Efficiency of Fall-Banded N: Effects of Application Date, Landscape Position and Inhibitors

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Abstract

We conducted two years of experiments in southern Manitoba to see whether fall-banded N fertilizers require delaying of application date to improve grain yields, as was the case for broadcast and incorporated fertilizers. We also looked at whether losses of fall-banded N are especially large in depressional areas of the field. At each of our four sites, we banded urea (46-0-0) three times in the fall, between September 15th (early fall) and October 20th (late fall) depending on weather conditions, and at one time in the spring, mid-row banded at planting.

At harvest, we found that in the low landscape positions, crop responses from fall-banded N, relative to spring-banded N, were improved by as much as 40% by delaying application until late in the fall, when soil temperatures had declined to 5 or 6°C. On the other hand, the efficiency of fall-banded urea in the better-drained high landscape positions was not affected by application date in the fall. Presumably, the increased efficiency of late fall-banded N in the low landscape positions was due to less conversion of the urea fertilizer to nitrate prior to winter, reducing over-winter losses.

The overall average efficiency of fall-banded N, in terms of grain yield increase as a percent of spring-banded N, was approximately 30% better in the high landscape positions than in the low landscape positions within the same field. This suggests that early fall application of N fertilizer is a viable option on land that is well-drained. However, in wet years, or on poorly drained land where the potential for late fall or early spring flooding is high, producers should wait as long as possible in the fall, or until the spring, to apply nitrogen fertilizer.

Introduction

To spread their workload, reduce spring tillage operations, and capitalize on lower fertilizer prices, many producers in Manitoba prefer to apply nitrogen (N) fertilizer in the fall rather than in spring. Southern Manitoba historically receives fall rains that make fieldwork difficult and producers are interested in applying N fertilizer as soon as possible after harvest, while soil conditions are still favourable. Unfortunately, early fall applications of ammoniacal fertilizers are expected to form more nitrate prior to the soil freezing than fertilizer applied later in the season (Nyborg et al. 1990), increasing the potential for over-winter and early spring losses of NO_3^- via leaching and denitrification (Yadvinder-Singh et al. 1994). Manitoba Agriculture and Food currently recommends that fall-applied N fertilizers be banded, as opposed to broadcast, and that application be delayed until soil temperatures are below 5EC (Soil Fertility Guide 2001). However, in delaying application there is the increased risk of the producer being caught by an early freeze-up, making field operations impossible.

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Proper timing of fertilizer application can greatly improve the efficiency of fall-applied N and have enormous implications toward farm profitability and environmental sustainability (Cowell and Doyle 1993). After reviewing 44 experiments comparing fall and spring applications of N fertilizers (broadcast and incorporated) in Alberta and Saskatchewan, Malhi et al. (1992) reported that overall yield increases and N uptake of barley grain from fall-applied N were half as effective as spring-applied N. Further studies in western Canada comparing various application dates in the fall determined that late fall-applied N generally produces higher crop yields, greater crop N uptake and reduces over-winter losses when compared to early fall applications (Malhi and Nyborg 1990a). In Manitoba, fall broadcast and incorporated urea was also reported to be inferior to spring applications, especially in the poorly drained heavy clay soils of the Red River valley (Ridley 1975; Ridley 1976; Ridley 1977). However, Ridley's research provided little information about the influence of date of application, landscape position, or weather conditions on the efficiency of fall-banded N.

The performance of fall-applied N is also heavily dependant on application techniques such as broadcasting, banding or nesting of fertilizers. Banding or nesting chemical fertilizers slows microbial activity within the soil (due to the high pH, high concentrations of NH_3^+, and increased osmotic pressure within the fertilizer band), lowering the risk of N immobilization, slowing nitrification and reducing N losses by leaching and denitrification (Harapiak et al. 1993; Yadvinder-Singh et al. 1994). In western Canada, applying nitrogen in bands or nests has consistently improved the efficiency of fall-applied fertilizers, with average yield increases from fall-banded urea double that of fall broadcast and incorporated urea (Ridley 1976; Ridley 1977; Racz 1979; Malhi and Nyborg 1984; Malhi et al. 1984; Malhi and Nyborg 1985; Malhi and Nyborg 1988; Malhi and Nyborg 1990b; Malhi et al. 1992). However, in these studies grain yields and N uptake from fall-banded N were still, on average, lower than spring-applied N. Recent work in south-western Manitoba reported no differences in grain yield and total crop N uptake between fall and spring-banded N in 2 of 3 years on a clay loam soil, and in all 3 years on a drier fine sandy loam (Grant et al. 2001). Results similar to Grant et al. (2001) have been reported in the drier soil zones of western Canada (Bole et al. 1984; Kucey 1986; Malhi et al. 1992), and when soil moisture contents in the fall and spring are low (Harapiak 1979; Ukrainetz 1984).

Landscape position is another factor that will influence the efficiency of fall-applied N, through the accumulation of water in lower lying areas of the field (Hanna et al. 1982). The effects of landscape position are most significant during the early spring period, when considerable ponding of snowmelt often occurs. These flooded soil conditions greatly increase the potential of denitrification losses. Numerous studies from Saskatchewan have reported that denitrification rates were higher in the wetter footslope and low level complexes than in the well-drained upper slope positions (Elliot and de Jong 1992; Pennock et al. 1992; van Kessel et al. 1993; Corre et al. 1995; Corre et al. 1996; Farrell et al. 1996). However, no experiments have focused on the impact of landscape position on the loss of fall-banded N under Western Canadian conditions.

Fertilizer additives such as urease inhibitors, nitrification inhibitors and coatings have been used in research trials to improve the efficiency of fall-applied N (Malhi et al. 1992; Yadvinder-Singh et al. 1994). Polymer coatings may be effective tools for preserving fall-applied urea in the ammoniacal form; however, these coated products are often very expensive. In comparison, urease and nitrification inhibitors are a more cost effective means of retarding the conversion of urea to nitrate. A number of inhibitors (thiourea, ATC, N-Serve, CS_2, $(NH_4)_2\ CS_3$, and K_2CS_3) were tested with urea and/or aqueous NH_3 in Alberta. These inhibitors were all effective in slowing nitrification and reducing over-winter N losses of fall-applied fertilizers, especially when the N fertilizer plus inhibitor were banded (Malhi et al. 1992). Very limited work at three sites in Manitoba indicated that the addition of N-Serve (nitrapyrin) increased the percent uptake of fall-banded N by 30%, when compared to fall-banded urea without nitrapyrin (Ridley 1976). However, the effectiveness of a double inhibitor containing N-(n-butyl) thiophosphoric triamide (NBPT) and dicyandiamide (DCD) has not been investigated in fall banding trials in Western Canada.

The objective of this project is to evaluate the interactive effects of date of application, landscape position, fertilizer additives, and weather and climate on the efficiency of fall-banded N fertilizer in Manitoba. This project will also generate fundamental information on the effect of soil moisture and temperature on the rate of ammoniacal N transformation into nitrate via the nitrification process, and the amount of fall-applied fertilizer N lost by leaching and denitrification after the ammoniacal N has nitrified.

Materials and Methods

Site Selection and Description

Field experiments were conducted over two fertilization/growing seasons; fall 2000 to harvest 2001 (year 1), and fall 2001 to harvest 2002 (year 2). In total, seven small plot sites were established throughout southern Manitoba (four intensive sites and three satellite sites). In year 1, one intensive experiment was established near the town of Kane on Red River-Osborne heavy clay soil. In the second year of the project, two intensive sites were situated on Red River-Osborne heavy clay soil near the towns of Kane and Rosser, while a third intensive site was located on Newdale clay loam soil at the AAFC Brandon Research Centre’s Phillips Research Farm. The Red River/Osborne and Newdale soil series represent common soils in eastern and western Manitoba respectively and provide two distinctly different potentials for N fertilizer loss due to significant differences in soil texture, topography and climate. To complement the intensively monitored experimental sites, three additional satellite sites were established; one site near Oak Bluff in year 1, and two sites near Oak Bluff and Sperling in year 2. The satellite trials were all located on Red River-Osborne heavy clay soil, and employed similar treatments to those of the intensive experiments. However, only yield and N uptake of the crop was measured.

Experimental Design and Treatments

At the intensive sites, a split-plot design was utilized with landscape position mainplots and fertilization treatment subplots. Three of the four intensively monitored sites were located in the relatively level lacustrine landscape of the Red River Valley, with elevation differences of less than 1 m per km within each site. Eight mainplots, consisting of four plots in high areas and four plots in low areas, were selected throughout the field using a Total Station and the Surfer grid and contour software (Surfer 1997). Each mainplot contained six, 2 x 10 m fertilization treatment subplots, with all six treatments assigned at random to the subplots within each mainplot. A more simplistic split-plot design was employed at the satellite sites. At each satellite site, four complete replicated blocks of fertilization treatments were placed into one high and one low landscape position, based on their relative positions in the field to one another.

The six fertilization treatments were based on time of fertilizer application and included: early fall application, early fall application with a double urease and nitrification inhibitor (NBPT and DCD respectively), mid fall application, late fall application, and a spring application (mid-row banded at time of seeding). Nitrogen was applied as urea fertilizer (46-0-0) banded at a rate of 80 kg N ha^{-1}, with 40 cm spacing, at a depth of 7.5 cm. Application of the urea was targeted for September 15, September 30 and October 15 of each year. However, in year 1, excess moisture caused a delay in application dates, at both Kane and Oak Bluff, to September 29, October 12, and October 26. In year two, treatments were applied at Brandon on September 15, October 1, and October 15; at Rosser, Sperling and OakBluff on September 19, October 1, and October 19; and at Kane on September 26, October 9, and October 19. During fertilization, band rows were clearly marked with small wooden stakes and pin flags to ensure precise sampling of the banded areas, especially in the spring.

Crop Measurements

AC Barrie wheat (*Triticum aestivum*) at a rate of 1.5 to 2 bu/acre was grown as the test crop at all sites. MAP (11-52-0) was applied in the seedrow at a rate of 40 kg MAP (P_2O_5) ha^{-1}. All pesticides were applied at recommended rates based on the Manitoba Crop Protection Guide using a 4 m bicycle sprayer, including a pre-seeding burn off with Glyphosate.

At midseason (50% heading), a 1 m x 2 row sample of above ground plant tissue was hand harvested from each subplot. The midseason samples were dried at 35 to 40°C to a constant weight and dry matter yield (kg ha^{-1}) was measured. At physiological maturity, a 3 m x 2 row sample of above ground plant tissue was harvested from each subplot, dried, threshed and weighed for grain and straw yields. Tissue samples collected at midseason and harvest were ground with a Wiley mill to pass a 2 mm sieve and analyzed for total N using a Leco CNS Analyzer (Leco CNS 2000 Elemental Analyzer Instruction Manual 1996). Prior to threshing in year 1, some harvest samples from Kane (2000/01) were damaged by mice while in storage. Therefore, grain yields at this site only were estimated from straw yields using the linear regression equation $y = 0.6011x + 206.62$ ($R^2 = 0.763$). This equation was determined by correlation analysis of straw yields with grain yields from Kane (2001/02), Rosser (2001/02) and samples from Kane (2000/01) that were not significantly damaged by the mice.

Soil Sampling and Analyses

To characterize the overall N behaviour in each subplot, the soil was sampled to 120 cm in mid-September, at seeding and harvest. The background levels of soil NO_3^--N in mid-September, prior to fertilization, are reported in Table 1.

Table 1. Concentrations of Soil NO_3-N at the Intensive Sites Prior to Fertilization

Year	Site	Landscape Position	NO_3-N to 30 cm (kg ha^{-1})*	NO_3-N to 120 cm (kg ha^{-1})*
2000/01	Kane	High	31	116
		Low	34	102
2001/02	Kane	High	48	173
		Low	39	70
	Rosser	High	49	119
		Low	32	71
	Brandon	High	33	145
		Low	18	75

* estimated assuming a soil BD of 1.24 g cm^{-3} for 0-30cm and 1.33 g cm^{-3} for 30-120cm

In addition to sampling to 120 cm, separate soil samples of 0-15 and 15-30 cm were gathered three times in the fall (≅ 2 week interval) from the band zone and between the band zones, to monitor the transformation of banded fertilizer. Sub-samples were mixed into one composite for each combination of zone, sample depth and treatment in the field. Weather and soil conditions again dictated when soil samples were collected at the individual sites. In year 1 at Kane, the third fall sampling period was missed because of snow and frozen soil conditions. In year 2, fertilized subplots were sampled three times at Kane and Brandon, but excessive rainfall cancelled the second fall sampling period at Rosser. Moist soil samples were refrigerated and stored at a temperature of 2°C. All soil samples were air dried at 30-35°C for 48 to 72 hours and ground to pass a 2 mm sieve using a high-speed soil grinding mill. Ground soil samples were extracted for water soluble nitrate and nitrite, exchangeable ammonium, and urea nitrogen by shaking 5 g of soil with a 25 ml solution of 2M KCL and phenyl mercuric acetate (PMA) for 30 minutes and filtered through Whatman no. 40 filter paper. PMA, a urease inhibitor, was added to the solution to stop the significant hydrolysis of urea by soil urease that can occur during the extraction of soils for determination of urea (Douglas and Bremner 1970). A Technicon Autoanalyzer II Single-Channel Colorimeter was used to determine the concentrations of NO_3^--N + NO_2^--N and NH_4^+-N in the extract using the automated cadmium reduction method and the automated phenate colorimetric method respectively (Maynard and Kalra 1993). In this method, NO_3^--N is reduced to NO_2^--N; however, NO_2^--N in the extract was measured by analyzing the original extract a second time without the reducing step (Ellis 2001). The nitrite-N was subtracted from the nitrate/nitrite-N value. The Technicon method used in the determination of urea-N is a modification of the carbamido-diacetyl reaction, as described by Douglas and Bremner (1970). Electrical conductivity (EC) and pH of all 0-15 and 15-30 cm soil samples were measured using a 2:1 water to soil extract, an Orion conductivity meter and a Fisher Accumet pH meter (Hogg and Henry 1984; Hendershot et al. 1993).

Gravimetric soil moisture contents of 0-7.5, 7.5-15 and 15-30 cm were measured weekly at all intensive sites from early fall to freeze-up, and from early spring to planting. Over the same period, soil temperatures were monitored electronically every 15 minutes using a StowAway® Tidbit® temperature probe placed directly into one of the fertilizer bands (7.5 cm depth) within each early fall application subplot. Rainfall data was collected at all intensive sites using a tipping bucket rainguage and a HOBO® event driven data logger. Weather conditions, including precipitation and aerial temperature were obtained from Agrometeorological Centre of Excellence (ACE) weather collection devices located near the individual intensive sites.

Data Analyses

Statistical analyses were conducted using the General Linear Model procedure of the Statistical Analysis System package (SAS 1999). The soil and plant data was tested for normality using the Proc Univariate function of SAS, and all variables showed relatively normal distributions (results not presented). Fisher's (protected) least significant difference (LSD) test was used to compare the subplot (fertilization) and mainplot (landscape position) treatment means (Steel et al. 1987). For the fertilization treatment means, a probability level (α) of 0.05 was used as the significance threshold for the soil and plant variables. However, due to the high variability inherent in field-based landscape experiments a higher probability level is often used to detect treatment differences among landscape positions (van Kessel et al. 1993). Employing the typical probability threshold of 0.05 or lower in landscape studies increases the chances of a Type II error (β), of failing to detect treatment differences when, in fact, these differences did occur (Walley et al. 1996). Therefore, a probability threshold of 0.10 was used for all landscape variables and interactions, which is within the typical range of probability values ($p \leq 0.10$ to 0.20) used in many landscape studies (Pennock et al. 1992; van Kessel et al. 1993; Corre et al. 1996; Manning et al. 2001).

Results and Discussion

All results presented in this paper are based on the intensive field sites only.

Crop Data

Overall, growing conditions were fair to good at the intensive sites in both years of the study. In year 1, wet field conditions in the spring delayed seeding to June 4th at Kane (2000/01). In year 2, Kane (2001/02) and Brandon (2001/02) were seeded on May 21st. Rosser (2001/02) was seeded on May 27th. During both growing seasons, each site situated within the Red River valley endured one major rainfall event of 3-5". At Kane (2001/02), this event occurred in July shortly after anthesis, while Kane (2001/02) and Rosser (2001/02) received a heavy rainfall event in early June when the crop was at the 3-4 leaf stage.

Midseason: At midseason, total dry matter biomass was significantly greater for high landscape positions than for low landscape positions (Table 2). The high landscape positions also had greater crop N uptake at midseason then the low landscape positions, but due to the site year by landscape position interaction the LSD is not reported. Midseason N uptake was significantly greater in the high landscape positions then in the low landscape positions at two of the four sites; Rosser (2001/02) and Brandon (2001/02) (data not presented). Spring-banded N significantly increased both midseason dry matter biomass and midseason N uptake, when compared to the fall-applied fertilization treatments. Comparing the two early fall applications with and without inhibitors, there were no substantial differences in midseason biomass and/or midseason crop N uptake.

Table 2. Effect of Landscape Position, Application Date and Inhibitors on Mean Midseason Dry Matter Yield and N Uptake (kg ha-1) for all Intensive Sites

Treatment		Mean Dry Matter Yield (kg ha^{-1})	Mean N Uptake (kg ha^{-1})
Landscape Position Means			
High		2917a	89.3
Low		2323b	64.4
LSD (p=0.10)		431	-[y]
	Fertilization Means		
	Early fall	2686b	79.6b
	Mid fall	2626b	78.3b
	Late fall	2779b	83.1b
	Spring	2991a	90.5a
	Control (no N)	1899c	49.3c
	Early fall w/ inhibitors	2737b	80.2b
	LSD (p=0.05)	188	6.1
ANOVA	df	Pr > F	
Site year	3	0.0588	0.5852
Landpos	1	0.0268**	0.0019**
Site year*Landpos	3	0.1189	0.0416*
Trt	5	0.0001**	0.0001**
Site year*Trt	15	0.1966	0.0572
Landpos*Trt	5	0.6375	0.8727
Site year*Landpos*Trt	15	0.3538	0.3260
Block(Site*Landpos)	24	0.0001**	0.0001**
Residual C.V. (%)		14.50	16.09

[y] LSD is not reported b/c there was a Site year*Landpos interaction.

* significant at p < 0.10 (used only for landscape position variables and interactions)

** significant at p < 0.05

Harvest: At physiological maturity, mean grain yield and total N uptake were 20 and 25% greater in the high landscape positions than in the low landscape positions (Table 3). However, due to the site year by landscape position interaction, statistical analyses of the landscape position effects on grain yield and total crop N uptake are reported at the individual intensive sites only (Table 4). The effects of landscape position on grain yield and total crop N uptake were apparent at three of the four intensive sites; Kane (2000/01), Rosser (2001/02) and Brandon (2001/02). At each of these sites, the high landscape positions produced significantly greater grain yields and total crop N uptake than the low positions. Grain yields were 265, 996, and 1283 kg ha $^{-1}$ greater in the high landscape positions than in the low landscape positions at Kane (2000/01), Rosser (2001/02) and Brandon (2001/02) respectively. Crop N uptake was an average of 42 kg ha^{-1} greater in the high landscape positions than in the low landscape positions over the same three intensive sites.

At Kane (2001/02), grain yield and total crop N uptake appeared to be greater in the low positions than in the high positions, but the differences were not significant. The higher grain yield and N uptake in the imperfectly drained lower positions at Kane (2001/02) was likely due to a prolonged dry period at this site during July and August, when the high landscape positions became more drought stressed than the lower landscape positions.

Spring and late fall-banded N applications generally increased the mean grain yields and total N uptake of the crop, compared to the other fall applications, with or without inhibitors (Table 3). The LSD analysis for grain yield is not reported because there was a landscape position by fertilization treatment interaction. Further statistical analyses of the landscape position by fertilization treatment interaction for grain yield determined that in the high landscape position there were no significant differences in crop response among fertilization treatments. However, in the low positions, spring-banded N significantly increased grain yields compared to early fall, mid fall and early fall with inhibitors. Grain yields appeared to be slightly higher for spring-banded than for late fall-banded N, but statistically they were not different. Grain yield and total N uptake of individual fertilization treatments consistently ranked higher in the high landscape positions than in the low landscape positions (i.e. early fall in high vs. early fall in low).

Mean crop N uptake tended to be greater for spring and late fall applications than for early and mid fall applications without inhibitors, but these differences were not significantly different (Table 3). The only significant difference in total crop N uptake at harvest was between the spring-applied and early fall with inhibitors treatments. There were no significant differences in crop response between the two early fall treatments, with and without inhibitors, in either landscape position.

Table 3. Effect of Landscape Position, Application Date and Inhibitors on Mean Dry Matter Grain Yield and Total N Uptake (kg ha-1) for all Intensive Sites

Treatment		Grain Yield (kg ha^{-1})	Total N Uptake (kg ha^{-1})
Landscape Position	Fertilization		
High	Early fall	2528a	116.3
	Mid fall	2530a	117.0
	Late fall	2482a	116.4
	Spring	2446a	118.0
	Control (no N)	1917b	81.5
	Early fall w/ inhibitors	2448a	112.5
	LSD (p=0.05)[x]	-	na
Low	Early fall	1939c	83.1
	Mid fall	1910c	84.1
	Late fall	2158ab	95.2
	Spring	2166a	96.2
	Control (no N)	1232d	52.2
	Early fall w/ inhibitors	1960bc	86.4
	LSD (p=0.05)[x]	-	na
Landscape Position Means			
High		2392	110.3
Low		1894	82.9
LSD (p=0.10)[w]		-	-
	Fertilization Means		
	Early fall	2234	99.7ab
	Mid fall	2220	100.5ab
	Late fall	2320	105.8ab
	Spring	2306	107.1a
	Control (no N)	1575	66.8c
	Early fall w/ inhibitors	2204	99.4b
	LSD (p=0.05)	-[v]	-[x]
ANOVA	df	Pr > F	
Site year	3	0.1106	0.1675
Landpos	1	0.0051**	0.0012**
Site year*Landpos	3	0.0028**	0.0059**
Trt	5	0.0001**	0.0001**
Site year*Trt	15	0.4885	0.4548
Landpos*Trt	5	0.0330*	0.4561
Site year*Landpos*Trt	15	0.6105	0.8432
Residual C.V. (%)		13.62	15.75

[x] used LSMEANS which does not provide an LSD value.

[w] LSD is not reported b/c of Site year*Landpos; please refer to Table 4.

[v] LSD is not reported b/c of Landpos*Trt interactions.

* significant at $p < 0.10$ (used only for landscape position variables and interactions)

** significant at $p < 0.05$

[na] Not Applicable

Table 4. Effect of Landscape Position, Application Date and Inhibitors on Dry Matter Grain Yield and Total Crop N Uptake (kg ha-1) at Individual Intensive Sites

Treatment		Site							
		Kane				Rosser		Brandon	
		2000/01[z]		2001/02		2001/02		2001/02	
		Grain Yield (kg ha^{-1})	N Uptake (kg ha^{-1})	Grain Yield (kg ha^{-1})	N Uptake (kg ha^{-1})	Grain Yield (kg ha^{-1})	N Uptake (kg ha^{-1})	Grain Yield (kg ha^{-1})	N Uptake (kg ha^{-1})
Landscape Position Means									
High		2293a	120.9a	1809	80.3	2374a	116.4a	3091a	123.6a
Low		2028b	101.6b	2343	97.8	1378b	66.9b	1828b	65.2b
LSD (p=0.10)		184	9.6	ns	ns	808	43.7	-[y]	-[y]
ANOVA	df	Pr > F							
Landpos	1	0.0309**	0.0082**	0.2271	0.3207	0.0536*	0.0703*	0.0038**	0.0008**
Residual C.V. (%)		9.12	10.11	16.70	23.07	14.98	16.21	13.06	16.03

[z] Grain yields for Kane 2000/2001 were predicted from actual straw yields.

[y] used LSMEANS which does not provide an LSD value.

* significant at $p < 0.10$ (used only for landscape position variables and interactions)

** significant at $p < 0.05$

Similar trends are seen for both grain yield increases and fertilizer N use efficiency (NUE), within the respective landscape positions, as was the case for grain yield (Table 5). In the high landscape positions, there were no real differences in increased grain yield and fertilizer NUE among the fertilization treatments. In the low landscape positions, increases in grain yield from late fall and spring-banded fertilization treatments were significantly higher than those from early fall, mid fall and early fall with inhibitors. The fertilizer NUE of late fall and spring-banded N in the low landscape positions was 12 to 16% higher then that of the early and mid fall-banded treatments, with and without inhibitors.

Table 5. Estimated Grain Yield Increase and Fertilizer NUE for all Intensive Sites

Treatment		Grain Yield Increase		Fertilizer NUE	
Landscape Position	Fertilization	kg ha^{-1}	% of Spring	% of Applied	% of Spring
High	Early fall	611a	116	44	95
	Mid fall	613a	116	44	97
	Late fall	565a	107	44	96
	Spring	529a	100	46	100
	Control (no N)	-	-	-	-
	Early fall w/ inhibitors	531a	100	39	85
Low	Early fall	707b	76	39	70
	Mid fall	678b	73	40	73
	Late fall	926a	99	54	98
	Spring	934a	100	55	100
	Control (no N)	-	-	-	-
	Early fall w/ inhibitors	728b	78	43	78

Grain yield increases and fertilizer NUE were typically higher in the low landscape positions than in the highs. Difference in the degree of N response between the landscape positions was due to relatively poor grain yields and N uptake from the control treatment in the low landscape position, compared to the high landscape position. The low crop yields and N uptake for the control in the low landscape positions were caused, in part, by low concentrations of soil N in the low areas (data not presented). Higher soil moisture contents in the low areas during the fall and early spring, combined with early fall applications of ammoniacal fertilizers, increased the potential for over-winter and early spring losses of NO_3^- via denitrification. Urea applied later in the season, when soil temperatures were cool did not convert to nitrate as quickly and was less subject to over-winter losses. In the high positions, prolonged water saturation of the soil was not common, even in the spring, and therefore the potential for N losses were much lower.

Correlation analysis showed that the effect of date of application on relative grain yields was significantly different for the high landscape positions compared to the low landscape positions (Fig. 1). Overall, the results suggest that selection of suitable timing for application of fertilizer N to optimize crop yields is much more critical for poorly drained fields, and for poorly drained areas within a field, than for better drained land.

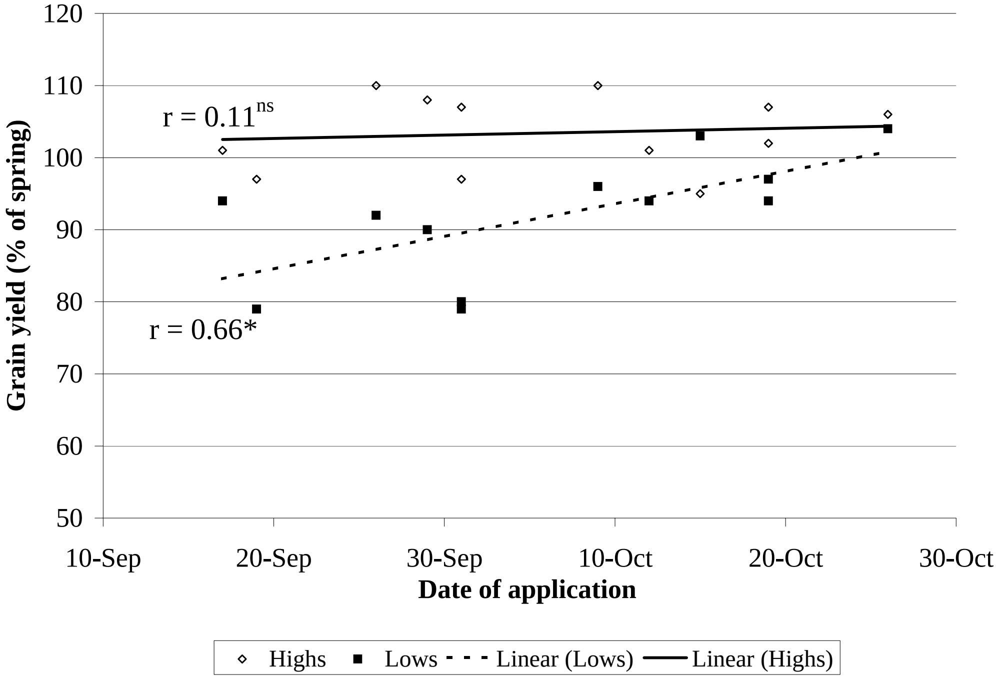

Fig. 1. Effect of date of N application in the fall on wheat grain yields from fall-banded urea relative to spring-banded urea (High vs. Low positions *P* = 0.067[†]) (ns, †, * indicates no significance, and significance at 0.1 and 0.05 levels respectively).

Soil Data

Landscape position did not have a significant effect on the conversion of banded-urea to nitrate under the moisture conditions present at the sites. Delaying the date of application of fall-banded urea fertilizer into the late fall and the presence of NBPT and DCD slowed nitrification and increased the percent recovery of fertilizer N as NH_4^+-N in the soil prior to freeze-up. Date of application, soil temperature on the date of application, the accumulation of soil heat units (SHU) and nitrification heat units (NHU) were all linearly related to the percent of recovered fertilizer N as NH_4^+-N (Figures 2-5). Accumulated SHU and NHU best described the relationship with percent of recovered fertilizer N as NH_4^+-N at the end of the fall, with and without inhibitors. The percent recovery of fertilizer N as NH_4^+-N prior to the winter was greater for the early fall-banded urea with NBPT and DCD than for the early fall-banded urea without inhibitors (Fig. 6).

In the high landscape positions, the performance of fall-banded urea, relative to spring-banded urea, was not affected by application date, soil temperature on date of application, cumulative soil heat units or cumulative nitrification heat units. This suggests that application date for fall-banded N is not a factor in better-drained landscape positions and in well-drained fields. However, in the low landscape positions, delaying application until late in the fall, when soil temperatures had cooled to 5 or 6ºC, greatly increased relative grain yields and total N uptake by the crop. Soil temperature at time of fertilizer application gave the highest correlation with relative grain yields in the low landscape positions (r = -0.79**); date of application gave a slightly lower correlation (r = 0.66*). Soil heat units (SHU) and nitrification heat units (NHU) accumulated from date of application until freeze-up gave inferior correlations (r = -0.56^{ns} and -0.49^{ns}, respectively).

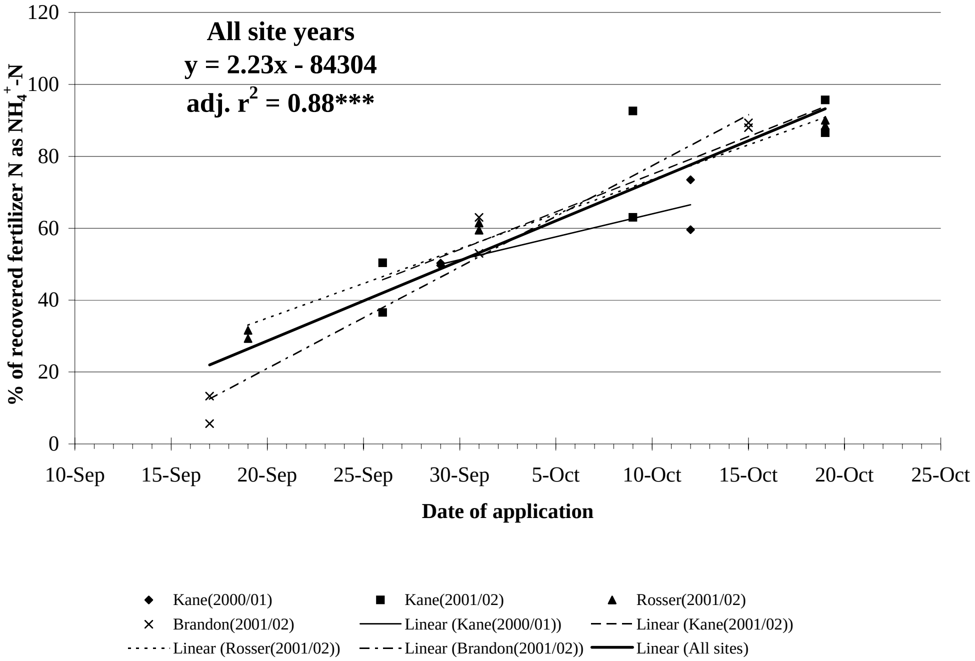

Fig. 2. Effect of date of N application in the fall on the percent recovery of fertilizer N as NH_4^+-N in the soil using the final fall sampling period only (*** indicates significance at 0.001 level).

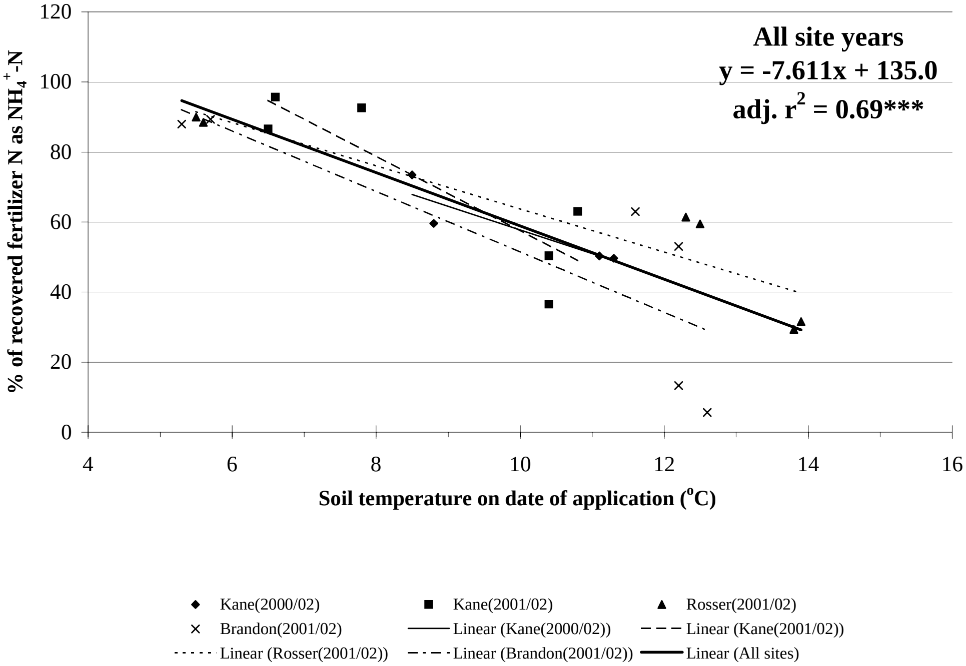

Fig. 3. Effect of soil temperature at 7.5 cm on date of N application in the fall on the percent recovery of fertilizer N as NH_4^+-N in the soil using the final fall sampling period only (*** indicates significance at 0.001 level).

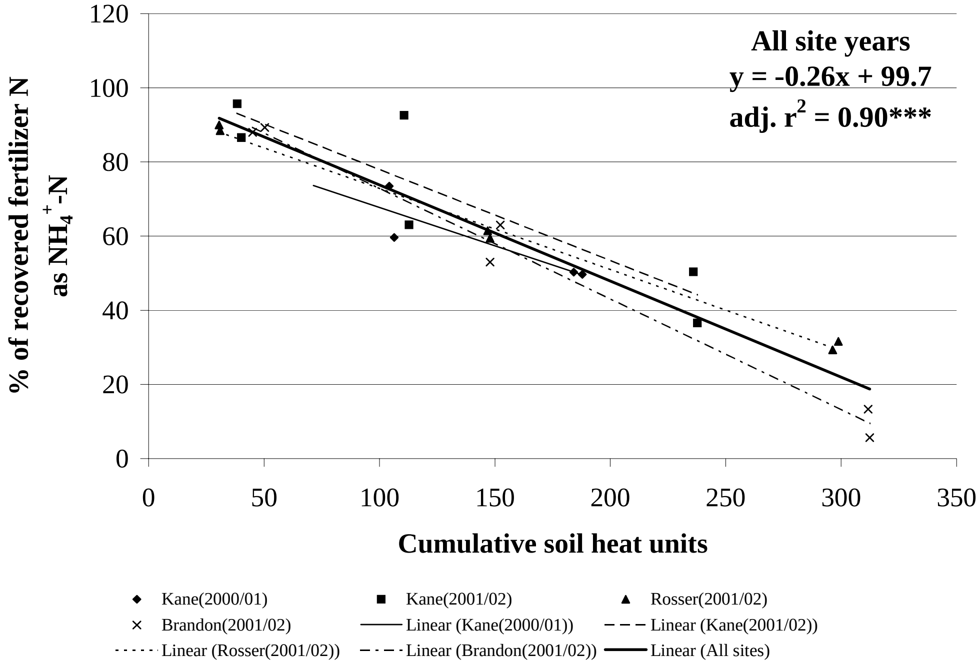

Fig. 4. Effect of cumulative soil heat units in the fall on the percent recovery of fertilizer N as NH_4^+-N using the final fall sampling period only (*** indicates significance at 0.001 level).

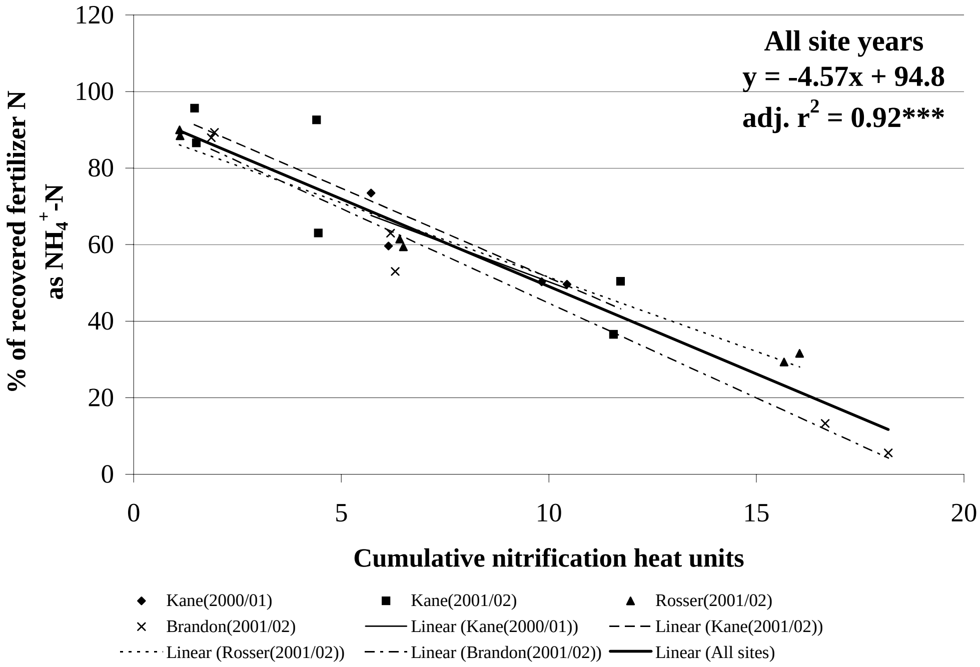

Fig. 5. Effect of cumulative nitrification heat units in the fall on the percent recovery of fertilizer N as NH_4^+-N using the final fall sampling period only (*** indicates significance 0.001 level).

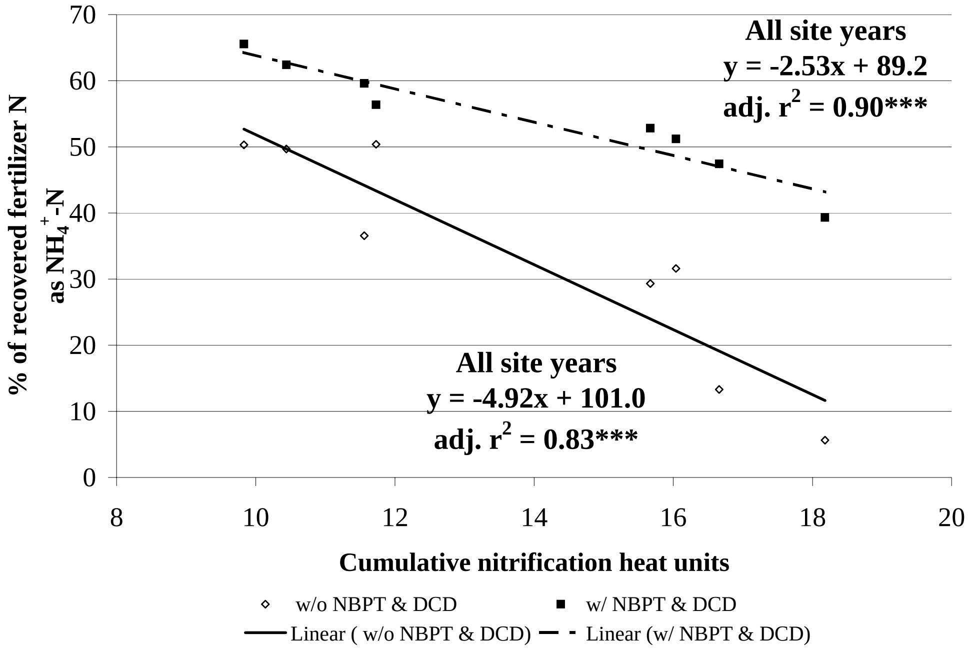

Fig. 6. Effect of cumulative nitrification heat units in the fall on the percent recovery of fertilizer N, with and without NBPT and DCD, as NH_4^+-N using the final fall sampling period only (*** indicates significance at 0.001 level) (slope comparison *P* = 0.02*).

Conclusions

Landscape influences on crop productivity were not consistent over all site-years because of variation in local growing season conditions. Overall, grain yield and total crop N uptake was greater in the high landscape positions than in the low landscape positions at three of the four intensive sites. Spring and late fall applications of fertilizer N generally produced the highest grain yields and N uptake by the crop, with largest differences between spring and early fall-banded N in the low landscape positions. In the low landscape positions, grain yield, total N uptake, grain yield increases and fertilizer NUE were significantly higher for the spring applications than for early fall, mid fall and early fall with inhibitors. There was little apparent crop benefit to the use of the double inhibitor, as there was no real evidence of greater yield or N uptake by the crop with the inhibitors than without, at either landscape position. One possible explanation for the poor overall performance of the inhibitors is that it may not be feasible to expect the inhibitors to maintain the fertilizer N in the NH_4^+ form for this length of time (mid September to mid May). Another possible explanation is that the potential for N loss may not have been severe enough to fully utilize the capabilities of the NBPT and DCD inhibitors.

Ridley (1976, 1977) reported that the efficiency of fall broadcast and incorporated N was lower in the lowland regions of Manitoba than in the upland regions. Over 13 sites, average yields of fall-applied N were two-thirds that of spring applications in the lowland regions. However, in the better-drained soils of the Manitoba uplands, fall-applied N was only 10-15% less effective than spring-applied urea. In the present study, we found that the average efficiency of fall-banded N, in terms of grain yield increase as a percent of spring-banded N, was 30% better in the high landscape positions than in the low landscape positions within the same field. These findings show that that there is as much variability in efficiency of fall-applied N within a field as there is between regions of southern Manitoba, and suggests that selection of suitable timing for application of fertilizer N to optimize crop yields is much more critical for poorly drained fields, and for poorly drained areas within a field, than for better drained land. For those producers whose land is well drained, early fall application of N fertilizer is a viable option. However, on poorly drained land where the potential is high for prolonged flooded conditions during the fall or spring, producers should wait as long as possible in the fall, or until the spring, to apply nitrogen fertilizer.

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