Research Branch
Technical Bulletin 1992-8E

Fall compared to spring application of nitrogen fertilizers in Alberta

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Fall compared to spring application of nitrogen fertilizers in Alberta

S.S MALHI
Agriculture Canada
Research Station
Lacombe, Alberta

M. NYBORG
Department of Soil Science
University of Alberta
Edmonton, Alberta

E.D. SOLBERG, D.J. HEANEY
Soils Branch
Alberta Agriculture
Edmonton, Alberta

Technical Bulletin 1992-8E

Research Branch
Agriculture Canada
1992

Copies of this publication are available from
Director
Research Station
Research Branch, Agriculture Canada
Bag Service 5000
58th St. at the C & E Trail
Lacombe, Alberta
T0C 1S0

Cat. No. A54-8/1992-8E
ISBN 0-662-20082-9

Également disponible en français sous le titre
Comparaison des applications automnales et printanières d'engrais azotés en Alberta

CONTENTS

ACKNOWLEDGMENTS

The authors thank the Agricultural Research Council of Alberta (Farming for the Future Program), Alberta Agriculture Research Trust, Western Co-operative Fertilizers Limited and the Sulphur Institute for financial support. Acknowledgment is given to Alberta Agriculture Soils and Animal Nutrition Laboratory for certain analyses.

SUMMARY

In Alberta and other Prairie Provinces, fall-applied N is often less effective than spring-applied N. The study was conducted to find reasons for inferiority of fall-applied N, and to determine the effect of various factors on the relative effectiveness of fall-versus spring-applied N and to investigate methods to improve the efficiency of fall-applied N. The poor performance of fall-applied urea was attributed to nitrification over the winter and subsequent denitrification in early spring after the snow melt. The loss of fall-applied N from mineral N pool was also caused by immobilization. The effectiveness of fall-applied N was improved by using ammonium-based fertilizers, delaying application in fall, and placing N fertilizer in widely-spaced bands and more so in nests or as large pellets. Inhibitors were also effective in increasing yield response of barley to fall-applied N, but may not be cost-effective. The relative efficiency of fall- versus spring-applied N was also increased with increasing N rate and soil test NO_3-N level, fine texture, better drainage, drier soil conditions in fall and spring, and from Grey Luvisolic soil zone in northern to Brown soil zone in southern Alberta.

RÉSUMÉ

En Alberta, tout comme dans les autres provinces des prairies, la fumure azotée appliquée en automne est souvent moins efficace que celle appliquée au printemps. Cette étude a été entreprise pour en déterminer les raisons et pour comparer l'effet de certains facteurs sur l'efficacité de l'application de fumure azotée automnale et printanière et pour examiner des méthodes qui pourraient améliorer le rendement de la fumure azotée automnale. La faible production associée à l'épandage d'urée automnale a été attribuée à une nitrification durant l'hiver suivie d'une dénitrification après la fonte des neiges. La perte de fumure azotée automnale du pool d'azote inorganique a aussi été causée par immobilisation. On a amélioré l'application de fumure azotée automnale grâce entre autres à l'utilisation de fertilisants à base d'ammonium, en retardant l'application plus tard à l'automne et en plaçant un fertilisant à large granulométrie, en bandes bien espacées. Des inhibiteurs ont accru le rendement de l'orge sur fumure azotée automnale même s'ils peuvent s'avérer non-rentables. On a également amélioré l'efficacité relative de la fumure azotée automnale, en augmentant la teneur d'azote et d'azote nitrique du sol, avec une texture plus fine, un meilleur drainage, des conditions de sol plus sec à l'automne et au printemps et ce, de la zone des sols luvisoliques gris au nord de la province jusqu'à la zone des sols bruns au sud.

INTRODUCTION

In Alberta, and the other Prairie Provinces, nitrogen (N) fertilizers are often applied in fall rather than in spring for spring-sown crops. Fertilizing with N in the fall, rather than in the spring, has two main advantages - lower fertilizer prices and convenience. The main disadvantage is that yield increases from fall application can be considerably lower than those obtained from spring application (Table 1). The effectiveness of fall-applied N as compared to spring-applied N can be influenced by a number of factors. Management factors include: kind of N fertilizer, date of fall application, method of placement, use of nitrification inhibitors and slow-release N fertilizers, and straw handling. Other factors are: soil texture, drainage, fall soil moisture, soil-climatic zone, depth of placement and early growing season precipitation; rate of N, soil test nitrate-N level and yield response to applied N. This bulletin contains information for fertilizer dealers, agricultural extension personnel and farmers on the effect of these factors on the effectiveness of fall- versus spring-applied N. The information is based on field experiments, most of which were conducted in central and north-central Alberta.

Table 1 Yield increase and N uptake of barley grain from fall and spring applications of urea incorporated into soil at 56 kg N/ha (average of 44 experiments)

Measurement	Time of N application		Relative efficiency[§]
	Fall	Spring	
Increase in grain yield (kg/ha)	970	1840	55
% recovery of applied N in grain	27	55	50

[§]Relative efficiency was calculated as yield increase from fall-applied N, divided by yield increase from spring-applied N and multiplied by 100.

REASONS FOR INFERIORITY OF FALL-APPLIED N

Soil sampling of fall-fertilized plots from fall through winter has shown that fall incorporated urea slowly forms nitrate (nitrification) over the winter, even when soils are frozen (Table 2). Nitrate is subject to loss by denitrification (formation of nitrogen gases) when soil is wet and poorly aerated. In a number of experiments, early spring recovery of ^{15}N-tagged[1] fall-applied N in soil was very low and the amount recovered was highly dependent on the kind of fertilizer applied (Table 3 and Fig. 1). Nitrogen loss was much greater from nitrate-based fertilizer than from ammonium-based fertilizer. Early spring N loss was primarily due to

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1 ^{15}N is a heavy isotope of N that researchers use to track fertilizer N through the soil and plant. This provides an easy accounting of N applied.

denitrification rather than leaching. Fall-applied N had not moved below the 60 cm depth (Table 3). Similar experiments with ^{15}N-tagged N indicate nitrate losses take place during episodes of mild weather in winter and during spring thaw whenever snow melts and the soil is wet.

Table 2 Apparent nitrification of applied N during winter, after incorporation of urea at 56 kg N/ha on 6 October (average of 6 experiments)

Fertilizer[§] treatment	% of applied urea N found as nitrate-N 21 Oct.	7 Dec.	6 Mar.
Urea - incorporated	23	43	57
Urea - banded	8	19	25
U+I - incorporated	5	8	12
U+I - banded	1	2	5

[§] U+I refers to urea + inhibitor pelleted together in a ratio of 2:1, respectively.

Table 3 The recovery of fall-applied ^{15}N-labelled fertilizers applied in October or December at 112 kg N/ha from the soil N in the following May

Soil depth (cm)	Percent recovery of ^{15}N-labelled fall-applied N: Average of two experiments: KNO_3 (incorp.)[§]	Urea (incorp.)	$(NH_4)_2SO_4$ (banded)	Average of three experiments: KNO_3 (banded)	$(NH_4)_2SO_4$ (banded)	$(NH_4)_2SO_4$ + thiourea (banded)
0-15	18	46	80	15	92	97
15-30	23	16	3	11	2	1
30-60	2	1	0	1	0	0
60-90	0	0	0	0	0	0
90-120	0	0	0	0	0	0
Total	43	63	83	27	94	98

[§]Incorporated.

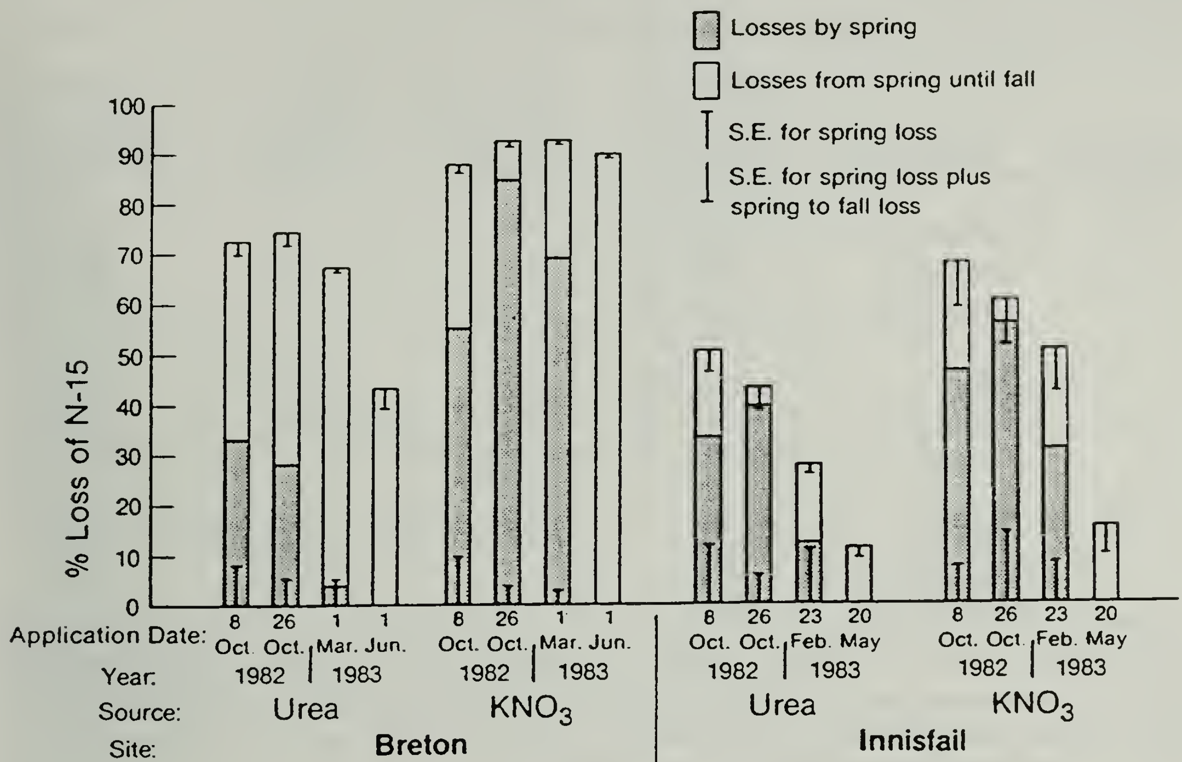

Fig. 1. Loss of ^{15}N from soil at sowing and from soil and plants at harvest, with four dates of application for each fertilizer and site.

FACTORS AFFECTING EFFICIENCY OF FALL- AND SPRING-APPLIED N

Kind of N Fertilizer

In a series of experiments, calcium nitrate and urea were incorporated into soil in the fall and average yields were lower with calcium nitrate than urea (Table 4). In four experiments comparing fall application of ammonium sulphate with urea, ammonium sulphate produced greater yields. In another four experiments, fall-applied ammonium nitrate yielded slightly less than fall-applied urea. These three sets of comparisons (Table 4) indicate that nitrate-based fertilizers are often inferior to ammonium-based fertilizers when applied in the fall.

Table 4 Yield increase and N uptake of barley grain with fall and spring incorporation applications of N fertilizers at 56 kg N/ha in field experiments

No. of tests	Treatment§	Increase in grain yield (kg/ha)	% recovery of applied N in grain	Relative efficiency (Yield)†	Relative efficiency (N recovery)†
21	CN-fall	802	21	48	41
	Urea-fall	940	26	56	51
	Urea-spring	1683	51		
4	AS-fall	1435	37	61	54
	Urea-fall	1130	31	48	45
	Urea-spring	2335	69		
4	AN-fall	750	24	58	59
	Urea-fall	848	27	66	66
	Urea-spring	1285	41		

§CN, AS and AN refer to calcium nitrate, ammonium sulphate and ammonium nitrate, respectively.
†Relative efficiency was calculated as yield increase (or N recovery) from fall-applied N, divided by yield increase (or N recovery) from spring-applied N and multiplied by 100.

Date of Fall Application

Nitrification rates in soil are positively correlated to soil temperature. As a result, conversion of added ammonium to nitrate should be greater with early fall when soils are warm than with late fall application when soils are cool. Soil temperature steadily decreases from mid-September to early November when the soil begins to freeze (Figure 2). One would thus expect more over-winter loss of fall-applied N and subsequently lower N uptake and yield of the crop, with the application of ammonium fertilizers in early as compared to late fall. To investigate this scenario, 15 experiments were conducted in which urea was broadcast and incorporated at 2 or 3 dates in the fall. The recovery of mineral N (ammonium plus nitrate) in the spring was greater when applications were made in late fall as compared to early fall (Figure 3). The % recovery of fall-applied N as soil mineral N found in spring increased from 31% with urea added on 20 September to 73% with urea applied on 31 October (based on the linear regression).

Fall incorporated urea produced less barley yield relative to urea applied in the spring (Figure 4). Delaying application in the fall markedly improved yield response. Yield increase from fall-applied N as a % of yield increase from spring-applied N rose from 23% for urea

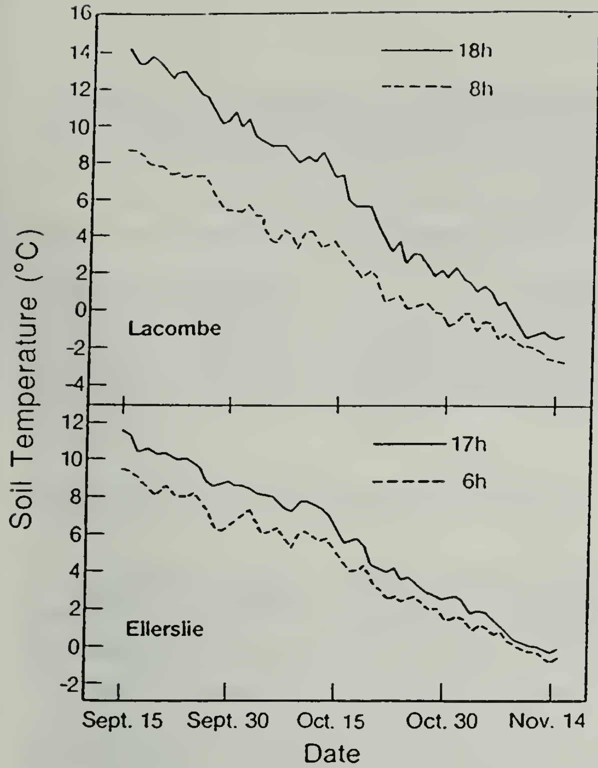

Fig. 2 Mean daily soil temperature in the morning (6 or 8 h) and the afternoon (17 or 18 h) at 5 cm depth at meteorological stations in Ellerslie (northcentral Alberta) and Lacombe (central Alberta), averaged from 1975 to 1984

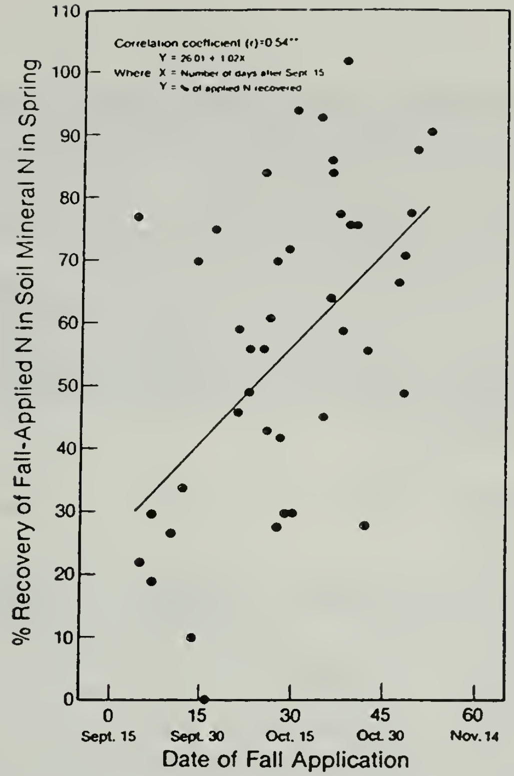

Fig. 3 Effect of date of N application in fall on the recovery of applied N as mineral N in soil in spring from urea at N rates of 50 or 56 kg/ha.

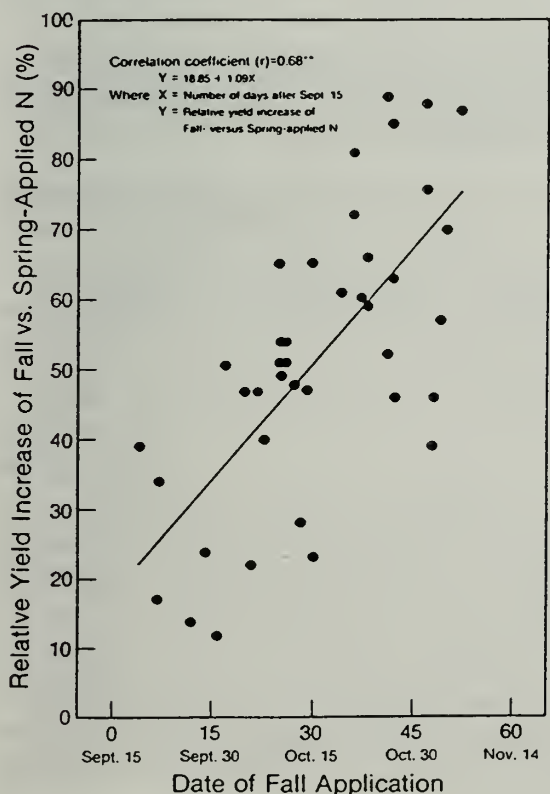

Fig. 4 Effect of date of N application in fall on relative yield increase of barley grain from fall- versus spring-applied urea at N rates of 50 or 56 kg/ha.

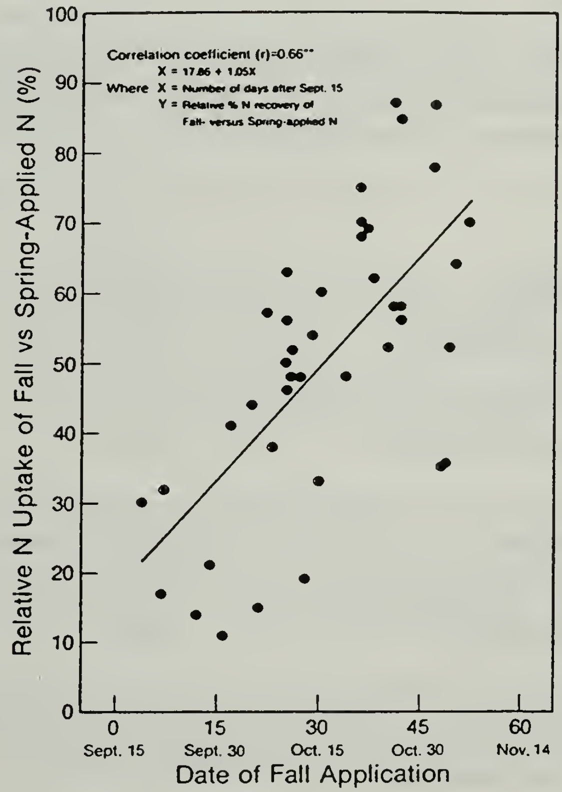

Fig. 5 Effect of date of N application in fall on N uptake in barley grain from fall-applied urea relative to spring-applied urea at N rates of 50 or 56 kg/ha.

Table 5 The recovery of applied N as ammonium-N and mineral N in soil (0-90 cm) in May, yield increase and N uptake of barley grain with the application of urea and U+I[§] (2:1) in October at 56 kg N/ha (average of 10 field experiments)

	N applied in fall				N applied in spring	
Parameter	Urea-Incorp.[†]	Urea-Banded	U+I-Incorp.[†]	U+I-Banded	Urea-Incorp.[†]	Urea-Banded
% recovery in soil as ammonium-N	8	15	30	46		
% recovery in soil as mineral N	62	68	75	85		
Increase in grain yield (kg/ha)	1070	1250	1440	1740	2000	2090
% recovery of applied N in grain	31	37	44	57	63	67

[§]U+I (2:1) refers to urea + inhibitor pelleted together in a ratio of 2:1, respectively. Thiorea is a nitrification inhibitor.
[†]Incorporated.

Table 6 Grain yield increase and % recovery of applied N in grain and in soil in spring from urea solution and aqua NH_3 with and without inhibitors banded in fall and spring (average of 6 experiments for aqua NH_3 and 10 experiments for solution urea)

Fertilizer treatment[§]	Yield increase (kg/ha)	% recovery of applied N In grain	In soil (0-30 cm) Ammonium-N	In soil (0-30 cm) Mineral N
Aqua NH_3-fall	763	26	1	49
Aqua NH_3 + Inhibitors - fall	1144	41	18	69
Aqua NH_3-spring	1557	55		
Urea-fall	972	29	4	44
Urea + Inhibitors - fall	1358	40	34	73
Urea-spring	1853	61		

[§]Inhibitors used were ATC, N-Serve 24E, CS_2, $(NH_4)_2CS_3$, K_2CS_3 and thiourea applied at 2, 4, 10, 20, 24 and 45 kg/ha, respectively.

applied on 20 September to 69% for urea applied on 31 October. The values of N uptake by barley showed similar pattern to yield increase values (Figure 5). The N uptake was greater with late fall compared to early fall application.

The efficiency of fall incorporated urea as compared to spring incorporated urea varied greatly from experiment to experiment. This is not unexpected as the experiments were conducted on a variety of soils over a number of years. Nevertheless, early fall application for barley was inefficient while application in late fall at times achieved efficiencies close to spring application (Figures 4 and 5). Keep in mind, however, that these experiments used incorporated urea. Banding which tends to increase the efficiency of fall application, may be less sensitive to application date.

Inhibitors and Slow Release N Fertilizers

Ammonium can neither easily leach from soil nor is it subject to denitrification in soil. Nitrate can be lost through both mechanisms. Inhibitors, which suppress the formation of nitrate from ammonium-based fertilizers, should reduce over-winter loss of fall-applied N and increase crop yield. A number of inhibitors (thiourea, ATC, N-Serve 24E, CS_2, $(NH_4)_2$ CS_3 and K_2CS_3) were tested with urea or aqueous NH_3. These inhibitors were all effective in suppressing nitrification of fall-applied N (Tables 2, 5 and 6) and in reducing over-winter N losses, especially when the N fertilizer plus inhibitor were placed in bands (Tables 5 and 6). In most cases, these reduced losses translated into substantial increases in barley yield (Tables 5 and 6). However, placing fertilizer in concentrated bands or nests was equal or better than the inhibitors (see section on Methods of N Placement).

This research tested only one slow-release N fertilizer, sulphur-coated urea (SCU). Sulphur-coated urea was not effective in improving the effectiveness of fall-applied N and it gave poor barley yields when applied in the spring. The explanation was that N release from SCU was too slow to meet the crop needs.

Methods of N Placement

Nitrification inhibitors were effective in improving barley yield response to fall-applied N. However, they may not be convenient to apply with N fertilizers or cost-effective. In addition, many of the inhibitors were found to slow the release of mineral N from native soil N. Therefore, field experiments were conducted to find if the effectiveness of fall-applied urea could be improved by concentrating the fertilizer through placement in bands, and in nests or as large pellets.

Yield and recovery of applied N in barley grain were considerably lower with fall application than spring application in four experiments comparing broadcast, incorporated and banded (22.5 cm spacing) applications (Table 7). Overall, broadcast application was least effective and band placement was most effective. Nevertheless, yields with fall banding were still inferior to those with spring banding.

Experiments were conducted with further concentration of urea or aqua NH_3 by placing in widely-spaced bands (45 cm spacing) or in nests or as large pellets. The nest method of application was performed by placing a number of commercial fertilizer granules at a point

Table 7 Yield increase and % recovery of applied N in barley grain with fall and spring applications of urea at 56 kg N/ha following different methods of placement (average of 4 experiments)

	Fall-applied N			Spring-applied N		
Parameter	Broadcast§	Incorp.†	Banded‡	Broadcast	Incorp.†	Banded
Increase in grain yield (kg/ha)	543	848	1018	998	1285	1425
% recovery of applied N in grain	18	27	33	31	41	46

§Surface broadcast.
†Incorporation.
‡Bands were 22.5 cm apart.

below the soil surface. For the large pellet method, urea pellets ranged from 1- to 3-g weights. Single pellets were placed below the surface on a fixed grid. Grid spacings increased with pellet size in order to give the same N rate in all treatments. The main purpose of bands, nests or pellets is to keep the fall-applied N in ammonium form by reducing the contact area between fertilizer and soil.

Almost all of the fall-applied incorporated urea granules nitrified by May (Table 8). The recovery of applied N as NH_4-N increased markedly when the fertilizer was banded or nested. The recovery of applied N in mineral N was also much greater with banding and even greater with nesting than mixing, indicating that over-winter N losses were reduced substantially when urea was placed in bands or nests. Yield and recovery of applied N in grain was also improved (Table 8). The barley yields with nests of urea were very close to those obtained with spring-applied N. The results were similar with aqua NH_3 placed in bands or nests. In a few experiments, nitrification inhibitors were used with nest placement, but there was no further improvement in crop yield from the use of inhibitors.

When straw is returned to the field, it tends to temporarily immobilize N and can affect the amount of fertilizer N available for the next crop. Two field experiments investigated whether or not the effect of straw can be minimized by placing N fertilizer in bands or in nests or as large pellets. For fall-applied N, placing urea in nests improved barley yields and N use efficiency in both straw-off and straw-on treatments, though yields were slightly lower when straw was retained than when it was removed (Table 9). With spring-applied N, the yield difference between straw-off and straw-on plots was 625 kg/ha for the incorporation application and only 190 kg/ha when the fertilizer was banded at sowing. Apparently, less of the applied N will be immobilized in the soil organic matter as shown by the ^{15}N experiments (Table 10). This leaves more fertilizer N for crop uptake.

Table 8 Effect of method of placement on yield increase and % recovery of applied N in grain and in soil in May from urea applied at 50 or 56 kg N/ha in the fall and in the spring (average of 20 experiments)

Fertilizer treatment[§]	Yield increase (kg/ha)	% recovery of applied N		
			In soil (0-60 cm)	
		In grain	NH_4-N	Mineral N
Urea incorp.[†]-fall	839	23	4	42
Urea banded-fall	1238(950)	36(26)‡	20(16)	66(52)
Urea nested-fall	1509(1535)	46(45)	50(36)	77(84)
Urea incorp.[†]-spring	1644(1763)	51(54)		

§Bands were 45 cm apart. In 7 experiments urea nested was 2-g, or 2.5-g pellets.
†Incorporation.
‡In brackets are the results with aqua NH_3 in four experiments.

These experiments indicate that banding and nest placement or large urea granules are good alternative to chemical nitrification inhibitors for conserving fall-applied N both from economical and environmental point of view. Use of concentrated placement in bands or nests allows effecient production, reduces the potential of environmental impact from nitrate leaching and denitrification and incurs no added chemical expenses.

Six field experiments were conducted to answer the question of whether or not large urea pellets are as effective as commercial urea when applied in spring. Urea placed in nests or as large pellets (2-g or larger) at sowing was much less effective in increasing barley yield than commercial urea incorporated into the soil just prior to sowing or side banded at sowing (average yield increase was 853 kg/ha for large urea pellets and 1517 kg/ha for commercial urea). In one experiment, yield response to applied N decreased from 1240 kg/ha with 1-g pellets to 490 kg/ha with 3-g pellets. The main reason for this poor performance of large pellets applied in spring was the slow diffusion of N from the pellet to the plant roots and essentially the fertilizer N in pellets becomes isolated from many of the growing plants for a period of time in the early peak growing season.

In the Prairie Provinces, denitrification of spring-applied N fertilizers (as opposed to fall-applied N) is not a serious problem in most years. Thus spring-applied nest or large pellets are of no particular advantage. Any risk of N loss from spring-applied N can be easily overcome by banding and does not need the use of large pellets.

Table 9 Influence of disposal of straw of the previous crop and method of N placement on grain yield of barley and N use efficiency with fall and spring application of urea at 50 kg N/ha (average of 2 experiments)

	Grain yield (kg/ha)		N use efficiency (kg grain/kg N)		% recovery of applied N	
Fertilizer treatment§	Straw-Off	Straw-On	Straw-Off	Straw-On	Straw-Off	Straw-On
Control	2065	1665				
Urea incorp.†-fall	2815	2740	15.0	21.5	35	30
Urea banded-fall	3210	2815	22.9	23.0	40	32
Urea pellets-fall	3300	3105	24.7	28.8	43	54
Urea incorp.†-spring	3435	2810	27.4	22.9	49	42
Urea-banded-spring	3460	3270	27.9	32.1	54	53

§Fall bands were 45 cm apart. Pellets contained 2-g of urea. In spring urea was banded 4 cm beside and below the seed row.
†Incorporation.

Table 10 Influence of method of placement and straw addition on the recovery of ^{15}N-labelled urea applied at 50 kg N/ha at sowing, in barley plants and soil at harvest

		% recovery of applied N			
		In plants		In soil	
Location	Method of placement	Without straw	With straw	Without straw	With straw
Rimbey	Incorp.§	60.1	51.7	29.9	36.9
	Banded	73.9	71.0	18.8	21.2
	Nested	76.0	77.8	15.8	20.7
Ellerslie	Incorp.§	11.8	13.8	36.4	48.9
	Banded	27.1	27.6	22.0	26.9
	Nested	50.8	46.6	22.0	26.9

§Incorporation.

Depth of Placement of Spring-Applied N

The availability of fertilizer N to the crop can be affected by its position in relation to plant roots. Under dryland conditions the upper most layer of soil generally dries out early in the cropping season. Roots near the surface become inactive and do not take up nutrients. As a result, fertilizer is "stranded" in this dry surface layer (J.T. Harapiak-Personal Communication). Furthermore, N fertilizer, especially urea, at or near the surface is vulnerable to loss through ammonia volatilization. This can limit crop response to the applied N. Field experiments were conducted to study the effects depth of N fertilizer placement on crop growth (Table 11). In four experiments (No. 18-21), the yield benefit of urea incorporated to a depth of 10-12 cm over surface-applied urea amounted to 290 kg/ha, while the advantage of banding over surface-applied urea was 430 kg/ha.

In another experiment (No. 8), grain yield was much higher for deeper incorporation and for deeper banding as compared to shallow incorporation or banding. In this experiment, depth of shallow incorporation or shallow banding was not more than 4 cm and surface soil was very dry during the early part of the growing season. In the shallow incorporation treatment, it is likely that the fertilizer N was "stranded" near the surface and was not available to plants early in the growing season. In the other experiments under more favourable moisture conditions, there were little or no differences in yield between shallow and deep placements.

These results indicate that the response to applied N can be modified by the depth at which the fertilizer is applied. The advantage of deep placements over shallow placement appears to be offset if rainfall occurs soon after fertilizer application. The advantage is likely to be greater during relatively dry years when the fertilizer is "stranded" during the key early growth stages. This lower yield with shallow spring-applied N can mask the relative difference between fall- and spring-applied N.

Rate of N, Soil Test NO_3-N Level and Yield Response

In general, the yield response to each additional increment of applied N normally decreases with increasing rate of N. Therefore, one would expect smaller relative yield difference between fall- versus spring-applied N (relatively) when the rate of fertilizer is high. Eight field experiments were conducted to determine the effect of rate of urea N on the relative efficiency of fall- versus spring-applied N (Table 12). The differences between fall- and spring-applied N for N use efficiency and % N recovery of applied N decreased, as N rate increased. The relative efficiency of fall- versus spring-applied urea increased from 47 to 73% when the N rate was increased from 25 to 100 kg N/ha. This does not imply that high N rates reduce over-winter loss, but instead they mask the differences between fall and spring-applied N. The use of extra N fertilizer to compensate for the over-winter N loss is neither an economical nor an environmentally sound practice. Other techniques such as banding or nesting or large pellets should be used to improve the effectiveness of fall-applied N.

Table 11 Effect of depth of placement of urea, on grain yield of barley, applied at time of sowing in 33 field experiments in central and north-central Alberta

Experiment number	Control Shallow-tilled§	Control Deep-tilled§	Yield of barley grain (kg/ha) Urea Shallow-tilled Shallow-incorporated	Urea Deep-tilled Deep-incorporated	Urea Shallow-tilled Shallow-banded	Urea Deep-tilled Deep-banded
1-4	2020	2860	3880	3890		
5-7	1960	1980	2930	2880	3160	3180
8	1710†	2100	1790†	3090	2460	3390
9-17		1520		3750	3830	
18-21		1100	2090‡	2380	2520	
22-33	1900		2740		2770	

§Shallow-tilled (5 to 7 cm depth) and Deep-tilled (10 to 12 cm depth).
†The plots were tilled to a depth of less than 4 cm.
‡Urea was broadcast and not incorporated into soil in these experiments.

Yield response to fertilizer N also decreases with increasing levels of plant-available N in soil. In our work in central Alberta, there was little response to fall- or spring-applied N on soils with large amounts of NO_3-N as compared to soils with low levels of NO_3-N (data not shown).

Texture, Drainage and Fall Soil Moisture

To determine the effect of soil conditions on the relative efficiency of fall- versus spring-applied urea, field sites were separated by texture, drainage and wetness of soil in the fall (Table 13). The sites with imperfect drainage, soil moisture above field capacity in fall and coarse to medium texture tended to show lower relative efficiency of N use than the sites with good to moderate drainage, soil moisture below field capacity in fall and fine to very fine texture.

Soil-Climatic Zone

Laboratory incubation studies showed that soils in all agro-climatic zones in Alberta have similar potentials for NO_3-N loss under anaerobic conditions (Table 14), but the actual loss from fall-applied N in the field depends on soil-climatic conditions. The Brown and Dark Brown soil zones are relatively dry and soils seldom become water saturated during the spring thaw. While

Table 12 Effect of N rate on N use efficiency, % recovery of applied N in grain and relative efficiency of fall-versus spring-applied urea (average of 8 experiments)

Rate of N (kg N/ha)	Time of application	N use efficiency (kg of grain /kg of N)	% recovery of applied N in grain	Relative efficiency (yield)§	Relative efficiency (N recovery)§
25	Fall	15.7	20.0	47	42
	Spring	34.1	48.9		
50	Fall	16.6	25.8	59	60
	Spring	28.9	43.7		
100	Fall	15.8	27.1	73	69
	Spring	20.0	34.9		

§Relative efficiency was calculated as yield increase (or N recovery) from fall-applied N, divided by yield increase (or N recovery) from spring-applied N and multiplied by 100.

Black and Gray Luvisolic zones are relatively moist and soils are usually water saturated for several days after the snow thaw. Field experiments using ^{15}N-labelled KNO_3 were carried out from Beaverlodge in northern Alberta to Lethbridge in southern Alberta to determine the over-winter loss of winter-applied N in various soil zones of Alberta (Table 14). The over-winter loss of applied N was much greater in the central and northern portions than in the southern portions of Alberta. However, these experiments were conducted only one year and the values given in Table 14 would differ in other years depending on localized climatic conditions.

The results of 99 field experiments were summarized to compare the yield response of barley or wheat to fall- versus spring-applied urea incorporated into soil in different soil zones in Alberta (Table 15). The relative efficiency of fall-versus spring-applied N was lower in the Gray Luvisol and Black soil zones as compared to Dark Brown and Brown soils zones.

CONCLUSIONS

Fall-applied N was inferior to spring-applied N because of substantial over-winter nitrification and subsequent N loss in early spring through denitrification. Over-winter N loss was greater from nitrate than from ammonium, and ammonium-based fertilizers were more effective than nitrate-based fertilizers in increasing yield of barley.

The effectiveness of fall-applied N was greatly improved by placing urea in widely-spaced bands and more so by placement in nests or as large pellets. This increased effectiveness

Table 13 Effect of factors on the yield increase and N recovery of fall versus spring applications of urea at 56 kg N/ha in 44 field experiments

Factors	No. of expts.	Relative efficiency (Yield)[§]	Relative efficiency (N recovery)[§]
Texture			
Coarse to medium	26	51	46
Fine to very fine	18	61	56
Drainage			
Well to mod. well	32	57	51
Imperfect	12	47	44
Fall moisture			
<75% of FC[†]	12	62	55
75 to 100% FC	20	56	52
>FC	12	46	42

[§]Relative efficiency was calculated as yield increase (or N recovery) from fall-applied N, divided by yield increase (or N recovery) from spring-applied N and multipled by 100.
[†]FC (field capacity) refers to moisture content in soil at 33 kPa.

Table 14. Denitrification potential and actual over-winter N loss from winter-applied ^{15}N-labelled KNO_3 in soils from northern to southern Alberta

Location	Area of Alberta	Denitrification potential (mg N/kg soil/day)	% of winter-applied N lost over the winter
Beaverlodge	Northern	19	93
Ellerslie	North-central	20	79
Rimbey	Central	23	74
Calgary	South-central	21	30
Granum -Vauxhall	Southern	22	18

Table 15 The relative efficiency of fall- versus spring-incorporated§ N in various soil zones†

Soil zone	No. of sites	Relative efficiency (Yield)‡	No. of sites	Relative efficiency (N recovery)‡
Luvisolic	17	63	16	63
Black	54	73	48	66
Dark Brown	15	86	11	80
Brown	13	97	13	89

§The N fertilizer was incorporated to a depth of 5 to 7 cm in most of the experiments in the Brown and Dark Brown soil zones and about one-third of the experiments in the Luvisolic and Black soil zones, and to a depth of 10 cm in other experiments.

†Relative efficiency was calculated as yield increase (or N recovery) from fall-applied N, divided by yield increase (or N uptake) from spring-applied N and multiplied by 100.

‡Source - Bole et al. 1984. Regional and environmental influence on N use efficiency. Pages 1-29 in Proc. Alberta Soil Science Workshop, 21-22 Feb. 1984, Edmonton, Alberta.

was due to slower nitrification and possibly reduced immobilization of applied N by banding or nesting as compared to incorporation. Surface-broadcasting was least effective. Delaying urea application in fall until close to freeze-up also improved the efficiency of fall-applied N. Spring application of urea in nests or as large pellets reduced yield response because the fertilizer becomes spatially unavailable to plants for a period of time in early peak growing season.

Inhibitors were effective in slowing nitrification, reducing over-winter N loss and improving yield response of barley to fall-applied N. However, inhibitors may be inconvenient to apply and may not be cost-effective. Sulphur-coated urea (a slow-release fertilizer) was not effective in improving the efficiency of fall- or spring-applied N.

The relative efficiency of fall- versus spring-applied N increased with increasing N rate, increasing soil test NO_3-N level, finer texture, better drainage, and drier soil conditions in fall and early spring. Over-winter N loss was greatest in the Gray Luvisolic soil zone and least in the Brown soil zone.

RECOMMENDATIONS

1. Use ammonium-based N fertilizers for fall application.

2. Apply N fertilizer in widely-spaced bands below the soil surface or use any other fertilizer application technique which reduces soil-fertilizer contact.

3. Delay fall application to as close to freeze-up as possible.

4. For maximum benefit from spring-applied N, incorporate N fertilizer to a depth of 10-12 cm or band below seeding depth.

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