A SUMMARY OF PLACEMENT AND FALL VERSUS SPRING APPLICATION OF NITROGEN FERTILIZERS

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ABSTRACT

In fifty-two field experiments since 1973-74, the yield of barley grain without N averaged 1570 kg/ha, but the yield was increased by fall and spring application of incorporated urea (56 kg N/ha) to 2540 and 3470 kg/ha, respectively. Early fall application was only half as efficient as late fall application. In five field experiments with N-15, the recovery in the spring of fall applied nitrate was low (13 to 60%) while recovery of late fall banded ammonium was much higher (82 to 99%). These losses came about through denitrification and not by leaching. Variable amounts of applied nitrate and ammonium were immobilized in the soil.

Fall banding (45cm spacing) and fall nesting (45cm by 45cm spacing) of urea (or aqua ammonia) gave larger yield increases than fall incorporation. In five experiments before 1978-79, yield increases of barley grain from fall application of urea by incorporation, banding and nesting were 960, 1240, and 1560 kg/ha, respectively. In the same order, yield increases were 740, 1100, and 1510 kg/ha in ten more recent experiments. However, the size of yield increases from fall banding were variable from experiment to experiment, ranging from being similar to fall incorporation to being similar to the high-yielding fall nests.

With spring application of urea, banding produced slightly higher yields than incorporation, while nesting tended to produce lower yields.

Retaining rather than removing the straw of the previous crop depressed the yield of barley grain by 650 kg/ha in six field experiments, and the retention of straw halved the uptake of fertilizer N by the crop. Preliminary results suggest that placement of fertilizer N in large pellets may overcome the immobilization of fertilizer N by the straw.

INTRODUCTION

Fall applied N fertilizers are often less effective than spring applied N fertilizers (Ridley, 1977; Paul and Rennie, 1977; Nyborg and Leitch, 1979). However, the opposite sometimes is found (Harapiak, 1979). The method and time of application of fall-added N fertilizer, and, apparently, the degree of dryness of soil after spring application of the N, play a role in the effectiveness of the N (Harapiak, Timmermans and Flore,

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1982; Nyborg, Malhi and Monreal, 1980; Nyborg and Leitch, 1979).

The purpose of this paper is to summarize our work for the past eight years and to set out practical conclusions.

METHODS AND MATERIALS

Fifty-two field experiments were conducted in the period from 1973-74 to 1980-81, and the majority were conducted within 120 km of Edmonton. The experiments were differing in numbers of treatments, but individual sub-plots were 6.8m by 1.8m insize.The experimental design was a complete randomized block with four replicates. The crop was Galt barley.

Five uncropped experiments received N-15 labelled fertilizers, and the experiments were conducted with soil in 30 cm diameter cylinders. These bottomless cylinders, which were 18 cm in height, were set into the soil with their top rim even with the surface.

RESULTS AND DISCUSSION

The several aspects of this subject will be treated separately in this section.

Fall versus spring application of incorporated urea

Application of urea in the fall gave only half as much yield increase of barley grain as did application in the spring based on 52 experiments accumulated since 1974. It is noted the nitrogen fertilizer (urea) was well incorporated into the soil. In most of the experiments, there was a large yield response to fall N (average of 970 kg/ha) and a much larger response to spring N (average of 1900 kg/ha). That is to say, the experiments were responsive both to N and to the time of application of the N.

Table 1. Average yield and N-uptake of barley grain with fall versus spring urea (56 kg N/ha) mixed into the soil to a depth of 10 to 15 cm. Fifty-two experiments during 1974 to 1981.

Urea treatment	Yield of grain (kg/ha)	% Uptake of fertilizer N by grain
No N	1570	
Fall N	2540	27
Spring N	3470	58

The 52 experiments were conducted at 20 sites and 44 of these experiments were conducted at 13 sites lying within 120 km of Edmonton. There was one experiment in the Peace River region, four experiments at three sites in the Olds-Didsbury area, and three experiments in north-central Saskatchewan. For these outlying areas the yield increases with fall application as a per cent of spring application were 69%, 62%, and 60%, respectively. These outlying experiments had smaller differences between fall and spring applications than did the nearby experiments, but they were also put out later in the fall. As will be shown, the time of fall application is an important factor in effectiveness of N.

In none of the 52 experiments was the response greater with fall applications than spring application, but in four experiments the difference was less than 200 kg of grain per ha. However, when the per cent fertilizer N uptake by the grain was the criterion for these four experiments, fall application gave distinctly lower values (fall N uptake was 71% of spring N uptake).

Ammonium and nitrate in fertilizer and soils

There was a question of loss of fall applied N being peculiar to urea fertilizer, but our results did not indicate so. Fall losses tended to be greater with calcium nitrate than with urea, while losses were less with ammonium sulphate than urea (Table 2). This demonstrated that nitrates were more susceptible to losses than ammonium. However, ammonium-based fertilizer is nitrified to a degree in the fall, especially when the fertilizer is applied early in the fall.

Table 2. The average N-uptake by barley grain from fertilizers (56 kg N per ha) incorporated into the soil.

No. of experiments in the comparison	% Recovery of applied N in barley grain		
	Fall application		Spring
	Urea	$Ca(NO_3)_2$	Urea
20	30	23	59
	Fall application		Spring
	Urea	$(NH_4)_2SO_4$	Urea
7	36	41	66

Table 3 demonstrates that the earlier the fall application of urea, the greater the nitrification by late winter, and the greater the losses by spring. The results in Tables 2 and 3 show that the amount of loss of fall applied fertilizers was in relation to the amount of nitrates.

Other work (Malhi, 1978) and the results in Table 3 pointed out that most of the losses of fall-applied fertilizer did not take place until the spring thaw when the soil was near saturation.

The fate of fall applied N-15 labelled fertilizers

There are several ways by which fall applied fertilizer N, as compared to spring applied N, could be lost from use by the subsequent crop. Nitrate and ammonium have different mechanisms of loss. For nitrate, there is denitrification (whereby the nitrogen is lost to the air) when soils are very wet, leaching out of the soil, and immobilization (the tying-up of nitrate in soil organic matter). For ammonium, there is immobilization, volatilization of ammonia into the air when the fertilizer is applied to the top of the soil (especially with calcareous soil) and fixation of ammonium by clays (although this mechanism is probably least important). Considering the loss of fall applied fertilizers in those rather simplified ways, we set out five experiments with tagged ammonium and nitrate applied late in the fall followed by soil sampling in May.

Table 3. Recovery of urea fertilizer (56 kg N/ha) in March and May after incorporation into the soil the previous fall (one experiment at Ellerslie, 1979-80).

Date of application	Recovery of fertilizer N (%)			
	Soil samples taken in March			Samples taken in May
	NH_4-N	NO_3-N	Total	Total
Sept. 25	34	71	104	27
Oct. 11	53	56	103	43
Nov. 1	81	24	105	67

In the first experiment, 40% and 16% of the fall-applied N (on October 24) was lost into the air (denitrification) by May with potassium nitrate and ammonium sulphate, respectively (Table 4). In Experiment No. 1, the soil was dry in the late fall and in winter (only slightly over the soil wilting point), but in Experiment No. 2, five cm of water was added after fertilization late in the fall. Losses to the air were increased for potassium nitrate (74%), but not for ammonium sulphate (18%).

Table 4. The fate of N-15-labelled fertilizers (112 kg N/ha) applied on October 24, with analyses of soil samples taken to 120 cm in May. Experiments No. 1 and 2 at Ellerslie.

		% of applied ^{15}N		
Experiment No.	Treatments	Lost from soil	Immobilized	Available N**
1	KNO_3-mixed	40	22	38
	$(NH_4)_2SO_4$-banded	16	18	66
2*	KNO_3-mixed	74	11	15
	$(NH_4)_2SO_4$-banded	18	30	52

* Five cm of water added immediately after fertilization
** Ammonium plus nitrate

The applied ammonium was not moved downward more than 30 cm, and the nitrate more than 60 cm. We found no tagged N between these depths and 120 cm. Thus, we concluded that leaching was not one of the mechanisms of loss in the experiments. While not shown in Table 4, the immobilization was almost counterbalanced by mineralization (that is, release of crop-available ammonium and nitrate, originating from soil organic matter). The conclusion from these two experiments was that most of the loss occurred by denitrification from the nitrate.

Three new experiments were conducted the following year (Table 5). The fertilizers were applied in bands into the frozen soil to minimize any nitrification during the winter. In addition, two of the soils (Experiments No. 4 and No. 5) were well above field capacity when they were frozen, and this high soil moisture content in the winter is not typical. In the three experiments loss by denitrification from potassium nitrate was high (59 to 87%), but low from ammonium sulphate (1 to 13%). There was immobilization from both fertilizers, with the highest value (49%) from ammonium sulphate at Experiment No. 3. In these three experiments, the immobilization was not counterbalanced by mineralization to any extent.

The conclusions from all five experiments were that the most important mechanism of losing available fertilizer N was denitrification of nitrates, followed by immobilization of ammonium and nitrates.

Table 5. The fate of ^{15}N-labelled fertilizers (112 kg N/ha applied on December 20 and 21, with analyses of soil samples taken to 150 cm in May. Experiments No. 3, 4, and 5 were at Ellerslie, Calmar, and Egremont, respectively.

Experiment No.	Treatments	% of applied ^{15}N Lost from soil	Immobilized	Available N*
3	KNO_3-band	59	16	25
	$(NH_4)_2SO_4$-band	1	49	50
4	KNO_3-band	87	7	6
	$(NH_4)_2SO_4$-band	13	14	73
5	KNO_3-band	72	15	10
	$(NH_4)_2SO_4$-band	4	15	81

*Ammonium plus nitrate

The time of application of urea fertilizer in the fall and yield of barley

The effectiveness of fall applied urea in increasing the yield or N uptake by barley was greater as the application time became later (Table 6). This was shown in 12 experiments with different application dates. Urea applied in late September was less than half as effective as urea applied in late October. Obviously, the earlier the application of urea, the greater the formation of nitrate with more denitrification in the spring. However, the amount of immobilization may have been involved as well.

Table 6. Yield increase and fertilizer N-uptake for barley with urea (56 kg N/ha) mixed into the soil. Average of 12 experiments.

Date of application	Yield increase (kg/ha)	N-uptake by barley grain (%)
Sept. 19-27	570	16
Oct. 3-12	900	26
Oct. 19-26	1210	37
Nov. 1-6	1180	39
May	1820	60

Methods of application in the fall and in the spring

The comparison of surface application, incorporation, and banding (22 cm spacing) in the fall and in the spring, with urea and ammonium nitrate, was made in our early work. As would be expected, yield increases were substantially larger with incorporation than with leaving the fertilizers on top of the ground (Table 7). Banding gave somewhat greater yield increases than incorporation. However, in the subsequent years urea incorporated (10 to 15 cm deep) in the spring was taken as the standard. This was done because incorporation was the most common method of application in the northern prairies.

Table 7. The increase in yield of barley grain from applying 56 kg of fertilizer N per ha with fall and spring application and with different methods of application, 1973-74. (The results are shown as averages of four experiments).

Fertilizer	Method of application	Yield increase (kg/ha) Fall	Spring
Ammonium nitrate	Left on top of soil	560	1220
Ammonium nitrate	Mixed into soil (10 cm deep)	760	1360
Ammonium nitrate	Banded (4 cm deep, 22 cm spacing)	930	1560
Urea	Left on top of soil	600	1020
Urea	Mixed into soil (10 cm deep)	900	1300
Urea	Banded (4 cm deep, 22 cm spacing)	1030	1400

Inhibitors of nitrification to reduce loss from fall applied fertilizers

Inhibitors of nitrification have been shown to reduce losses from fall applied ammonium-based fertilizers in the Prairie Provinces, at least sporadically (Bailey, 1982; Nyborg, Malhi and Monreal, 1980; Harapiak, 1979; and Malhi and Nyborg, 1979). Thiourea, at the rate of 44 kg/ha, and formed into pellets with urea, substantially benefited yield increases and N-uptake of barley (Table 8). The thiourea plus urea pellets were approximately 0.2 g in weight while the commercial urea pellets in treatments No. 2, 3, 6 and 7 weighed much less (0.01 to 0.02 g). As we found later, the pellet size in itself reduced the rate of nitrification.

Table 8. Yield and N-uptake of barley grain with urea and urea plus thiourea (2:1) in ten experiments in 1973-74 and 1974-75. The rate of N was 56 kg/ha for both the urea and the urea plus thiourea.

	Treatment				
No.	Fertilizer	Method	Time	Yield (kg/ha)	N-uptake (%)
1	No N			1160	
2	Urea	Mix	Fall	2040	31
3	Urea	Band	Fall	2210	36
4	Urea + T*	Mix	Fall	2540	43
5	Urea + T*	Band	Fall	2850	56
6	Urea	Mix	Spring	3040	59
7	Urea	Band	Spring	3140	63
8	Urea + T*	Mix	Spring	3040	63

* T signifies thiourea

The 10 experiments whose averages are shown in Table 8 were for the most part set out in the first half of October. Consequently, the difference between fall and spring barley yields, and differences among the treatments made in the fall were substantial.

In two other experiments (1978-79), the average yield increase from fall applied banded urea was 960 kg/ha, while with the inhibitors carbon disulphide, potassium trithiocarbonate, ATC, and N-Serve 24E added to the bands the yield increases went to 1430, 1520, 1430, and 1560 kg/ha, respectively (Nyborg and Malhi, 1980). The yield increase with spring application of urea itself was 2580 kg/ha. Four experiments conducted in previous years with ammonium trithiocarbonate and carbon disulphide added to banded aqua ammonia applied in the fall, gave an average yield increase of 520 kg/ha from the addition of the inhibitors.

In two experiments (1978-79), adding thiourea to nests of urea, or urea and N-Serve 24E to nests of aqua ammonia, did not further the large yield increases obtained with nests alone (Nyborg and Malhi, 1980). In two experiments in 1979-80, where applications were made in early October, banding of ATC with urea gave no benefit compared to banding of urea in one case but gave 360 kg/ha of grain in another. In two experiments in 1980-81, where applications of urea were made in late October, the yield increases for incorporation and banding were 680 and 1370 kg/ha, respectively; and adding N-Serve 24E to the bands did not improve the yield.

This recitation of our field results with inhibitors is to show the variability of results. Inhibitors normally need to be banded with an ammonium-based fertilizer in order to be effective. In our results, banding of the fertilizers, as compared to incorporation, sometimes gave little benefit (especially with early fall application) while other experiments gave a large benefit (especially with late fall application). That is, the yield increase from inhibitors may depend inversely on the size of the yield increase from banding of the fertilizer by itself.

There may be another factor involved in the somewhat erratic performance of the inhibitors. The inhibitors generally reduced nitrification well for both urea or aqua ammonia, but the inhibitors tended to lower the amount of ammonium released by the soil organic matter (Nyborg and Leitch, 1979; Malhi and Nyborg, 1982).

<u>Comparing incorporation, banding and nesting of fall applied urea and aqua ammonia</u>

The method of banding for urea (or other dry fertilizers) was placement in narrow bands (approximately 4 cm deep with spacings of 22 or 45 cm). The aqua ammonia was injected 10 to 12 cm. The 45 cm spacing was used after 1976-77. Nesting consisted of placing commercial fertilizers at a constricted point (not more than 2 cm in diameter) at a depth of approximately 4 cm. Usually, one point was centered on each area (45 by 45 cm), and 2.55 g of urea was placed at each point. Larger or smaller areas, with concomitant weight of fertilizer per nest, had also been used. Several times, large pellets of urea were used instead of the nests of commercial urea, and the results for nests and pellets were similar.

The results from the five nest experiments before 1978-79 were given in Nyborg, Malhi and Monreal, 1980. In those experiments, using urea at 56 or 84 kg of N/ha, fall incorporation, fall banding, fall nesting, and spring incorporation increased the yield of barley by 960, 1240, 1560, and 1830 kg/ha, respectively.

In the six experiments in 1978-79 and 1979-80, the spacings were exclusively 45 cm between bands and from nest to nest. Banding improved the yield increase of incorporation by some 40% (Table 9). With incorporation, nesting doubled the yield increase. However, fall nesting fell short of spring incorporation, especially for barley N-uptake.

In the four experiments in 1980-81 (Table 10), banding improved the yield increase of incorporation by 60%. Nesting doubled the yield increase obtained with incorporation. With the 1980-81 results, the fall nesting produced slightly more yield and N-uptake than spring incorporation. However, 1980-81 was the first time that spring incorporation was shallow. That is, shallow incorporation may be less effective than deep incorporation (10 cm or more), but that remains to be seen.

Table 9. Comparisons of incorporation, banding and nesting with urea (56 kg N/ha) for barley. Average of two experiments in 1978-79 and four in 1979-80. (Experiments set out in the fall from September 27 to October 14.)

Treatment		Yield increases	*Recovery of
Time	Method	of grain (kg/ha)	fertilizer N (%)
Fall	Incorporated	760	25
Fall	Banded	1080	36
Fall	Nested	1530	54
Spring	Incorporated	1860	72

*Recovery of N in grain plus straw

Table 10. Comparisons of incorporation, banding and nesting with urea (56 kg N/ha) for barley. Average of four experiments in 1980-81.

Treatment			Yield increases	**Recovery of
Fertilizer	Time	Method	of grain (kg/ha)	fertilizer N (%)
$Ca(NO_3)_2$	Fall	Mixed	550	17
Urea	Fall	Mixed	710	21
Urea	Fall	Banded	1130	41
Urea	Fall	Nest (or pellets)	1480	50
Urea	Spring	Mixed*	1340	44

*The spring applied urea was incorporated to approximately 4 cm deep. In previous years, the spring applied urea was incorporated to a depth of 10 cm.

**Recovery of N in grain plus straw.

Two of the 1980-81 experiments contained fall treatments with deep (15 cm) placement of pellets and with forest grade urea in bands. While not shown in Table 10, the deep pellets gave slightly more yield than the shallow pellets, and forest grade urea gave a greater yield than conventional commercial urea. These two results need to be verified by another year's field work.

Results of one of the 1980-81 experiments are not included in those given in Table 10, because the response to N was less than the usual and the yields were similar to those with calcium nitrate. Of the seventeen experiments with fall nests or pellets conducted since 1974-75, this was the only case when these techniques did not produce higher yields with fall nests than with fall incorporation.

To sum up, the last three years' of results from 10 experiments showed with no nitrogen the yield was 1480 kg/ha, while with fall application by incorporation, banding and nesting yield increases were 740, 1100, and 1510 kg/ha, respectively. These experiments were conducted, on the average, before the middle of October (October 11) and one would not expect as large a difference among these methods when the fertilizers were applied later in the fall.

Bands and nests with aqua ammonia

The increases in yields and increases in N-uptake with fall nests, rather than bands, were similar for aqua ammonia and urea (Table 11). The main point from the results in Table 11 is that nesting functioned as well with aqua ammonia as with dry urea, and this may have implications for designing field scale equipment which would apply fertilizers in nests.

Bands and nests for spring application

Banding as compared to incorporation of urea at time of seeding, gave only a small benefit, based on the ten experiments in 1974 and 1975 (Table 8). The bands were approximately 4 cm deep and spaced 22 cm apart, with deep incorporation at 10 to 15 cm. The rate of N was 56 kg/ha. The barley yield increases were 1880 and 1980 kg/ha with incorporation and banding, respectively. In the same order, the % uptake of fertilizer N in grain was 59 and 63 .

Nest placement would not be expected to have superiority over banding or deep incorporation at seeding, or soon before. We assume that usually the soil is not wet for a long enough period to cause denitrification between the first tilling of soil and the active growth of the crop. Two experiments were conducted in 1980 and two in 1981, and nests or pellets (one per 45 by 45 cm area) placed at seeding gave somewhat lower yields than incorporation. Visual examination of the early crops showed that in the nest or pellet treatments many of the plants had not yet been able to reach the N fertilizer. With the nests or pellets placed one per a 22 by 22 cm area, the yield increases were similar to those obtained with deep incorporation. In two of the experiments, the two different spacings (45 by 45 cm; and 22 by 22 cm) were used two weeks before seeding and were tilled at the time of seeding. Yield increases were similar to those obtained by deep incorporation. However, in our opinion, nest placement in the spring in the Prairie Provinces will have no advantage compared to banding, and may sometimes be slightly inferior to banding.

Table 11. Comparisons of banding and nesting with urea and aqua ammonia (56 kg N/ha) for barley. Urea was placed 4 cm deep when banded and nested and aqua ammonia at 10 cm. (Average of two experiments in 1978-79 and two experiments in 1979-80.)

Treatments			Yield of grain	*Recovery of
Fertilizer	Time	Method	(kg/ha)	fertilizer N (%)
No N			2120	
Urea	Fall	Mixed	2960	29
Urea	Fall	Banded	3220	41
Aqua NH_3	Fall	Banded	3070	36
Urea	Fall	Nested	3760	63
Aqua NH_3	Fall	Nested	3660	58
Urea	Spring	Mixed	4010	83
Aqua NH_3	Spring	Banded	3880	68

*Recovery of N in grain plus straw

Masking differences among methods and times of application

We draw attention to the large increases in yield and N-uptake from N fertilizer at most of the experiments which were conducted. On the average, the 52 experiments gave a yield increase of 1900 kg/ha of barley grain from the spring application of 56 kg/ha of N (see Table 1). The per cent uptake of fertilizer N by grain plus straw was usually more than 65%. That is because of the general N deficiency in the areas where the experiments were conducted, combined with the modest rate of N application (56 kg N/ha). Thus, differences among methods and times of application were very apparent. However, on soils that gave only small yield responses to N, or when the rate of applied N was high, differences among methods and times become masked. For example, in six experiments where the 112 kg of N/ha rate was used, there was little difference in yield increase with fall or spring additions (although the N-uptake was much higher with spring application). However, with the 56 kg/ha rate of N, the yield increases were nearly twice as much with spring than fall application.

Disposal of straw and placement of N

Until two years ago, we did not always retain the stubble at the sites of the field experiments. Some sites were in fields where the straw had been baled by the farmer. At several sites the heavy straw cover was removed to ease the difficulty of tillage in preparing the experiment in the fall. Our assumption, in accordance with the general understanding of agronomists in the Prairie Provinces, was that the presence or absence of straw made little difference to the amount of N fertilizer needed for a spring sown crop. However, observation of our own experiments suggested that with the presence of straw residue the crop was more responsive to N fertilizer.

In six experiments (two in 1979-80 and four in 1980-81), the retention of straw decreased crop yield by an average of 650 kg/ha of barley grain, even after application of 56 kg N/ha of fertilizer N. The uptake of fertilizer N by the barley grain was only half as much where the straw was kept rather than removed.

In one of the experiments, small pellets (0.35 g each) were compared to conventional urea when straw was both retained and removed. Both fertilizers were incorporated into the soil. The small pellets applied in the fall gave somewhat higher yield increases than the conventional fertilizer added in the fall (Table 12). Even with small pellets, the straw treatment fell much short of the minus straw treatments. The hope is that with bigger pellets, there will be little immobilization of fertilizer N by the straw.

Table 12. Yield of barley grain at Egremont as influenced by the disposal of the straw of the previous barley crop and the fall or spring application of urea (56 kg N/ha) in 1980-81.

Treatment No.	Straw	Fertilizer and method	Yield of grain (kg/ha)
1	Removed	None	1500 d**
2	Removed	Fall; incorporation*	2430 bc
3	Removed	Fall; small pellets (0.35 g); incorporation	2880 b
4	Removed	Spring; incorporation	3800 a
5	Retained	None	800 e
6	Retained	Fall; incorporation	1420 d
7	Retained	Fall; small pellets (0.35 g); incorporation	2110 c
8	Retained	Spring; incorporation	2520 bc

* Incorporation to a depth of 10 to 12 cm
**Values not followed by a common letter are statistically different (P=0.05)

Earlier work with urea pellets and ground straw added to a soil in the laboratory showed immobilization was much reduced by bigger pellets (Nyborg, Malhi and Monreal, 1980).

Tomar and Soper (1981) found that banding of urea as compared to broadcasting of urea resulted in more uptake of fertilizer N by barley, and less immobilization of the fertilizer N in the soil. Further, the differences were much widened where straw was added to the soil. They concluded that the yield of barley can be lowered when straw is mixed into the soil, and placement of N can be used to overcome the problem.

GENERAL DISCUSSION AND CONCLUSIONS

Fall application of urea gave approximately half as much yield increase of barley grain as did spring application. Very roughly, aqua ammonia, ammonium sulphate, and ammonium nitrate had similar differences between the fall and spring. The values for urea were an average of 52 experiments from the past eight years. It would be tempting to concoct a rule of spring application being twice as effective as fall application. However, the yield increases from fall application in relation to spring application varied greatly from experiment to experiment. The date of application in the fall played a role. Early fall application (late September) was approximately half as effective as late fall (towards the end of October or into November). Using average yield increases and setting the value of spring application as one, late fall became two-thirds and early fall one-third. That approached being a rule-of-thumb when using incorporation of urea.

The proportion of fall applied fertilizer N which has been nitrified by the time of the spring thaw is probably a fairly accurate prediction of the amount of loss by denitrification. In our N-15 experiments with fertilizer N applied as nitrate, denitrification loss was much more than immobilization. When the fertilizer N was applied as ammonium, and nitrification was kept to a minimum, from 14 to 49% of the N was immobilized. On the basis of the N-15 experiments, and yield increases and N-uptake of barley in 52 other field experiments, the recovery of fall applied N as plant available N was nearly always inferior to spring application. The inferiority of fall N was attributed mostly to nitrate instead of ammonium.

Use of bands, or more so, use of nests or large pellets, increased the performance of fall N. In the fall, incorporation, banding, and nesting gave average yield increases from 15 experiments, of 810, 1140, and 1520 kg/ha, respectively, while spring incorporation showed 1720 kg/ha. The 15 experiments were set out on October 15 on the average, and with the later applications there was a tendency for the yield increases from banding to become closer to the increases from nesting. In any case, placement of fall N (and especially nesting) had a double effect on reducing losses of available N: slowing nitrification and thus denitrification; and lessening immobilization. The way in which placement of fertilizer N reduces immobilization is through retaining the fertilizer N as ammonium (rather than the mobile nitrate) so that the applied N remains at the constricted bands or nests away from contact with the soil and residues.

Inhibitors of nitrification, which were applied with banded fall N, were variable in their effect on yield increases. We speculate that their effect on increases in yield would have been greater if the inhibitors had been consistently applied early in the fall. However, our results suggested that several inhibitors slowed the release of available nitrogen from the soil itself.

In most of our field experiments, yield increases of barley grain were 1500 to 2500 kg/ha from the standard rate of N application of 56 kg/ha in the spring. That is to say, the soils were very responsive to N. The experiments were conducted in an area (north-central Alberta) or at sites which had soils which were low in soil test N at the time of seeding (usually less than 25 kg/ha of nitrate-N in the 0-60 cm depth). Thus, differences in time or method of application of N fertilizer were rather easily shown by yield response (or even more easily shown by N uptake). With less responsive soils and/or high rates of N fertilizers, any differences in yield increases among time and method of application became small. However, differences were still found if they were based on N uptake. The point here is fairly obvious, namely that unless soils are quite responsive to fertilizer N and only modest amounts of fertilizer N are applied, differences in yield increases become masked.

The results obtained in this work on differences among times of N application and among methods of application were obtained mostly in north-central Alberta, and do not necessarily pertain to the southern portion of the Province. For most of our experiments, the topsoil became saturated as the snow melted in the spring, and apparently denitrification took place with sizeable losses of nitrate. There is a question of the occurence of saturated soils in the spring with accompanying denitrification in southern Alberta.

The recent work of Harapiak, Timmermans and Flore (1982), generally showed smaller yield increases from N applied in the fall rather than the spring, when broadcast application was used. With banding or "deep banding", there was little difference between fall and spring. However, those workers brought other factors to bear on the application of N: the effect of time and methods of P application; and the amount of soil moisture available to the crop. Our own work does not consider these factors, and the standard spring application of N was only incorporation into the soils.

The present work corroborates the work of others in showing band placement of N fertilizer usually produces more yield than incorporation or broadcasting. There are now suitable field-scale implements to place N fertilizers in bands. Nest placement or use of large pellets are superior to bands for fall application of N fertilizers, but suitable implements are not now available. Further, the large pellets (2 to 3 g) are not commercially available to accomodate these methods of application.

The conclusions from our work are simple: in our area, fall applied N was only about half as effective as spring applied N for increasing crop yield and N uptake when the fertilizer N was incorporated; the inferiority of fall applied N increased as the application was made earlier, and that was because there was more nitrification as the ammonium-based fertilizers were added earlier in the fall; fall banding (especially late fall banding) and more so nesting, greatly increased the effectiveness of fall N; fall nesting approached spring incorporation in effectiveness of fertilizer N; and fall applied ammonium-based fertilizer placed in nests survived most of the loss from denitrification and probably the tie-up in crop residues.

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