UPTAKE OF SOIL AND LABELLED FERTILIZER NITROGEN BY DIFFERENT VARIETIES OF WHEAT

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ABSTRACT: A pot experiment was conducted on five wheat varieties, four belonging to *Triticum aestivum* and one to *T. turgidum*, using ^{15}N-labelled $(NH_4)_2SO_4$ to study fertilizer application response, N use efficiency, influence on fertilizer N loss and interaction of fertilizer N and soil N. Fertilizer use efficiency of different varieties ranged between 44% and 55%; differences among the varieties being significant. The contribution of fertilizer N to the total plant N was 30% for all varieties with no significant difference. Uptake of soil N by different varieties was similar and about 5% of the total soil N. In the presence of fertilizer N, availability of soil N was significantly enhanced; the five varieties generally showed significant differences. Losses of fertilizer N ranged between 9% and 20%; the differences between the varieties were significant.

Key Words: ^{15}N; N balance; N immobilization; N Loss; N Uptake; Priming Effect; Rhizodeposition; Wheat; Pakistan.

INTRODUCTION

Use of commercial nitrogen (N) fertilizers in agriculture has resulted in significant crop yield increases. However, the nitrogenous fertilizers are highly inefficient and plants use only up to 50% of the applied fertilizer N (Kundler, 1970; Hauck, 1971). From 10% to 50% of the fertilizer N is lost from the soil-plant system in different ways (Kundler, 1970; Hauck, 1971), thereby causing economic losses as well as environmental pollution. The rising cost of N fertilizers and potentially adverse environmental effects associated with their use emphasize the need for efficient use of fertilizer N.

The efficiency of N use in crop production can be best achieved through manipulation of the entire soil-plant-fertilizer system. One way to achieve this goal is to select crop varieties more efficient in using available N whether applied as fertilizer or that already present in soil. Olson and Kurtz (1982) studied that the crop varieties/cultivars showed significant differences in this regard.

The study on fate of fertilizer N by using ^{15}N, revealed that plants given fertilizer N take up more unlabelled N from the soil than plants receiving no fertilizer N (Jansson, 1958, 1971; Westerman and Kurtz, 1973; Hauck, 1971; Bremner, 1976; Jansson and Persson, 1982; Hart et al., 1986). Although there is considerable controversy over the causes and interpretation of this phenomenon (Jenkinson et al., 1986), it is logical to assume that the process of stimulated soil-N availability and related processes viz., biological interchange and immobilization-mineralization will affect the overall crop productivity and N economy (including use efficiency, loss and residual value of fertilizer N) in agroecosystems. Thus N fertilizers are not only a direct source of plant available N but also make the soil N more available to plants. It is known, however, that mineralization/availability of soil N is increased at increasing rate of

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N addition and in the presence of easily oxidizable carbon compounds (Broadbent and Norman, 1946; Azam et al., 1988, 1989). The different crop varieties by virtue of the difference in rhizodeposition may, therefore, influence the N transformation processes in soil. Whether or not different crop varieties/cultivars influence the process of stimulated soil-N mineralization and fertilizer N-soil N interactions demands experimentation.

The objective of this study was to compare some wheat varieties for yield performance, response to fertilizer application and the influence on fate of applied fertilizer N and native soil N.

MATERIALS AND METHODS

The clay loam soil was collected from experimental fields of Nuclear Institute for Agriculture and Biology, Faisalabad. Air-dried and sieved (<0.5mm) soil contained 0.6% C, 0.06% N and had pH of 7.2.

The experiment was conducted in pots at the Nuclear Institute for Agriculture and Biology, Faisalabad during the normal wheat growing season (November, 1988 to May, 1989). Four kg soil was filled in 30 pots of 5 kg capacity. Six replicate pots were sown (6 seeds/plot) with five commercial wheat varieties. Four varieties 'Pak-81', 'Fbd-85', 'Punjab-85', and 'LU-26' belonged to *Triticum aestivum* and one 'Durum' belonged to *T. turgidum*. Three pots were given 240 mg N each as $(^{15}NH_4)_2SO_4$ (1% ^{15}N ex.). The remaining three pots were left unfertilized. The plants were grown to maturity. Above ground parts were harvested and the roots were carefully removed from the soil for maximum recovery and washed free of soil particles. The grain was separated and all the plant components (root, straw and grain) were dried at 70°C to a constant weight. Finely ground material of each component was analyzed in triplicate for total N (Bremner and Mulvaney, 1982). Acidified and concentrated distillates were subjected to isotope-ratio analysis on a modified double inlet mass spectrometer (Varian MAT GD 150) which was accurate to 0.001 atom % ^{15}N or better.

RESULTS AND DISCUSSION

Maximum plant height was attained by 'LU-26' and minimum by 'Durum' and the two varieties showed significant differences among themselves and with other three varieties (Table 1). 'Durum' showed significantly higher tillering compared to other varieties which were not significantly different among themselves in this regard. Root biomass differed significantly in different varieties, maximum biomass being observed in 'Durum'. Straw yield was statistically similar in all the varieties, however, 'LU-26' showed significantly more grain yield with least number of tillers than other varieties. A high grain yield in 'LU-26' could easily be attributed to a more efficient transport of N from fertilizer and soil to the grain portion relative to straw as indicated by higher ratio of grain N/straw N (Table 2). A better transport of N to the grain portion was accompanied by a higher grain yield (Table 1) although N concentration and thus protein content of the grain in 'LU-26' was the lowest (Table 3). Grain/straw ratio was also better in 'LU-26' (Table 1). Application of N fertilizer caused a significant improvement in all other agronomic parameters except plant height. Total plant height showed an increase of 32% to 54% over control (no nitrogen added) in different varieties due to fertilizer application; the differences among the varieties were generally non-significant except for 'LU-26' which differed significantly from other varieties.

The different varieties were compared for total plant N and its distribution in root, straw and grain (Table 2). Generally more than 50% of the total plant N was attributable to grain and of the remainder about two third was found

Table 1. Agronomic parameters of different wheat varieties grown with or without N fertilizer, at Nuclear Institute for Agriculture and Biology, Faisalabad

Variety		Plant height (cm)	No. of tillers	Root weight (g/pot)	Straw weight (g/pot)	Grain weight (g/pot)	Total weight (g/pot)	Grain/ straw
'Pak-81'	–N	86.0	6.3	3.7	12.7	7.1	23.5	0.56
	+N	89.0	7.3	4.4	18.4	11.4	33.9	0.62
'Fbd-85'	–N	83.8	6.0	3.0	11.6	6.1	20.7	0.53
	+N	83.6	7.3	4.0	17.4	10.5	31.9	0.60
'Pun-85'	–N	85.6	5.7	3.9	12.4	6.9	23.1	0.56
	+N	82.3	7.6	3.6	17.3	9.6	30.5	0.55
'Lu-26'	–N	90.5	5.7	3.0	13.5	9.2	25.4	0.68
	+N	87.7	9.8	3.4	18.6	15.1	37.1	0.81
'Durum'	–N	73.6	7.7	4.1	13.5	8.0	25.6	0.59
	+N	75.7	12.7	4.3	17.8	12.3	34.4	0.69
LSD (P = 0.05)		5.4	0.8	0.3	1.1	0.8	2.6	0.02

Table 2. Recovery of N in different plant components of the five wheat varieties grown with or without fertilizer N at Nuclear Institute for Agriculture and Biology, Faisalabad

(mg N/pot)

Variety		Root	Straw	Grain	Total	Grain/straw
'Pak-81'	–N	15.7	44.9	59.6	120.2	1.32
	+N	20.0	74.8	113.0	207.7	1.51
'Fbd-85'	–N	15.0	35.7	54.5	105.2	1.53
	+N	17.1	60.2	112.3	189.6	1.87
'Pun-85'	–N	18.1	35.8	62.3	116.0	1.74
	+N	20.3	66.3	102.2	188.8	1.54
'Lu-26'	–N	13.1	38.9	63.6	115.6	1.64
	+N	15.4	58.6	125.3	199.4	2.14
'Durum'	–N	15.9	41.4	63.9	121.2	1.54
	+N	17.5	67.7	105.4	190.6	1.56
LSD (P = 0.05)		1.8	3.3	6.8	5.5	

in straw. Amongst the five varieties, 'Durum' appeared to be a better user of N but its N yield as grain was similar to that of 'LU-26'. Application of fertilizer N caused a significant increase (57-80%) in the N uptake by different varieties; the increase was mainly attributable to grain portions which showed almost double N yield. 'LU-26' was better in transporting N to the grain portion relative to straw as indicated by grain N/straw N ratios. In general, % N content of plant components of the five varieties showed significant differences (Table 3); 'LU-26' and 'Durum' which showed higher yields, had lower N content in all the three components, but the N content increased significantly in different varieties due to fertilizer application. All the varieties derived about 30% (range 30-32%) of their N from the applied fertilizer and did not show significant difference in this regard (Table 4). Studies have revealed that fertilizer N contribution vary widely depending upon rate of fertilizer application and other factors (Hart et al., 1986). Percentage contribution of the fertilizer N to the total N content of different plant components was also essentially similar. However, on an average, grains derived relatively higher proportion of their N from the fertilizer.

Table 3. Percent N content of plant components of different varieties grown with or without N

Variety		Root	Straw	Grain
'Pak-81'	−N	0.43	0.35	0.84
	+N	0.49	0.41	0.99
'Fbd-85'	−N	0.50	0.31	0.89
	+N	0.43	0.34	1.07
'Pun-85'	−N	0.47	0.28	0.90
	+N	0.56	0.38	1.07
'Lu-26'	−N	0.44	0.29	0.69
	+N	0.45	0.31	0.83
'Durum'	−N	0.39	0.31	0.80
	+N	0.41	0.38	0.86
LSD (P = 0.05)		0.04	0.05	0.04

Table 4. Percent contribution of applied fertilizer N to the total N content of whole plant and different components

Variety	Root	Straw	Grain	Total
'Pak-81'	27.58	29.02	34.13	31.68
'Fbd-85'	28.33	29.41	34.01	32.03
'Pun-85'	30.33	30.45	31.82	31.18
'Lu-26'	25.24	29.34	33.61	31.71
'Durum'	27.32	28.90	31.05	29.94
LSD(P=0.05)	2.7	2.9	2.1	2.2

Significant varietal differences were observed for the N use efficiency. The plants of different varieties used 44-55% fertilizer N applied (Table 5). 'Pak-81' used up to 55% fertilizer N while 'LU-26' used 53%. From 57% to 67% of the plant N derived from the fertilizer was located in grain; 'LU-26' was found to transport a higher proportion of fertilizer N to the grain portion and showed the highest ratio of grain N/straw N of fertilizer origin. The efficiency of fertilizer N use has been reported to vary between 20% and 80% depending upon crop and agronomic practices (Kundler, 1970; Hauck, 1971; Hart et al., 1986).

The 31%-40% fertilizer N was still present in soil after harvesting wheat. Overall balance of applied fertilizer N showed a loss of 9%-20%, maximum loss of 20% occurred in 'Durum' (Table 5). Losses of fertilizer N ranged between 10% and 30% depending upon different agricultural practices (Kundler, 1970;

Table 5. Percentage recovery of applied fertilizer N in soil and different plant components after harvesting and fertilizer N balance

Variety	Root	Straw	Grain	Total plant	Soil	Balance
'Pak-81'	4.60	18.08	32.15	54.83	31.18	–13.99
'Fbd-85'	4.04	14.75	31.84	50.63	40.42	– 8.96
'Pun-85'	5.13	16.82	27.11	43.93	40.33	–10.62
'Lu-26'	3.25	14.33	35.10	52.68	37.26	–10.06
'Durum'	3.99	16.30	27.27	47.56	32.79	–19.68
LSD (P = 0.05)	0.18	1.82	3.21	2.91	2.05	0.82

Hauck, 1971; Azam et al., 1985). These losses are attributed to NH_3 volatilization and/or NO_3 leaching. However, foliar loss of gaseous N may also contribute partially to the overall losses. Several reports suggest a significant loss of N from plant tops (Hooker et al., 1980; Silva and Stutte, 1981; Parton et al., 1988). More loss of N from 'Durum' may partially be attributed to greater number of tillers. However, other factors may also contribute to the differences in N loss from different varieties since 'Pak-81' and 'Fbd-85' had similar number of tillers but caused significant differences in the amount of N lost. Varietal differences in foliar N losses have recently been reported (Stutte and Weiland, 1979; Stutte and Silva, 1981).

Regression analysis of fertilizer N lost from the soil-plant system and that recovered in the soil at harvest (Table 5) showed significant correlation (r = 0.775) in different varieties. The variety showing maximum recovery of fertilizer N in soil caused minimum loss; the differences among the varieties were generally significant. The varietal differences in affecting fertilizer N loss may partially be explained on the basis of fertilizer N transformations in soil. The variety causing a rapid incorporation of fertilizer N into soil organic matter will result in reduced susceptibility of the applied N to losses. This can be achieved through the release of root exudates and sloughed off root material (together termed as rhizodeposition) which will cause a rapid immobilization of the available N whether applied as fertilizer or that mineralized from soil organic matter. Since different plant types may differ in the amount and quality of the rhizodeposition (Kipe-Nolt et al., 1985; Keith and Oades, 1986; Biondini et al., 1988); they can be assumed to influence the fate of fertilizer N through immobilization-mineralization.

Wheat plants used 105-121 mg/pot of the native soil N which represented 5% of the total soil N; 'Durum' wheat showed the maximum uptake. Application of N fertilizer increased the plant uptake of native soil N by 12%-23%. The increase in plant availability of soil N due to application of fertilizer N differed significantly with the varieties; maximum increase being observed for 'Fbd-85' followed by 'LU-26' and minimum in 'Durum'. Most of the extra soil N taken up by the plants was in grain; 'LU-26' was the most effec-

Table 6. Effect of applied fertilizer N on uptake of native soil N by different varieties and its distribution in root, straw and grain

(mg/pot)

Variety		Root	Straw	Grain	Total plant
'Pak-81'	−N	15.70	49.92	59.55	120.17
	+N	14.49	53.66	74.45	142.00
					(21.83)
'Fbd-85'	−N	14.95	35.67	54.54	105.16
	+N	12.26	42.49	74.13	128.88
					(23.72)
'Pun-85'	−N	18.05	35.82	62.33	116.20
	+N	14.14	46.11	69.71	129.96
					(13.76)
'Lu-26'	−N	13.30	38.85	63.59	115.57
	+N	11.53	41.43	83.19	136.15
					(20.58)
'Durum'	−N	15.86	41.41	63.85	121.12
	+N	12.72	48.13	72.66	133.51
					(12.39)
LSD (P = 0.05)		0.81	3.13	7.65	7.15

Figures in parenthesis indicate excess of native soil N made available to plants as a result of fertilizer N application.

tive in transporting this N (up to 95%) to the grain portion.

It was found that plants given fertilizer N take up more soil-N than plants receiving no fertilizer N and that five varieties showed significant differences. Several other workers have also shown increased mineralization/ availability of soil N following fertilizer additions and the effect increases with increased rate of addition (Aleksic et al., 1968, Legg and Stanford, 1968; Westerman et al., 1972; Azam et al., 1988, 1989). The enhanced N mineralization may simply be a pool substitution, a process by which fertilizer N stands proxy for the soil N and the latter is made available to plants. Nevertheless, this is an attribute of the added fertilizer that the soil N which was otherwise unavailable to the plants, is made available and should logically be included in the estimations of fertilizer use efficiency. Jenkinson et al. (1986) have recently discussed in detail the causes of stimulated soil-N mineralization and have termed the phenomenon as "added nitrogen interaction" (ANI). According to them, ANI is real if the addition of fertilizer N increases the uptake of soil-N by plants. Data presented, therefore, showed a positive and real ANI which differed significantly in the varieties tested. Jenkinson et al. (1986) reported that ANI is directly proportional to the rate of immobilization. Thus anything that increases immobilization, such as addition of an organic energy source with a high C/N ratio, will increase the size of ANI (Jansson, 1958).

The varietal differences observed here in affecting the ANI may, therefore, be attributed to the differences in the rhizodeposition by different varieties. The latter may be influenced differently in different varieties depending upon the response of roots to fertilizer application. Hills et al. (1978) have reported a stimulation of root proliferation following fertilizer addition and this stimulation may vary with the crop and varieties.

From the foregoing discussion, it appears that the different crop varieties significantly influence the fate of applied fertilizer N and utilization of native soil N. The influence may be attributed to the effect of plants on N transformation processes in soil particularly N immobilization which ultimately affects the loss and use of the fertilizer N. The plants may, however, differ in their response to fertilizer application as regards root proliferation and rhizodeposition. More studies are, therefore, needed on the soil N-fertilizer N interactions as influenced by the nature of crop and to establish a relationship between rhizodeposition and fertilizer N dynamics. The information, thus obtained will help to select varieties with better fertilizer N economy.

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LITERATURE CITED

1. Aleksic, Z., Broeshart, H. and Middleboe, V. 1968. The effect of nitrogen fertilization on the release of soil nitrogen. Plant and Soil, 29 : 474-478.
2. Azam, F., Malik, K.A. and Sajjad, M.I. 1985. Transformations in soil and availability to plants of ^{15}N applied as inorganic fertilizer and legume residues. Plant and Soil, 86 : 3-13.
3. Azam, F., Mulvaney R.L. and Stevenson, F.J. 1988. Quantification and potential availability of non-symbiotically fixed ^{15}N in soil. Biol. Fertil. Soils, 7 : 32-38.
4. Azam, F., Mulvaney, R.L and Stevenson, F.J. 1989. Synthesis of ^{15}N labelled microbial biomass in soil in situ and extraction of biomass N. Biol. Fertil. Soils, 7 : 180-185.
5. Biondini, M., Klein, D.A. and Redente, E.F. 1988. Carbon and nitrogen losses through root exudation by *Agropyron cristatum*, *A. smithii* and *Bouteloua gracilis*. soil Biol. Biochem. 20 : 477-482.
6. Bremner, J.M. 1976. Use of tracers for soil and fertilizer nitrogen research. Adv. Agron. 28 : 219-266.
7. Bremner, J.M. and Mulvaney, C.S. 1982. Total nitrogen. In: Page, A.L., Miller, R.H. and Keeney, D.R. (eds.) Methods of Soil Analysis. Am. Soc. Agron. Monogr. 10(2) : 594-624.
8. Broadbent, F.E. and Norman, A.G. 1946. Some factors affecting the availability of the organic nitrogen in soil - A preliminary report. Soil Sci. Soc. Am. Proc. 11 : 264-267.
9. Hart, P.B.S., Rayner, J.H. and Jenkinson, D.S. 1986. Influence of pool substitution on the interpretation of fertilizer experiments with ^{15}N. J. Soil Sci. 37 : 389-403.
10. Hauck, R.D. 1971. Quantitative estimates of nitrogen-cycle pro-

cesses - Concepts and review. In: Hauck, R.D. (ed.) Nitrogen-15 in Soil Plant Studies. p. 65-80. IAEA, Vienna.

11. Hills, F.J., Broadbent, F.E. and Fried, M. 1978. Timing and rate of fertilizer nitrogen for sugarbeets related to nitrogen uptake and pollution potential. J. Environ. Qual. 7 : 368-372.
12. Hooker, M.L., Sander, D.H., Peterson, G.A. and Daigger, L.A. 1980. Gaseous N losses from winter wheat. Agron. J. 72 : 789-792.
13. Jansson, S.L. 1958. Tracer studies on nitrogen transformations in soil with special attention to mineralization-immobilization relationships. Ann. Royal Agric. Col. Sweden, 24 : 101-361.
14. Jansson, S.L. 1971. Use of ^{15}N in studies of soil nitrogen. In: McLaren, A.D. and Skujins, J. (eds.). Soil Biochemistry. p. 129-166. Marcel Dekker, New York.
15. Jansson, S.L. and Persson, J. 1982. Mineralization and immobilization of nitrogen in agricultural soils. In: Stevenson, F.J. (ed.) Nitrogen in Agricultural Soils. Am. Soc. Agron. Monogr. 10(2) : 226-252. Madison, Wisconsin.
16. Jenkinson, D.S., Fox, R.H. and Rayner, J.H. 1986. Interactions between fertilizer nitrogen and soil nitrogen-the so-called 'priming' effect. J. Soil Sci. 36 : 425-444.
17. Keith, H. and Oades, J.M. 1986. Input of carbon to soil from wheat plants. Soil Biol. Biochem. 18 : 445-449.
18. Kipe-Nolt, J.A., Avalakki, U.K. and Dart, P.J. 1985. Root exudation of sorghum and utilization of exudates by nitrogen-fixing bacteria. Soil Biol. Biochem. 17 : 859-863.
19. Kundler, P. 1970. Utilization, fixation and loss of fertilizer nitrogen (review of international results in the last 10 years basic research). Albrecht-Thaer-Arch. 14 : 191-210.
20. Legg, J.O. and Stanford, G. 1967. Utilization of soil and fertilizer N by oats in relation to the available N status of soils. Soil Sci. Soc. Am. Proc. 31 : 215-219.
21. Olson, R.A. and Kurtz, L.T. 1982. Crop nitrogen requirements. In: Stevenson, F.J. (ed.) Nitrogen in agricultural soils. Am. Soc. Agron. Monogr. 10(2) : 567-604. Madison, Wisconsin.
22. Parton, W.J., Morgan, J.A., Altenhofen, J.M. and Harper, L.A. 1988. Ammonia volatilization from spring wheat plants. Agron. J. 80: 419-425.
23. Silva da, P.R.F. and Stutte, C.A. 1981. Nitrogen loss in conjunction with transpiration from rice leaves as influenced by growth stage, leaf position, and N supply. Agron. J. 73: 38-42.
24. Stutte, C.A. and Silva da, P.R.F. 1981. Nitrogen volatilization from rice leaves. I. Effects of genotype on air temperature. Crop Sci. 21 : 596-600.
25. Stutte, C.A. and Weiland, R.T. 1979. Gaseous nitrogen loss and transpiration of several crop and weed species. Crop Sci. 18: 887-889.
26. Westerman, R.L. and Kurtz, L.T. 1973. Priming effects of ^{15}N-labelled fertilizer on soil nitrogen in field experiments. Soil Sci. Soc. Am. Proc. 37 : 725-727.
27 Westerman, R.L., Kurtz, L.T. and

Hauck, R.D. 1972. Recovery of nitrogen-15 labelled materials in Sonoran Desert soils. Soil Sci. Soc. Am. Proc. 36 : 82-86.