Nitrogen-15 Recovery by Spring Wheat as Influenced by Landscape Position and Nitrogen Fertilizer Source

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Introduction

The desire to reduce cereal production costs, and the environmental problems associated with N losses from the soil-plant system, continues to stimulate research aimed at improving nitrogen use efficiency by crops. The availability of N to crops depends on N source, landscape position, and method of placement. In a field study comparing ^{15}N recovery by barley from different N fertilizers, recovery was greatest from potassium nitrate followed by ammonium nitrate, ammonium sulfate and urea (Malhi et al., 1996). The amount of ^{15}N immobilized in the soil or volatilized was greatest from urea, followed by ammonium sulfate, then ammonium nitrate and finally potassium nitrate. However, banding urea beside and below the seed row increased ^{15}N recovery in the plant.

Recovery of fertilizer N is inconsistent among locations. Environmental conditions favoring denitrification, immobilization, and ammonia volatilization cause differences in ^{15}N recovery, accounting for these location differences. For example, in one study recovery of N from urea and potassium nitrate fertilizer was nearly complete (84%) at one location but at a second location which experienced heavy rains in late June, N recovery from urea and potassium nitrate, was only 56% and 10%, respectively (Nyborg et al., 1990).

Field soils are highly variable across landscapes and these differences affect crop productivity and N recovery. The redistribution of water toward convergent areas exerts the most prominent landscape-scale control on productivity in a field (Pennock et al. 1987). Landscape position has been reported to either influence (Jowkin and Schoenau, 1996) or not influence (Solohoub et al., 1996) spring wheat yields. Recent studies have demonstrated that specific N transformations in the soil, such as denitrification, are affected by landscape position (Pennock et al., 1992). Denitrification rates were lowest on the shoulders, intermediate in the footslopes, and highest in the level positions. Although denitrification is expected to affect N recovery, the effect of landscape position directly on ^{15}N-labeled fertilizer recovery has not been reported. The objectives of this study were to: (i) evaluate the influence of slope position on spring wheat grain and straw yields and recovery of fertilizer ^{15}N applied as urea, or ammonium nitrate (where either the ammonium ion is labeled with ^{15}N or the nitrate ion is labeled with ^{15}N), and (ii) quantify residual ^{15}N-nitrate remaining in the soil at harvest and thus prone to loss by denitrification and leaching.

Materials and methods

Field trials were conducted on typic boroll soils at three sites in Saskatchewan during the 1996 growing season, and at three sites during the 1997 growing season. All sites were characterized by a hummocky surface with a complex assemblage of knolls and depressions, with slopes ranging from 4-6%. The experimental area at each site was surveyed and the topographical information used to develop a digital elevation model of the surface (Pennock et al., 1994). The study sites were classified into two landscape element complexes; shoulders and footslopes.

Prior to seeding, soil was sampled to a depth of 15 cm at each sampling point. pH, organic matter, inorganic N, moisture content, cation exchange capacity, particle size, bulk density, and Ap horizon thickness were determined using standard methods. Each plot was fertilized with 70 kg N ha^{-1} of commercial urea or ammonium nitrate fertilizer and then 10 kg N ha^{-1} of the appropriate ^{15}N-labeled fertilizer superimposed. ^{15}N-labeled fertilizer was applied to a 1-m x 1-m microplot within each plot. ^{15}N-labeled urea (atom % ^{15}N = 9.73) was sub-surface injected (10-cm depth) into plots initially receiving commercial urea, and ^{15}N-labeled ammonium nitrate, with either the ammonium ion (atom % ^{15}N = 6.28) or the nitrate ion (atom % ^{15}N = 4.93) labeled was applied as a solution (5L volume) to plots initially receiving commercial ammonium nitrate fertilizer. An additional 5L of water was added to each microplot to incorporate the labeled ^{15}N-fertilizer into the soil.

The experimental design was a randomized complete block replicated five times on shoulder and footslope elements. In 1996, 80 kg ha^{-1} spring wheat (cv. Pasqua) was direct seeded into canola stubble at Wakaw, pea stubble at St. Benedict, and flax stubble at St. Louis. In 1997, 80 kg ha^{-1} spring wheat (cv. CD Barrie) was direct seeded into flax stubble at St. Louis and Watrous, and wheat stubble at Hepburn. In both years, 9 kg P ha^{-1} (0-45-0) was seed placed in all plots. Roundup™ (glyphosate) was applied at the recommended rate prior to seeding. At maturity, 1m^2 microplots from each treatment plot were hand harvested, treshed, and cleaned. Soil was sampled at 0-15 cm, 15-30 cm, 30-60 cm, and 60-90 cm depths. Straw, grain, and soil ^{15}N contents were measured with a continuous-flow isotope ratio mass spectrometer (Walley et al., 1996).

The statistical model included sources of variation due to landscape position, N treatment, location, replication and their interactions. Location and replication were regarded as random effects, whereas treatment and landscape position were regarded as fixed effects. Least significant difference (protected LSD) was used to compare means. The Azallini and Cox test was used to determine crossover interactions (Baker, 1988). This test for crossover interactions is conservative (Cornelius et al., 1993), and the actual number of crossover interactions may be higher than reported here.

Results and discussion

The landform by treatment (LF*T) interaction was not significant for any of the variables measured (Table 1). Consequently, data are presented as averages across landform positions. Not unexpectedly, location had a significant effect on all variables except N derived from fertilizer in the grain (Table 1). Differences in soil and environmental conditions among the sites affect overall yields as well as the amount of plant-available N. Averaged across N treatments, straw yield of wheat ranged from 4.04 t ha^{-1} at Watrous to 9.96 t ha^{-1} at Wakaw (data not shown). Wheat grain yield ranged from 1.47 t ha^{-1} at Watrous to 3.37 t ha^{-1} at Wakaw. Ndff in straw ranged from 99 g kg^{-1} at Hepburn to 239 g kg^{-1} at St. Louis in 1996. Ndff in soil ranged from 206 g kg^{-1} at St. Louis in 1997 to 410 g kg^{-1} at Watrous. The total Ndff recovered from plant and soil ranged from 264 g kg^{-1} at Watrous to 498 g kg^{-1} at St. Louis in 1996. The N unaccounted for ranged from to 181 g kg^{-1} at St. Louis 1996 to 462 g kg^{-1} at St. Louis in 1997.

Table 1. Analysis of variance for spring wheat grown on shoulders and footslopes at six locations in Saskatchewan.

Source	df	SY[1]	GY	Straw Ndff	Grain Ndff	Soil Ndff	TNR	TNL
Location (L)	5	237.24**	14.72**	9.38*	4.45	15.48**	37.00*	37.00**
Landform (LF)	1	18.67	3.16*	0.03	1.02	0.71	0.11	0.11
Replication (L LF)	48	1.14**	0.26**	0.32	0.52	0.81	1.33	1.33
L * LF	5	3.48*	0.44	0.45	2.09*	0.25	2.97	2.97
Treatment (T)	2	2.38	1.16*	6.15	12.28	8.28	52.98*	52.98*
L * T	10	2.41*	0.27	2.48**	5.45**	2.77**	7.49*	7.49**
LF * T	2	1.13	0.03	0.19	0.05	0.88	1.18	1.12
L * LF * T	10	0.64	0.16	0.39	0.54	0.28	1.31	1.31
Error	96	0.41	0.11	0.25	0.38	0.82	1.36	1.36

[1] SY = straw yield, GY = grain yield, Ndff = N derived from fertilizer, TNR = total N recovered, TNL = total N lost

Under the environmental conditions of this study, landform position was not a reliable predictor of any of the variables measured except grain yield (Table 1). Averaged across all locations, spring wheat grain yield was 2.79 t ha^{-1} on the footslopes and 2.52 t ha^{-1} on the shoulders (LSD $_{0.05}$ = 0.15, DF = 48, n = 90). The absence of a significant location by landform interaction indicates that this landform affect on grain yield was consistent across locations. Precipitation near or below average at all locations (data not shown) may explain the higher grain yields on the footslopes. In appears that under dry growing conditions, spring wheat benefits from the accumulation of water in the footslopes and yield higher in these areas compared to shoulders (Peterson et al., 1993; Fiez et al., 1994). Under wet growing conditions, the accumulation of water in footslopes was detrimental to yield resulting in higher grain yields on the shoulders compared to the footslopes (Stevenson et al., 1995). The direct cause of yield differences attributable to landscape position under different environmental conditions has not been determined.

The significant location by landform interaction for straw yield and Ndff in grain indicates that landform position affected these variables differently at different locations. However, in the case of straw yields only the magnitude of the yield changed with location; the ranking of yields on the landscape positions remained the same. At the Wakaw, Hepburn and 1996 St. Louis sites, straw yields where similar on the footslopes and shoulders but at the St. Benedict, Watrous and 1997 St. Louis sites, straw yields were higher on the footslopes compared to the shoulders (data not shown). In contrast, the location by landform interaction for Ndff in grain was a crossover type, meaning that the ranking and magnitude of Ndff in grain on the landscape positions changed across location. For example, at Wakaw Ndff in grain was higher on the shoulders (240 g kg^{-1}) than on the footslopes (161 g kg^{-1}) but at Watrous the reverse was observed; Ndff in grain on the footslopes was 196 g kg^{-1} and on the shoulders was 112 g kg^{-1}. Because locations were considered a random effect we did not attempt to explain the cause of these interactions. Any number of factors such as differences in soil and air temperatures, precipitation, elevation, disease pressure, soil physical and chemical factors, and their interaction could account for these interactions (Brandle and McVetty, 1988).

Spring wheat fertilized with urea yielded higher than spring wheat fertilized with ammonium nitrate (Table 2). The absence of location by landform and location by treatment interactions for grain yield indicates that the treatment effect was consistent across landform positions and locations (Table 1). The amount of ^{15}N remaining in the soil was higher for urea than for the nitrate-labeled ammonium nitrate. This indicates that more of the N from urea than ammonium nitrate was immobilized in the soil, probably due to the presence of only ammonium ions in the case of urea, compared to the presence of nitrate and ammonium ions from ammonium nitrate. However, the greater immobilization of urea N did not limit the N supply to the crop in terms of grain yield. Under the conditions of this study, urea performed as well as or better than ammonium nitrate fertilizer. Because urea hydrolyses to ammonium ions, it is tempting to attribute the poorer performance and recovery of the ammonium nitrate to the presence of nitrate ions. Perhaps nitrate is denitrified, or leached below the rooting zone. However, overall, the two forms of ammonium nitrate tested (where either the ammonium ion or nitrate ion was ^{15}N-labeled) did not differ in their ^{15}N recovery from the soil. If nitrate was unavailable to the crop, for whatever reason, the ^{15}N-nitrate form of the fertilizer would show consistently lower recoveries than the ^{15}N-ammonium form but this was not observed. The amount of ^{15}N fertilizer recovered from the soil from the different fertilizer sources was inconsistent across locations. This was probably due to differences in soil properties among the locations. Soil water, clay and organic matter content among other factors have a huge effect on N immobilization, as well as conditions conducive to denitrification, nitrification and volatilization.

Table 2. Mean nitrogen balance for spring wheat fertilized with ^{15}N-labeled urea or ammonium nitrate with either the ammonium ion labeled ($^{15}NH_4$-NO_3) or the nitrate labeled (NH_4-$^{15}NO_3$).

Fate of fertilizer ^{15}N	NH_4-$^{15}NO_3$	$^{15}NH_4$-NO_3	^{15}N-urea	LSD $_{0.05}$	Mean
Grain yield (t ha^{-1})	2.56	2.59	2.81	0.21	2.65
Straw yield (t ha^{-1})	6.82	7.02	7.22	0.63	7.02
Removed by grain (g kg^{-1})	192	183	266	95	214
Removed by straw (g kg^{-1})	166	113	171	64	150
Removed by grain and straw (g kg^{-1})	358	296	436	155	364
Remaining in soil (g kg^{-1})	290	330	364	91	328
Total recovered (g kg^{-1})	648	626	799	56	691
Unaccounted for (g kg^{-1})	352	373	201	56	309

The ^{15}N-fertilizer treatments affected straw yield, Ndff in straw, Ndff in grain and Ndff that was unaccounted for very differently from location to location. For example, at the 1997 St. Louis site, the straw yield of spring wheat fertilized with nitrate-labeled ammonium nitrate was higher (4.50 t ha^{-1}) than the straw yield of spring wheat fertilized with labeled-urea (3.59 t ha^{-1}). However, at Watrous the reverse occurred. In all, seven location by treatment crossover interactions were detected for straw yield, ten for Ndff in straw, nine for Ndff in grain, and six for Ndff that was unaccounted for. This means that it is impossible to predict ^{15}N recovery in the plant or straw yield resulting from a specific fertilizer at any location. Environmental conditions that favor denitrification, immobilization, and ammonia volatilization from soil and plants may induce differences in ^{15}N-labeled recovery across locations. In our study any number of random factors, and their interactions, associated with the different locations could be responsible for these interactions.

The distribution of fertilizer ^{15}N recovered in the soil (organic + inorganic ^{15}N pool) at the end of the growing season is shown in Table 3. Most of the fertilizer ^{15}N remained in the upper 15 cm of the soil. However, fertilizer ^{15}N also was found in each increment throughout the sampled profile, demonstrating that ^{15}N–nitrate was being leached through the soil profile. A mass balance for fertilizer N reveals that, on average, 330 g kg^{-1} remained in the upper 90 cm of soil, 215 g kg^{-1} was taken up by the grain, and 150 g kg^{-1} taken up by the straw leaving 300 g kg^{-1} of the applied fertilizer N unaccounted for. Under dry land conditions residual mineral N can be conserved in the soil and become available to subsequent crops. The 300 g kg^{-1} of fertilizer ^{15}N

Table 3. Distribution of fertilizer ^{15}N in soil after harvest of spring wheat grown at six locations in Saskatchewan.

Layer sampled (cm)	NH_4-$^{15}NO_3$	$^{15}NH_4$-NO_3	^{15}N-urea	$LSD_{0.05}$	Mean
	-------------------- (g kg^{-1}) --------------------				(g kg^{-1})
0-15	153	160	194	56	169
15-30	44	55	58	15	52
30-60	64	67	68	11	66
60-90	29	47	44	12	40
Total	290	330	364	168	
LSD $_{0.05}$					23

unaccounted for was probably lost through denitrification, volatilization, and/or leached from shoulders to depressional areas in a field. This represents nearly one third of the fertilizer-^{15}N being unaccounted for at the end of one growing season. Our results compared well with other studies conducted in western Canada (Mahli et al., 1989; Nyborg et al., 1990) and elsewhere (Legg and Meisinger, 1982; Dowdell and Webster, 1984). Nyborg et al. (1990) reported a range of ^{15}N recovered from labeled urea from 560 to 880 g kg^{-1}. They conclude that heavy rains combined with little ^{15}N uptake at early growth stages increased denitrification at the site where ^{15}N recovery was low. For optimum N use efficiency and environmental sustainability, producers should consider injecting N fertilizers beneath the soil surface, and/or using less mobile forms of N fertilizer.

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