Nitrogen Fertilizer Use and Losses in Irrigated Cropping Systems

C. van Kessel and N.J. Livingston
Department of Soil Science, University of Saskatchewan, Saskatoon

Abstract

The fertilizer-N use efficiency of irrigated canola, softwheat, durum, and spring wheat was determined in 1988 and 1989. Crops received various amounts of N, applied at time of seeding or split between time of seeding and during the growing season. In 1989 at two sites, Outlook and Birsay both located on a field owned by farmers, N-losses due to denitrification after irrigation were determined by means of acetylene blockage. Softwheat and durum were grown at Outlook and Birsay, respectively. In 1988, all treatments received 150 kg N/ha, split equally between time of seeding and 54 days after planting. In 1989, all crops received 200 kg N/ha, applied at time of seeding or split equally between time of seeding and during the growing season.

Fertilizer use efficiency (% FUE) in the crop of irrigated canola in 1988 averaged 37% in the soil at time of final harvest. In 1989 the average FUE in canola was 27.4%, in softwheat 42.3% and in durum 43.0%. The % FUE was 22 and 21% at Birsay and Outlook, respectively.

Nitrogen losses caused by denitrification were small at one site but significant at another. At the site with low input of N and irrigation water the N-losses were practically zero before the onset of irrigation, increased to a maximum loss of 50 g N/day/ha at 4 h after irrigation and declined to low levels at 10 h after irrigation. At the other site, with high N and irrigation water, the N losses from fertilized soil due to denitrification were approximately 5 kg N/day/ha, increased to 12.5 kg N/day/ha at 4 h after the application of water and declined to approximately 5 kg N/day/ha at 10 h after the water was applied.

Introduction

Recovery of applied fertilizer-N varies widely and is dependent on the climatic conditions, the extent of leaching, and N losses due to denitrification, among other factors (Campbell and Paul 1978, Bigeriego et al. 1979, Diebert et al. 1979). The efficiency of fertilizer-N can also be affected by time of application. In most studies, the total fertilizer recovery, plant and soil, did not reach 100% (Jones et al. 1981, Broadbent and Nakashima 1965). The difference between the amount of N applied and the amount of N recovered was attributed to leaching, runoff, denitrification and volatilization.

Denitrification losses of fertilizer-N under irrigated systems can be significant. Ryden et al. (1979) reported that as high as one third of the N can be lost due to denitrification. However, others have found much smaller losses (Breitenbeck et al. 1980, Mosier et al. 1982).

The objective of this study was to determine the efficiency of applied N and to determine losses of N by denitrification.

Materials and Methods

Canola (Westar) was grown in a two year experiment (1988 and 1989), while durum (Kyle) and softwheat (Fielder) were grown only one year under irrigation at the Outlook Irrigation Centre, Saskatchewan. In 1988 canola received 0 N, 75 kg N/ha of urea at planting labelled with ^{15}N and 75 kg N/ha of unlabelled urea at 54 days after planting (DAP), 75 kg N/ha of urea at planting unlabelled and 75 kg N/ha of labelled with ^{15}N urea at 54 DAP, 75 kg N/ha of urea/ammonium nitrate (UAN) at planting labelled with ^{15}N and 75 kg N/ha of unlabelled UAN at 54 DAP, 75 kg N/ha of UAN at planting unlabelled and 75 kg N/ha of labelled with ^{15}N UAN at 54 DAP, 150 kg N/ha of labelled ^{15}N-urea at time of seeding, or 150 kg N/ha of labelled ^{15}N UAN at time of seeding. In 1989 canola received 0 N, 100 kg N urea (U) labelled with ^{15}N at time of seeding, 100 kg N labelled U at time of seeding plus 100 kg N-U labelled with ^{15}N at 38 DAP, or 200 kg N-U labelled with ^{15}N at time of seeding. Softwheat received similar amounts of U but the second application occurred 45 DAP (Feekes 4-5 growth stage). Durum received similar amounts of N but in the form of ammonium nitrate (AN) and the second split of N also occurred at 38 DAP. The experiment was laid out as a randomized complete split plot design with crop as the main plot treatment and fertilizer rate as the split plot treatment. Irrigation water was applied through drip lines, spaced at 0.5 m. Crops were harvested 5 times during the growing season (*see* Swerhone et al. 1990). Dimensions of individual harvest plots measured 3.0 by 2.0 m. Labelled ^{15}N-U, UAN, and AN was applied to the ^{15}N-microplot located in the centre of the harvest plots. The ^{15}N-microplot measured 1.5 by 1.5 m. At time of seeding labelled ^{15}N fertilizer was dissolved in 5 liters of water and equally distributed over the whole ^{15}N microplot. After the application of fertilizer-N, additional water was applied through the drip lines. The second application of unlabelled N and ^{15}N-labelled N was carried out through the drip lines.

In 1989, at Birsay and Outlook durum and springwheat were fertilized with 200 kg N-U or AN or remained unfertilized. ^{15}N-microplots were installed in each plot which had received fertilizer and received comparable amounts of ^{15}N-labelled U or AN. Treatments were laid out in a randomized complete block design, replicated four times. Irrigation was carried out through a centre pivot. Denitrification rates were measured using the acetylene blockage method. Measurements were taken just before irrigation occurred, and 4, 7 and 10 h after irrigation. Denitrification rates were determined from soil cores taken from the top 10 cm. Each treatment was sampled twice.

At harvest, plants were dried at 60°C until constant weight, weighted and analyzed for total N, including NO_3^- and NO_2^- (Bremner and Mulvany 1982). Plants were dried, weighed and threshed, and seed and straw analyzed for total N and atom % ^{15}N. In 1988 soil samples were taken to a depth of 120 cm (15 and 30 cm increments) and analyzed for total N and atom % ^{15}N.

Analysis of ^{15}N was carried out by conversion of NH_4^+ to N_2 by LiBrOH and the $^{29}N_2/^{28}N_2$ ratio determined by a VG Micromass 602E isotope ratio mass spectrometer.

Calculations from ^{15}N data were as follows:

$$\%\ \text{Ndff}\ (\%\ \text{N derived from fertilizer}) = \frac{\text{atom}\ \%\ ^{15}\text{N excess (plant)}}{\text{atom}\ \%\ ^{15}\text{N excess (fertilizer)}} \times 100$$

$$\% \text{ FUE } (\% \text{ fertilizer use efficiency}) = \frac{\% \text{ Ndff} \times \text{total N}}{100}$$

The ^{15}N natural abundance of the available soil N pool as determined by the reference crop grown under zero N application was 0.3693 atom % and this value was used for calculating the atom % ^{15}N excess of both two crops.

Results and Discussion

The total yield and grain yield of the experiments conducted at the Outlook Irrigation Centre are reported elsewhere in the Proceedings (Swerhone et al. 1990).

The recovery of fertilizer-N in 1988 in grain ranged from 25.2 to 35.7% (Table 1). The form of N applied, i.e. U or UAN, had no effect on the fertilizer use efficiency. The average % FUE in the crop, grain plus straw, was 37% and was independent of the form of N applied. The recovery of fertilizer-N in the soil was between 35 and 39% and was largely found in the top 15 cm. Almost no fertilizer was found below 30 cm. The total % FUE in the crop and soil was between 71 and 81%, suggesting a loss of approximately 19 to 29% of the applied fertilizer N. The potential mechanisms which may account for the N loss are denitrification or volatilization.

In 1989, the overall % FUE recovery in canola was 27%, which appears to be lower than the recovery found in the previous year (Table 2). The two cereals, durum and softwheat, showed an average % FUE of 42 and 43%, respectively. The application of 100 or 200 kg N/ha did not significantly affect the recovery of the fertilizer-N. The application

Table 1. Nitrogen fertilizer recovery in soil and plant (Westar) at Outlook, 1988.

Treatment		Percent N recovered							
kg N/ha	Form of N	Plant			Soil (cm)				Plant and Soil
		Straw	Grain	Total	0-15	15-30	30-60	Total	
75* + 75	Urea	6.4	25.2	31.6	33.9	4.6	0.4	39.0	70.6
75* + 75	UAN†	7.8	35.7	43.5	31.9	4.3	1.6	37.8	81.3
150*	Urea	6.9	29.0	35.9	33.5	4.2	1.7	39.4	75.3
150*	UAN	8.2	28.4	36.6	25.0	7.1	3.5	35.6	72.2
LSD ($P < 0.05$)		NS	NS	NS	NS	NS	2	NS	NS
CV (%)		39.9	21.6	21.7	37.1	64.4	67.7	35.7	12.7

* Indicates labelled ^{15}N fertilizer

† Urea-ammonium nitrate mixture

Table 2. Fertilizer use efficiency of durum, soft wheat and canola at Outlook, 1989.

Crop	Treatment	Form of N	Grain	Straw % FUE	Total
Durum	100	AN	37.6	8.2	45.7
Durum	100+100	AN	30.1	8.4	38.5
Durum	200	AN	31.1	10.4	42.7
LSD (P <0.05)			NS	NS	NS
CV (%)			15.1	18.9	17.5
Soft wheat	100	Urea	35.6	8.7	44.3
Soft wheat	100+100	Urea	25.0	8.6	33.6
Soft wheat	200	Urea	37.8	13.3	51.1
LSD (P <0.05)			NS	2.3	11.2
CV (%)			18.7	13.2	15.1
Westar	100	Urea	22.1	5.8	31.5
Westar	100+100	Urea	15.5	6.4	21.9
Westar	200	Urea	20.9	7.9	28.7
LSD (P <0.05)			NS	NS	NS
CV (%)			36.3	20.4	22.5

of the second split of N, which was not labelled with ^{15}N, appears to decrease the % FUE of the first application of N. At the time the second split-N was applied, canola and the cereals were accumulating N and the available soil N pool would have been diluted by the second split N application. As the plant makes no distinction during uptake between ^{14}N and ^{15}N, a decrease in % FUE of 100 + 100 kg N/ha as compared with 100 kg N/ha application would be anticipated.

Total yield of durum at Birsay was not affected by N application and ranged from 12,000 to 13,000 kg/ha (Table 3). In contrast, total yield at Outlook was significantly affected by N application and ranged from 4,213 to 6,951 kg/ha. Grain yield followed a similar pattern as total yield at both sites. However, at Outlook a much more favourable harvest index was found as compared with Birsay and the grain yield of fertilized durum at Birsay was on average 36% higher as compared with springwheat at Outlook. Total dry matter of fertilized durum, however, was 104% higher than the fertilized springwheat at Outlook.

Total N accumulation followed a similar pattern as total yield. The highest total N was found at Birsay, 200 kg N/ha, which was approximately double the amount of total N found in Outlook (Table 4). At both sites the application of N-fertilizer increased total N accumulation significantly in the crop. Whereas the % N derived from fertilizer-N was

Table 3. Total yield and grain yield of durum and springwheat at Birsay and Outlook, Saskatchewan, 1989.

	Total (kg/ha)			Harvest index
	Total	Grain	Straw	
Durum (Birsay)				
Control	12833	4693	8140	0.37
Urea	13203	3634	9569	0.28
AN	13741	4176	9665	0.30
LSD (P <0.05)	NS	NS	884	0.07
CV (%)	3.7	14.1	5.6	12.8
Springwheat (Outlook)				
Control	4213	2064	2149	0.49
Urea	6951	2937	4014	0.42
AN	6193	2765	3428	0.44
LSD (P <0.05)	1605	NS	799	0.03
CV (%)	16.0	18.5	14.4	3.9

Table 4. Total N and percent fertilizer use efficiency of irrigated durum and springwheat.

Treatment	N/ha	kg N/ha			% Ndff		% FUE		
		Grain	Straw	Total	Grain	Straw	Grain	Straw	Total
Durum (Birsay)									
Control	0	108.0	31.1	139.1					
Urea	200	106.9	83.0	190.0	16.7	19.7	9.1	8.0	17.2
AN	200	123.6	76.7	200.3	29.9	29.0	18.6	11.1	29.7
LSD (P <0.05)		NS	17.7	42.8	3.8	7.8	2.1	2.2	4.1
CV (%)		15.5	16.0	14.0	9.2	18.7	8.7	14.0	10.1
Springwheat (Outlook)									
Control	0	52.2	7.1	59.3					
Urea	200	89.3	14.0	103.3	41.1	41.8	18.4	2.9	21.3
AN	200	85.8	12.3	98.1	44.5	44.3	19.3	2.7	22.0
LSD (P <0.05)		23.6	2.4	25.7	2.3	NS	NS	NS	NS
CV (%)		18.0	12.7	17.1	3.1	5.4	16.3	8.3	15.1

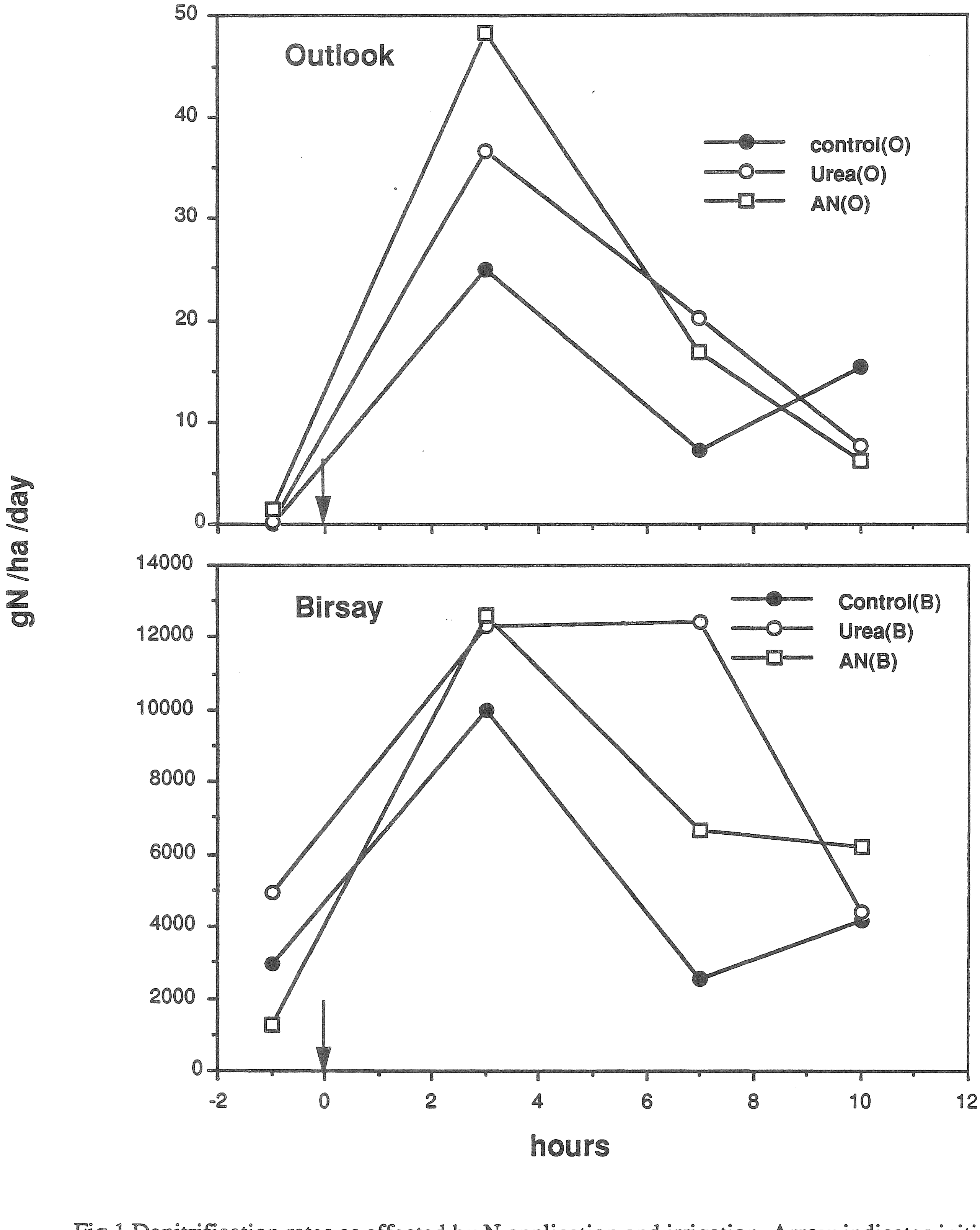

Fig.1 Denitrification rates as affected by N application and irrigation. Arrow indicates initiation of irrigation.

higher at Outlook as compared with Birsay, the FUE at both sites were very similar and were approximately 22%. However, the recovery was lower than that determined at the Irrigation Centre where durum and softwheat showed an average FUE of 42 to 43%. At the present time, no apparent reason is available to explain the lower % FUE at the two farmer's fields.

Losses of N due to denitrification at Outlook were insignificant before irrigation, increased to a maximum rate of approximately 50 g N/ha/day 3 h after irrigation and decreased again to low levels 10 h after irrigation (Fig. 1). At Birsay, N losses before irrigation were already significant and increased to 10 to 12.5 kg N/ha/day 3 h after irrigation and decreased to approximately 5 kg N/ha/day. The lowest N losses were found in the unfertilized treatments but the large variability made the differences non-significant. It is apparent from this study that the concentration of nitrate was not the limiting factor for denitrification but rather the moisture condition of the soil. If the soil moisture content reaches field capacity an anaerobic condition is created which subsequently enhances denitrification. Apparently, the conditions for denitrification were more favourable at Birsay (clay loam) than at Outlook (sandy). It has yet to be determined which are the major factors at Birsay contributing to such high levels of denitrification.

Acknowledgements

Financial support was provided by the Saskatchewan Water Corporation. The technical assistance of Brent Zettl and Kevin Komarnicki were crucial for the completion of the experiment. The typing skills of E. Farkas are as always highly appreciated.

Literature Cited

Bigeriego, M., R.D. Hauck, and R.A. Olson. 1979. Uptake, translocation and utilization of ^{15}N-depleted fertilizer in irrigated corn. Soil Sci. Soc. Am. J. 42: 528-533.

Breitenbeck, G.A., A.M. Blackmer, and J.M. Bremner. 1980. Effect of different nitrogen fertilizers on emission of nitrous oxide from soil. Geophys. Res. Lett. 7:85-88.

Bremner, J.M. and C.S. Mulvaney. 1982. Nitrogen-Total. *In* Page, A.L., R.H. Miller and D.R. Keeney (eds). Methods of Soil Analysis. Part 2. Am. Soc. Agron. Inc., Madison, WI. pp. 595-624.

Broadbent, F.E. and T. Nakashima. 1965. Plant recovery of immobilized nitrogen in greenhouse experiments. Soil Sci. Soc. Am. Proc. 29: 55-60.

Campbell, C.A. and E.A. Paul. 1978. Effects of fertilizer N and soil moisture on mineralization, N recovery and A-values, under spring wheat grown in small lysimeters. Can. J. Soil Sci. 58: 39-51.

Diebert, D.J., M. Bigeriego and R.A. Olson. 1979. Utilization of ^{15}N fertilizer by nodulating and non-nodulating soybean isolines. Agron. J. 71: 717-723.

Jones, A.J., E.O. Skogley, V.W. Meints and J.M. Martin. 1981. Nitrogen uptake by spring wheat, soil distribution, and recovery of N fertilizer from alternate crop-fallow and recrop field management systems. Agron. J. 73: 967-970.

Mosier, A.R., G.L. Hutchinson, B.R. Sabey and J. Baxter. 1982. Nitrous oxide emissions from barley plots treated with ammonium nitrate or sewage sludge. J. Environ. Qual. 11: 78-81.

Ryden, J.C., L.J. Lund, J. Letey and D.D. Focht. 1979. Direct measurement of denitrification loss from soils. II. Development and application of field methods. Soil Sci. Soc. Am. J. 43: 110-118.

Swerhone, G.D.W., C. van Kessel and N.J. Livingston. 1990. Response of irrigated crops to split-N application. Proc. of the 1990 Soil and Crop Workshop, New Frontiers in Prairie Agriculture. University of Saskatchewan, Saskatoon.