf during grain filling was significantly enhanced by both amount and method of N application. The grain protein content (GPC) increased significantly (p=0.05) from 10.3 percent in 120 kg N ha-1 drilled at sowing to 12.7 percent in broadcast. However, there was a decline in GPC with increase in irrigation number. Further, NRA showed a curvilinear relationship with GPC and grain N uptake. N recovery was found to be 30 percent in drill and 60 percent in BPSI method.

There was a significant (p=0.05) increase in 1000-grain weight, grain yield, biomass and total N uptake with irrigation. Similarly, fertilizer N drilled at sowing increased total biomass, ears per m^2, grain number per ear, grain N uptake and total N uptake over no N. Application of the same amount of N with BPSI further brought a significant improvement in these parameters. However, the grain size was significantly reduced with both fertilizer N rate and method of application.

***Key words*: Grain protein, N application with presowing irrigation, N profile, Nitrate reductase activity, Timings and frequency of irrigation.**

INTRODUCTION

In Northern India, wheat is the staple food of people. Even though it is produced in surplus, the grain protein content is low. Though protein content is genetically controlled but, to some extent, it can be enhanced through improved water and fertilizer N management (Sajo *et al*. 1992, Fischer *et al*. 1993, Akaya 1994, Kattimani *et al*. 1996). In irrigated wheat, application of urea before presowing irrigation (BPSI) was reported to be a better method of application (Singh *et al*. 1984). Higher efficiency with this method was stated to be due to the movement of applied N into the moist sub-soil, which enhanced its availability and uptake (Aggarwal and Sidhu 1992, Sandhu and Sidhu 1996). Subsoil mineral N becomes available to the crops when N in the surface soil is not available as the

* Corresponding author, E-mail: nkeskhon@hotmail.com

topsoil becomes dry (Gass *et al*. 1971). As long as N was not leached away from the root zone, subsoil N significantly increased grain protein content (Lotfollahi and Malakouti 2001).

Plants take up nitrogen predominantly as nitrate (Haynes and Goh 1978), which is assimilated into amino acids and then into proteins. Nitrate reductase (NR) is the key enzyme for reduction of nitrate to ammonia (Kleinhofs and Warner 1990). Nitrogen assimilation is mainly dependent on available NO_3^--N in the rooting zone. Nitrate reductase activity (NRA) is strongly inhibited by water stress (Hsiao 1973). In wheat, nitrate reductase is important during grain filling stage when nitrate reduction levels decline to minimum (Rao *et al*. 1977). Fertilizer and irrigation management practices that ensure nitrate availability during grain filling are likely to enhance N assimilation.

Effects on N rate, time of N application and irrigation on NRA and grain protein have been well documented (Sekhon and Aggarwal 1991, Sajo *et al*. 1992, Fischer *et al*. 1993, Akaya 1994, Vyas *et al*. 1999, Krishnakumari *et al*. 2000). However, information on nitrogen assimilation with respect to irrigation timings and mode of fertilizer N application is lacking. The present study was, therefore, undertaken to investigate (i) the effect of fertilizer N application before PSI on NRA under variable irrigation supplies and (ii) explore the possibility of using NRA as an index for enhancing grain yield and protein content in wheat.

MATERIALS AND METHODS

Experimental soil

A field experiment was conducted at the Punjab Agricultural University Research Farm, Ludhiana (30º56'N 75º52'E), India. The sandy loam soil belonging to Typic Ustochrept is deep, well drained and non-saline with a pH of 8.1 and tested 3.4 g kg^{-1} organic carbon, 27 kg ha^{-1} $NaHCO_3$ – extractable P and 101 kg ha^{-1} neutral normal ammonium acetate extractable K.

Treatments and design

The experiment was laid out in a split-plot design with three replications. Each sub plot measured 8 × 1.8 m^2. The main plot consisted of nine post-sowing irrigation treatments ranging from nil to four irrigations (Table 1) and the sub-plot three fertilizer N treatments viz. (without fertilizer N (N_o), (ii) 120 kg N ha^{-1} drilled below the seed at the time of sowing (N_d) and (iii) 120 kg N ha^{-1} broadcast just before presowing irrigation (N_b). A common presowing irrigation was applied one week before sowing. The mineral N ($NH_4^+ + NO_3^-$) distribution profile (Fig. 1) determined just before sowing from N_O and N_b shows that only 37% of the estimated N was present in the top 15 cm soil and the rest was transported to the sub soil (15-120 cm) with presowing irrigation. Each plot received 60 kg P_2O_5 and 60 kg K_2O per hectare as basal dose.

Table 1. Details of irrigation treatments.

S.No.		Irrigation treatments
1.	Rainfed	No postsowing irrigation
2.	I_4	7 cm irrigation 4 weeks after sowing (WAS)
3.	I_{12}	7 cm irrigation 12 WAS
4.	I_{18}	7 cm irrigation 18 WAS
5.	$I_{4, 12}$	7 cm irrigation each at 4 & 12 WAS
6.	$I_{4, 18}$	7 cm irrigation each at 4 & 18 WAS
7.	$I_{12, 18}$	7 cm irrigation each at 12 & 18 WAS
8.	$I_{4, 12, 18}$	7 cm irrigation each at 4, 12 & 18 WAS
9.	$I_{4, 8, 12, 18}$	7 cm irrigation each at 4, 8, 12 & 18 WAS

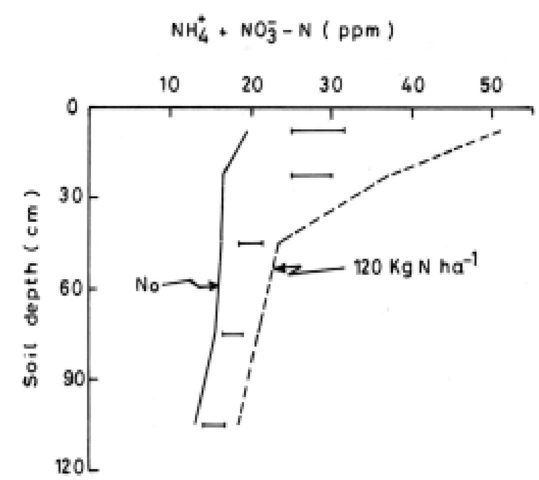

Fig.1. Mineral N distribution profile at sowing after applying 7 cm presowing irrigation with no and 120 kg N ha^{-1}. Horizontal lines represent LSD (0.05).

Experimental procedure

Wheat (*Triticum aestivum* L. cv. PBW-343) was sown on 5th November 1999 in 20 cm wide rows using a seed rate of 100 kg ha^{-1}. The seed was treated with chlorpyrifos @ 4 ml kg^{-1} to prevent termite attack. Two hand hoeings were given to check weed infestation and reduce surface evaporation. Rainfall and open pan evaporation, recorded at PAU meteorological observatory located at two km from the experimental site, and post-sown water inputs under various treatments, are given in Fig. 2 on weekly basis.

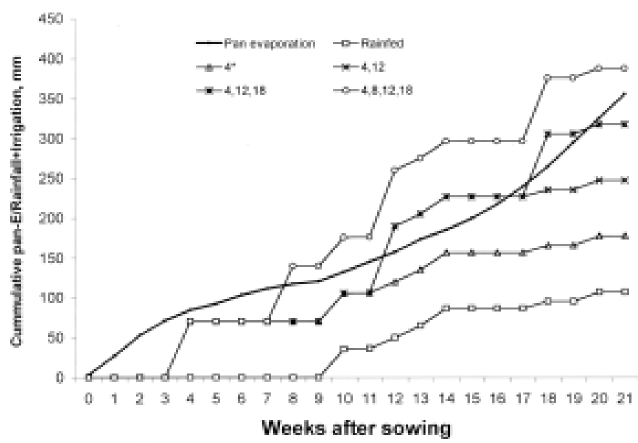

Fig.2. Cumulative pan evaporation and post sowing water inputs (rainfall + irrigation) under various irrigation treatments. *The numerals in legends represent the irrigation times in weeks after sowing.

Fully expanded top leaf at preflowering (9th December 1999) and flag leaf at three post flowering stages i.e. 2nd March 2000, 17th March 2000 and 29th March 2000 corresponding to 0, 15 and 27 days after anthesis (DAA) were used for *in vivo* assay of NR activity (Jaworski 1971). A sample of 200 mg leaf blade segments was suspended in a screw-cap vial containing 5 ml medium of 0.1 M phosphate buffer (pH 7.5), 0.02 M KNO_3, 1 per cent propanol and 2 drops of 0.05 mg ml^{-1} chloramphenicol. The vials were kept in the dark at 30ºC for 4 hours and nitrite released into the medium estimated colorimetrically using sodium nitrite as standard.

The crop was harvested at maturity for aboveground biomass and grain yield. One meter row length was harvested from each plot to evaluate yield-contributing parameters. Grain and straw samples were dried for 48 hours at 60ºC for determining N content by microkjeldahl method (Jackson 1973). Crude protein content, hereafter mentioned as grain protein, was computed by multiplying the grain N content with 5.7.

RESULTS AND DISCUSSION

Nitrate reductase activity

Irrigation had a significant ($p = 0.05$) positive effect on NRA both during vegetative phase and 27 days after anthesis (Fig. 3). Irrigation at 4 weeks after sowing (WAS) improved NRA significantly over no irrigation. NR activity of flag leaf at 27 DAA was significantly higher in treatments receiving irrigation at 18 WAS (7 DAA). Chowdhury (1995) and Vyas *et al.* (1999) reported that NR activity was improved with an increase in moisture availability. It appears that post anthesis irrigation ensured adequate moisture and nitrate supply that enabled the plant to maintain NRA even at later stages.

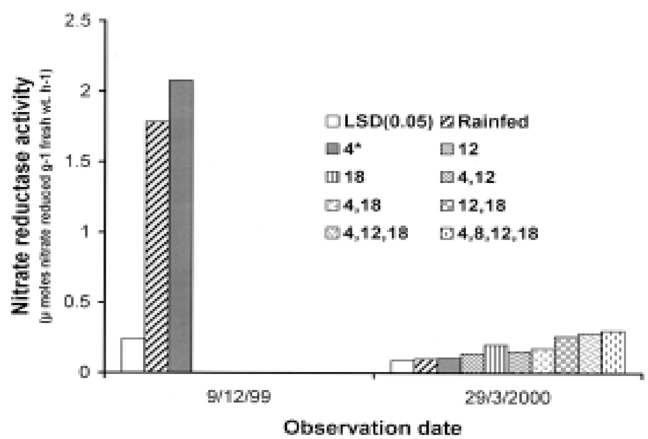

Fig. 3. Nitrate reductase activity of leaf blade during vegetative (9/12/99) and grain filling (29/3/2000) phases under various irrigation regimes. *The numerals in legends represent the irrigation times in weeks after sowing.

Application of 120 kg N ha^{-1} drilled at sowing increased the NR activity significantly ($p = 0.05$) and it was 1.34, 1.62 and 2.38 times that of unfertilized control at 0, 15 and 27 DAA, respectively (Fig. 4). The activity improved further on applying the same N with presowing irrigation as broadcast (N_b) and was 1.38, 1.84 and 1.61 times over N_d on 0, 15 and 27 DAA, respectively. The higher level

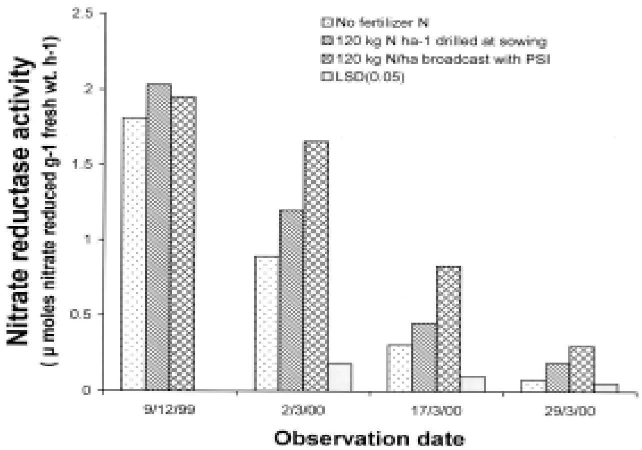

Fig. 4. Nitrate reductase activity of leaf blade during vegetative (9/12/99) and grain filling (2, 17, 29/3/2000) phases under different fertilizer N treatments.

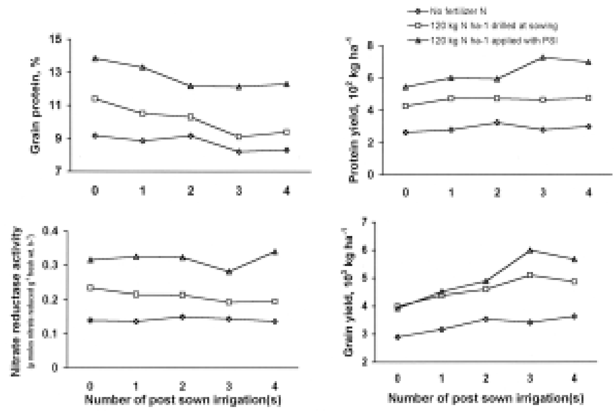

Fig. 5. Interactive effects of applied N and irrigation on mean NRA of flag leaf during grain filling, grain protein content, protein and grain yield.

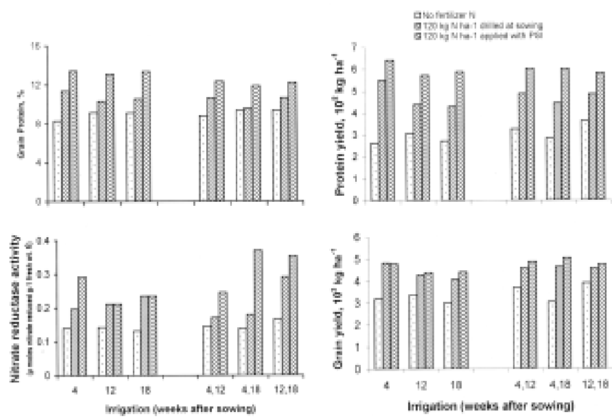

Fig. 6. Interactive effects of fertilizer N and timing of one and two irrigations on mean NRA of flag leaf during grain filling, grain protein content, protein and grain yield.

of flag leaf NRA in N_b reflects higher tissue nitrate concentration even during grain filling period, which indicated better N uptake. The mineral N distribution profile (Fig. 1) showed that 62 percent of fertilizer N was transported to the subsoil with presowing irrigation which might have become available to the plant at later stages due to deeper root proliferation when in the upper layers of soil, N is already depleted. Sidhu and Sandhu (1995) reported that in mustard, when fertilizer N was applied with presowing irrigation, a deep root system developed but when the same N was drilled at seeding, the roots were confined mostly to the plough layer.

NRA was highest in N_b throughout under various irrigation treatments followed by N_d and minimum under N_o (Fig. 5). One and two irrigations applied at different timings also showed the same trend (Fig. 6). However, single irrigation applied 4 WAS was superior to that applied at 12 or 18 WAS. Considering the relative performance in two irrigations, the trend was $I_{4, 18} > I_{12, 18} > I_{4, 12}$ in N_i, whereas it was $I_{12, 18} > I_{4, 18} > I_{4, 12}$ in N_d. The results indicate that during grain filling, the NRA tended to improve with delay in irrigation.

Grain protein

On an average (averaged over irrigation treatments), the grain protein content (GPC) was 8.3% without fertilizer N addition but significantly increased to 10.3% with N_d and 12.7% with N_b. Grain protein yield was 297 kg ha^{-1} without applied fertilizer N but increased to 467 and 617 kg ha^{-1} (1.57 and 2.08 times) with N_d and N_b, respectively. It appears that under N_b, greater amount of N was available in the subsoil, which enhanced deep root proliferation, and consequently more N uptake during grain filling, and better grain protein synthesis. Lotfollahi and Malakouti (2001) had also reported higher grain protein content with subsoil N application after flowering.

However, GPC decreased with an increase in the number of irrigations (Fig. 5). For example, it was highest in rainfed treatment (i.e. 11.4% with N_d and 13.85% with N_b) and the least with 3 irrigation treatments (i.e. 9.12% in N_d and 12.14% in N_b). Grain protein yield however was least in rainfed (i.e. 266, 426 and 544 kg ha^{-1}

respectively in N_0, N_d and N_b). Increase in protein yield under N_0 was highest (22%) with 2 irrigations whereas in Ni, protein yield increased by 34 and 28% respectively with 3 and 4 irrigations. Grain protein yield, however, was unaffected by irrigation regimes in N_d. In case of single irrigation applied at different stages, maximum GPC as well as protein yield was recorded when irrigated at 4 WAS (11.4% in N_d and 13.4% in N_b) and was lowest when irrigated 12 WAS (10.3% in N_d and 13.1% in N_b) (Fig. 6). Poor GPC in I_{12} could be attributed to the 86.3 mm rainfall between 10 and 14 WAS (Fig. 2) in addition to 7 cm irrigation water input at 12 WAS, which might have led to deep percolation loss of N. On the other hand, I_4 had the advantage of better moisture and nitrogen availability throughout the growth period compared to I_{12}.

NRA-protein relationship

It was reported earlier that the level of NRA is an index of reduced N available for protein synthesis (Nair and Abrol 1982, Singh and Singh 1985, Nair and Chatterjee 1990). An effort was made to correlate grain protein content with NRA during grain filling phase. Grain protein content was regressed against mean NRA (μmol NO_3^- reduced g^{-1} fresh wt. h^{-1}) during grain filling stage involving linear and square terms. The results showed (equation (i)) that both linear and square terms were significant ($p = 0.05$) and the relationship explained 81 percent variations in grain protein content. The maxima were reached at NRA value of 1.19 and after that the protein content declined.

$$Y = 3.1 + 16.4\ NRA - 6.92\ NRA^2\ (R^2 = 0.81,\ n = 27) \text{—(i)}$$

Yield and its attributes

Wheat grain yield responded significantly ($p = 0.05$) to both irrigation and method of fertilizer N application (Table 2/Fig. 5). On an average, irrigation at 4 WAS increased grain yield by 18% and 2 irrigations increased yield by 20% over rainfed. The maximum grain yield (4841 kg ha^{-1}) was recorded in $I_{4, 12, 18}$ treatment and was 34% higher over the rainfed. Fig. 2 shows that the demand and supply balance between pan evaporation and rainfall + irrigation water inputs matched well in $I_{4, 12, 18}$ during the crop growing season resulting in maximum yield. Water inputs in $I_{4, 8, 12, 18}$ treatment exceeded the evaporative demand which might have contributed to deep percolation and leaching of applied N. On the other hand, in 2, 1 and 0 irrigation treatments, increasing water deficits might have contributed to a progressive yield decline.

Fertilizer N application brought a significant increase ($p = 0.05$) in grain yield, which was influenced by irrigation inputs. For example, increase in grain yield under N_d over N_0 was the highest (1678 kg ha^{-1}) with 3 irrigations (Fig. 5). The yield increased further with N_b and it was 125, 289, 891 and 804 kg ha^{-1} higher over N_d with 1, 2, 3 and 4 irrigations, respectively. Sandhu and Sidhu (1996) also reported higher grain yield by applying fertilizer N with presowing irrigation over the drill application.

Regarding yield contributing parameters, 1000-grain weight was significantly ($p = 0.05$) affected by irrigation (Table 3). Grain size improved in treatments receiving irrigation at 18 WAS. The irrigation may have improved nutrient availability, which resulted in better grain development.

Fertilizer N drilled @ 120 kg ha^{-1} at sowing showed a significant increase in total biomass, number of ears per m^2 and grains per ear, which in turn brought a significant increase ($p = 0.05$) in grain yield also (Table 2 and 3). Broadcasting the same amount of N with presowing irrigation further improved these parameters significantly over the drill application method. However, the grain size was reduced under N_d and N_b. These results indicate that fertilizer N favored grain setting but reduced the grain size. The reduction in grain size may be attributed to the shortage of metabolites for a large number of competing sinks (grains).

Fertilizer N uptake and partitioning

Fertilizer N drilled @ 120 kg ha^{-1} resulted in 29.6 and 6.9 kg ha^{-1} higher N uptake by grain and straw, respectively, over the unfertilized (Table 2). Broadcasting the same amount of N before PSI resulted in 56.2 and 13.5 kg higher N uptake by grain and straw, respectively, over N_o. Compared to N_d, this was 32% higher in grain and 20% in straw. The increase in N uptake by fertilizer N drilled at sowing was mainly through increase in grain (36%) and straw (21.5%) yield, while the broadcast application further improved N uptake mainly through an

Table 2. Effect of irrigation and method of N application on wheat yield, N content and uptake.

Treatment	Yield (kg ha^{-1})		N content (%)		N uptake (kg ha^{-1})	
	Grain	Straw	Grain	Straw	Grain	Straw
Irrigation						
Rainfed	3611	5722	1.97	0.47	72.2	27.2
I_4	4266	7678	1.93	0.43	84.9	33.0
I_{12}	3998	6669	1.90	0.41	77.2	27.7
I_{18}	3821	6039	1.93	0.46	75.3	27.8
$I_{4,12}$	4384	8375	1.86	0.46	82.9	38.8
$I_{4, 18}$	4235	7839	1.80	0.40	78.3	33.9
$I_{12, 18}$	4402	7024	1.89	0.41	84.4	29.3
$I_{4, 12, 18}$	4841	9030	1.72	0.47	86.1	42.2
$I_{4, 8, 12, 18}$	4728	9217	1.78	0.41	86.5	38.3
LSD(0.05)	618	796	NS	NS	NS	7.4
Method						
Control	3346	6401	1.56	0.41	52.3	26.3
120 kg N ha^{-1}						
Drill	4549	7775	1.81	0.43	81.9	33.2
Broadcast	4867	8355	2.23	0.48	108.5	39.8
LSD (0.05)	236	418	0.08	0.04	6.1	4.3
Interaction	NS	NS	NS	NS	NS	NS

Table 3. Yield contributing parametes as affected by irrigation and method of N application.

Treatment	Ears/m row	Grains/ear	1000-grain wt. (g)
Irrigation			
Rainfed	85	30.1	42.2
I_4	94	29.6	41.0
I_{12}	99	28.3	42.3
I_{18}	89	29.4	44.9
$I_{4,12}$	108	30.2	43.1
$I_{4, 18}$	83	29.2	45.4
$I_{12, 18}$	94	30.0	45.9
$I_{4, 12, 18}$	86	31.0	46.4
$I_{4, 8, 12, 18}$	100	29.4	45.8
LSD(0.05)	NS	NS	2.4
Method			
Control	79	26.1	47.2
120 kg N ha^{-1}			
Drill	97	29.4	45.5
Broadcast	104	33.6	39.7
LSD(0.05)	8.5	2.4	1.2
Interaction	NS	NS	NS

Table 4. Percent N recovery as affected by irrigation and method of N application.

Treatment	N uptake* Kg ha^{-1}	Percent N recovery*** Drilled**	Brodcast**	Mean
Rainfed	68.6	28.3	49.0	38.7
One irrigation	72.3	34.1	56.7	45.4
Two irrigations	83.0	28.2	54.2	41.2
Three irrigations	86.0	31.0	74.8	52.9
Four irrigations	86.8	27.5	67.6	47.6
Mean	79.3	29.8	60.5	
LSD (0.05)				
Irrigation			NS	
Method			7.5	
Interaction			NS	

*Unfertilized, **120 kg N ha^{-1}, ***100(N uptake of treated-N uptake of control)/N applied.

increase in N content (23% in grain, 12% in straw). The results revealed that fertilizer N drilled at sowing is used preferentially for biomass production while that applied as broadcast was used for grain protein production.

Percent N recovery increased from 30% under drill application to 60% under broadcast application (Table 4). The recovery, however, was not affected by irrigation treatments.

It may be concluded that broadcasting fertilizer N before presowing irrigation is a better practice that improves grain quality (protein content) and yield as well. The reason behind this appears to be enhanced availability of applied N in the subsoil. This is quite evident from improved nitrate assimilation as indicated by higher NRA during grain filling stage. Higher nitrate uptake at grain filling may be attributed to better synchronization of N availability and plant root proliferation. Irrigation or fertilizer N application alone had a small response.

REFERENCES

Aggarwal, G.C. and Sidhu, A.S. (1992). Efficiency of urea application with pre-sowing irrigation on sandy loam and loamy sand. *J. Indian Soc. Soil Sci.* **40:** 44-48.

Akaya, A. (1994). Effect of nitrogen fertilizer source and application dates on yield, some yield components and protein content of wheat at Erzurum. *Turkish J. Agric. Forestry.* **18:** 313-322.

Chowdhury, S.R. (1995). Changes in internal plant water status and nitrate reductase activity in sweet potato under different irrigation regimes. *Orissa J. Hort.* **23:** 83-86.

Fischer, R.A., Howe, G.N. and Ibrahim, Z. (1993). Irrigated spring wheat and timing and amount of nitrogen fertilizer. I. Grain yield and protein content. *Field Crops Res.* **33:** 37-56.

Gass W.B., Peterson, G.A., Hauck, R.D. and Olson, R.A. (1971). Recovery of residual nitrogen by corn (*Zea mays* L.) from various soil depths as measured by ^{15}N tracer techniques. *Soil Sci. Soc. Am. Proc.* **35:** 290-294.

Haynes R.J. and Goh K.M. (1978). Ammonium and Nitrate nutrition of plants. *Biol. Rev.* **53:** 465-510.

Hsiao, T.C. (1973). Plant responses to water stress. *Ann. Rev. Plant Physiol.* **24:** 519-570.

Jackson, M.L. (1973). Soil Chemical Analysis. Prentice Hall Pvt. Ltd., New Delhi.

Jaworski, E.G. (1971). Nitrate reductase in intact plant tissues. *Biochem. Biophys. Res. Commun.* **43:** 1274-79.

Kattimani, K.N., Naik, V.R., Patil, B.N., Hanchinal, R.R. and Kulkarni, V.N. (1996). Effects of irrigation on yield, protein content and seedling vigour in wheat. *J. Maharashtra Agric. Univ.* **21:** 295-296.

Kleinhofs, A. and Warner, R.L. (1990). Advances in nitrate assimilation. In : B.J. Miflin and P.J. Lea (eds.), The Biochemistry of Plants, Vol. 16, Intermediary Nitrogen Metabolism, pp. 89-120. Academic Press, San Diego, CA.

Krishnakumari, M., Sharma, R.K. and Balloli, S.S. (2000). Effect of late application of nitrogen on yield and protein content of wheat. *Ann. Agric. Res.* **21:** 288-291.

Lotfollahi, M. and Malakouti, (2001). The effect of split nitrogen application on grain protein concentration of wheat. In : W.J. Horst *et al.* (eds.) Plant Nutrition - Food Security and Sustainability of Agro-ecosystems, pp. 340-341. Kluwer Academic Publishers, Netherlands.

Nair, T.V.R. and Abrol, Y.P. (1982). Nitrate reductase activity in flag leaf blade and its relationship to protein content and grain yield. *Plant Soil.* **57:** 147-149.

Nair, T.V.R. and Chatterjee, S.R. (1990). Nitrogen metabolism in cereals - case studies in wheat, rice, maize and barley. In : Y.P. Abrol (ed.) Nitrogen in Higher Plants, pp. 367-426. Res Studies Press, Taunton, England and John Wiley & Sons, New York.

Rao, K.P., Rains, D.W., Qualset, C.O. and Huffaker, R.C. (1977). Nitrogen nutrition and grain protein in two spring wheat genotypes differing in nitrate reductase activity. *Crop Sci.* **17:** 273-286.

Sajo, A.A., Scarisbrick, D.H. and Clewar, A.G. (1992). Effect of rates and timing of nitrogen fertilizer on the grain protein content of wheat (*Triticum aestivum*), grown in two contrasting seasons in south east England. *J. Agric. Sci.* **118:** 265-269.

Sandhu, K.S. and Sidhu, A.S. (1996). Response of dryland wheat to supplemental irrigation and rate and method of N application. *Fertilizer Res.* **45:** 135-142.

Sekhon, N.K. and Aggarwal, G.C. (1991). Source activity and sink strength in wheat as affected by soil fertility. In : K.K. Dhir, I.S. Dua and K.S. Chark (eds.), New Trends in Plant Physiology, pp. 285-288. Today and Tomorrow's Printers & Publishers, New Delhi, India.

Sidhu, A.S. and Sandhu, K.S. (1995). Response of mustard (*Brassica juncea* L.) to method of N application and timing of first irrigation. *J. Indian Soc. Soil Sci.* **43:** 331-334.

Singh, N.T., Dhaliwal, G.S., Sidhu, A.S., Aggrawal, G.C. and Singh, R. (1984). Efficiency of N application with presowing irrigation versus other methods. In: Nitrogen in Soils and Fertilizers. Bull No. 13, pp. 263-267. Indian *Soc. Soil Sci.* N. Delhi, India.

Singh, V.P. and Singh, M. (1985). Nitrate reductase activity and its relationship with grain protein and grain yield of wheat. *Indian J. Plant Physiol.* **28:** 235-242.

Vyas, S.P., Kathju, S., Garg, B.K. and Lahiri, A.N. (1999). Influence of supplemental irrigation and urea application on productivity and nitrogen metabolism of Sesame. *Indian J. Plant Phyisol.* **4:** 197-201.