Potential Uses for Agrotain and Polymer Coated Products

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INTRODUCTION

Urea is the major granular fertilizer used on the Canadian prairies, because it has a high N analysis, is easy and safe to handle and store and is relatively low cost. Urea is readily soluble in water and can be used in the formulation of urea ammonium nitrate (UAN) and compound fertilizers. But, urea has two major drawbacks:

1) It is subject to volatilization losses if surface applied;
2) It can produce severe seedling damage if seed-placed levels are too high.

Banding or broadcast-incorporation application of urea will reduce seedling toxicity and volatilization loss, but this requires extra trips across the field, with extra costs and possible loss of moisture and seed-bed quality. With reduced tillage systems, the soil disturbance associated with incorporation or fertilizer banding may not be desirable, while in perennial forages or in forestry, these application methods may not be possible. Urease inhibitors may be an economical option to increase the efficiency of surface applications and reduce the toxicity of seed-placed urea. Controlled release coated N may also be effective in reducing seedling damage and improving N use efficiency under reduced tillage management. Agrotain is a commercially available urease inhibitor containing the active ingredient n-(n-butyl) thiophosphoric triamide (NBPT). A number of coated N products are available for high value crops, but are not yet economically viable for small grain or oilseed production.

For any urease inhibitor or coated product to prove effective in a crop production system, several conditions must be met. Firstly, the urease inhibitor or coated product must work over a range of soil and environmental conditions. Secondly, potential seedling damage or losses of urea-containing fertilizers must be sufficiently large to reduce crop yield or protein content. Thirdly, the product must not damage the crop, consumers of the crop or environmental health. Fourthly, the benefits must be enough to justify the cost of the product.

UREA REACTIONS IN THE SOIL

Urea itself is not directly damaging to seedlings or subject to volatilization loss. When urea is applied to the soil, it rapidly converts to ammonia (NH_3) in a reaction catalyzed by the enzyme urease. The more rapidly the urea converts, the higher the concentration of NH_3 present. The NH_3 can be lost to the atmosphere when it remains near the soil surface. The NH_3 will also partially convert to NH_4^+ and both NH_3 and NH_4^+ can damage germinating seedlings. Seedling damage and volatilization loss both increase with increasing concentration of NH_3 in the solution The ammonium in the soil solution will also convert over time to nitrate. Nitrate can be lost by denitrification and leaching, particularly under wet soil conditions. In addition, both ammonium and nitrate can be tied up through immobilization by microorganisms in the soil as they decompose low-N organic residues. The amount and path of N losses will fertilizer source, rate, placement and timing as well as with soil properties and environmental conditions

FACTORS AFFECTING VOLATILE LOSSES OF UREA

Ammonia volatilization will increase with increasing concentration of NH_3 at the soil surface. Ammonia concentration in the soil solution increases with increases in soil pH and carbonate content, rate of urea hydrolysis, and fertilizer rate. Ammonia losses tend to be higher from course- than fine-textured soils, since fine-textures soils have a higher cation exchange capacity and can hold more NH_4 out of solution. Losses may be higher when the urea is applied to soil covered with organic residue as compared to bare soil, as hydrolysis of urea on the residue particles may increase NH_3 release. The residues may also keep the soil surface moist, allowing volatilization to continue for longer. Windy conditions will increase moisture loss and volatilization.

Moisture effects will vary depending on the situation. Granules must dissolve before losses occur, so if granules are broadcast on the soil and the soil dries before granule dissolution, volatilization will be arrested. Once the granules have dissolved, volatilization generally increases with evaporation of water from the soil, since the moisture loss will increase concentration of NH_3 at the soil surface. Therefore, losses will tend to be high if urea is applied to a moist soil. Light rains or heavy dews that keep the soil moist but do not move the fertilizer into the soil will increase volatilization loss. Significant rainfall or irrigation after fertilizer application will reduce volatilization loss, since the water will both dilute the NH_3 and carry the uncharged urea into the soil, reducing NH_3 concentration at the soil surface. Factors which increase evaporation will tend to increase volatilization losses, by moving NH_3 to the soil surface and increasing the concentration of NH_3 in the soil solution.

REDUCING LOSSES FROM SURFACE-APPLIED UREA OR UAN

Volatile losses of NH_3 from urea-containing fertilizers will increase as the concentration of NH_3 at the soil surface increases. Concentration of NH_3 at the soil surface increases as urea hydrolysis increases, through the action of the urease enzyme. Inhibiting urease activity slows the conversion of urea to NH_4^+ and retains the N in the urea form for a longer period. This will reduce the concentration of NH_4^+ present in the soil solution, reducing the potential for volatilization losses. Slowing the hydrolysis of urea allows more time for the urea to diffuse away from the application site or for precipitation or irrigation to dilute urea and NH_4^+ concentration at the soil surface and increase its dispersion in the soil. Diffusion and leaching can move the fertilizer through surface residue and into the soil, where it will be less likely to be lost by volatilization and immobilization.

EFFECTS ON UREASE ACTIVITY AND NH_3 VOLATILIZATION

The effectiveness of urease inhibitors in reducing urease activity can be evaluated by measuring volatilization of NH_3 from plots treated with urea-containing fertilizers, with and without the inhibitor. In studies conducted at Brandon Research Centre, Agrotain reduced NH_3 volatilization from mulched soils when applied with either urea or urea ammonium nitrate (Figure 1). Total volatile loss of N from urea over 7 days in two separate studies was reduced from 40 mg to 2 mg and from 88 mg to 12 mg by the addition of Agrotain. Agrotain delays urea hydrolysis, but does not eliminate it, so the effectiveness of Agrotain decreases with time after application. Loss of ammonia from the Agrotain treated urea began to occur 4 to 7 days after application. Use of Agrotain delays the time of maximum rate of volatilization, allowing diffusion of the urea downward and increasing the chance of rain moving the urea into the soil, where it would be protected from volatilization.

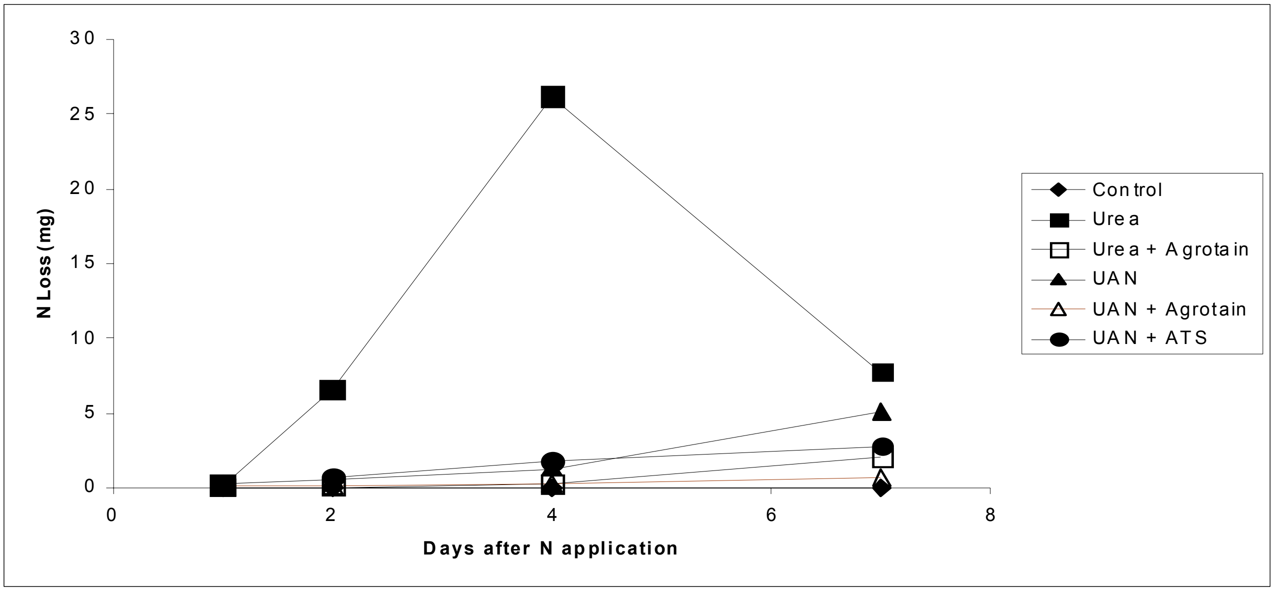

Figure 1: Volatilization losses from urea and UAN, with and without treatment with Agrotain, over a 7 day period

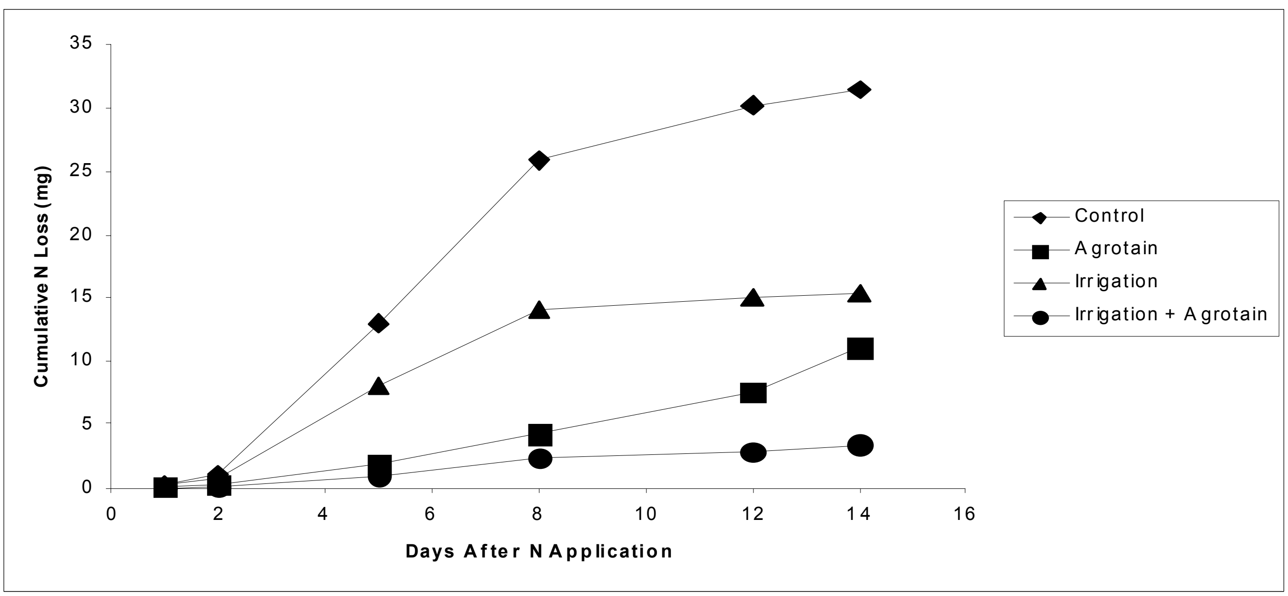

Figure 2: Volatilization loss from surface application of urea as affected by application of Agrotain, with and without addition of 2.0 cm of water on day 4 and day 7

Rainfall will also reduce volatilization losses. In studies by Christine Rawluk, addition of 2.0 cm simulated rainfall on day 4 after N application reduced but did not eliminate volatilization

(Figure 2). When an additional 2.0 cm of rainfall was applied on day 7, volatilization was essentially eliminated. Use of Agrotain was more effective than addition of 2.0 cm of rainfall in reducing volatilization. Lowest volatilization occurred when rainfall was added to Agrotain-treated urea.

REDUCING SEEDLING DAMAGE

Use of Agrotain or controlled release fertilizers may also increase the amount of fertilizer that can safely be placed with the seed. Seed-placement allows seeding and fertilizer application in a single operation, reducing labour and operational costs. It reduces soil disturbance, as compared to incorporated or banded applications and reduces equipment costs and draft requirements as compared to side-banded applications. As a specialized form of banding, it has the benefits of reduced volatilization and improved fertilizer use efficiency of an in-soil band. However, seed-placed urea-containing fertilizers can lead to severe seedling damage when applied at rates required to optimize crop yield. In some cases, side-banded N fertilizers may also cause toxicity problems, if the separation between the seed and fertilizer is insufficient. Seedling damage from seed-placed fertilizers is related to the concentration of NH_3/NH_4^+ in contact with the germinating seedling. Damage will increase with decreasing moisture levels during germination; so drying conditions after seeding will increase damage, while significant rainfall after seeding will decrease damage. Damage tends to be greater on coarse-textured soils or soils with low organic matter content because of their lower CEC and lower water-holding capacity. Increasing carbonate content and pH may increase damage, by increasing the proportion of NH_3 present and the subsequent NH_3 toxicity. Damage may be decreased by any action that decreases the concentration of urea in contact with the seed, such as increasing the width of the row over which the seed and fertilizer are spread, decreasing row spacing, side-banding, or decreasing fertilizer rate.

Table 1: Effect of seed-placed urea, with and without Agrotain, on stand density (plants/metre) and grain yield (tonnes/ha) of barley on a fine sandy loam, 1994-96.

N Rate	Stand		Grain Yield		Straw Yield	
(kg ha^{-1})	No Agrotain	Agrotain	No Agrotain	Agrotain	No Agrotain	Agrotain
0	24.9	24.9	2870	2870	2710	2710
20	26.1	27.0	3091	3095	2940	2773
40	24.0	25.3	3165	3462	2854	3343
60	19.9	23.5	3244	3283	3170	3090
80	18.7	23.4	3008	3298	3409	3264
100	15.3	23.4	2741	3910	3053	3513

Slowing the release of urea from the fertilizer granule can reduce the concentration of fertilizer in contact with the germinating seedling. Since seedling damage is caused by NH_3 and NH_4^+ rather than directly by the urea, slowing the hydrolysis of urea to reduce the concentration of NH_4^+ and NH_3 in contact with the seedling could also reduce toxicity. Slower release or slower hydrolysis also allows more time for the urea to diffuse away from the seed-row, decreasing NH_3 and salt concentration in the seed-row.

Studies over three years on two soils near Brandon evaluated the effect of seed-placed urea on barley stand density and grain yield (Tables 1 and 2). In the absence of Agrotain, barley stand density declined on both soils when urea was seed-placed at levels above 40 kg N ha^{-1} on the fine sandy loam soil and 60 kg N ha^{-1} on the clay loam soil. With Agrotain, stand decline from seed-placed urea was slight.

Table 2: Effect of seed-placed urea, with (UI) and without (NI) a urease inhibitor, on stand density (plants/metre) and grain yield (tonnes/ha) of barley on a clay loam soil, 1994-96.

N Rate	Stand		Grain Yield		Straw Yield	
(kg ha^{-1})	No Agrotain	Agrotain	No Agrotain	Agrotain	No Agrotain	Agrotain
0	24.8	24.8	2517	2517	2927	2927
20	23.9	25.9	2691	2699	2870	2930
40	23.4	25.9	2555	2905	3225	3763
60	22.1	25.0	2991	3232	3840	3783
80	18.9	25.5	2652	3401	3995	4005
100	16.1	22.8	2856	3172	4653	4313

On the fine sandy loam soil, grain yield was similar with and without the inhibitor until N level exceeded 60 kg N ha^{-1}. Above this level, grain yield declined with increasing N applications in the absence of Agrotain, but not when Agrotain was added. On the clay loam, grain yield was higher when the inhibitor was used when N levels exceeded 20 Kg N ha^{-1} (Table 2). From this study it appears that use of Agrotain can reduce the risk of seedling damage from seed-placed urea. On both soils, the inhibitor Agrotain reduced seedling damage and increased grain yield of barley at N levels up to 100 kg N ha^{-1}. This would be of particular benefit in a zero-till system, where disturbance from band application of fertilizer may be undesirable.

Table 3: Effect of rate of urea, Agrotain-treated urea, and controlled release urea (CRU) on stand density and grain yield of durum wheat (Mahli et al. 2003)

N rate	Stand Density --------------(plants $meter^{-1}$)---------------			Grain Yield ---------------------(kg ha^{-1})--------------------		
Kg ha^{-1}	Urea	Agrotain	CRU	Urea	Agrotain	CRU
28	88.2	90.6	93.4	1491	1844	1877
56	47.3	88.9	95.5	1169	2249	2300
84	34.6	79.4	83.5	1075	2571	2519
112	30.2	67.8	78.5	1028	2365	2571
140	28.7	61.5	70.4	891	2309	2414
Mean	45.8	77.6	84.3	1131	2268	2336

In other studies conducted by Malhi et al. near Melfort, controlled release urea forms were even more effective than Agrotain at reducing seedling damage from seed-placed urea. Stand density and final grain yield were reduced by high rates of seed-placed urea. Use of Agrotain or the polymer-coated CRU product produced consistently higher stand density and grain yield than the untreated urea.

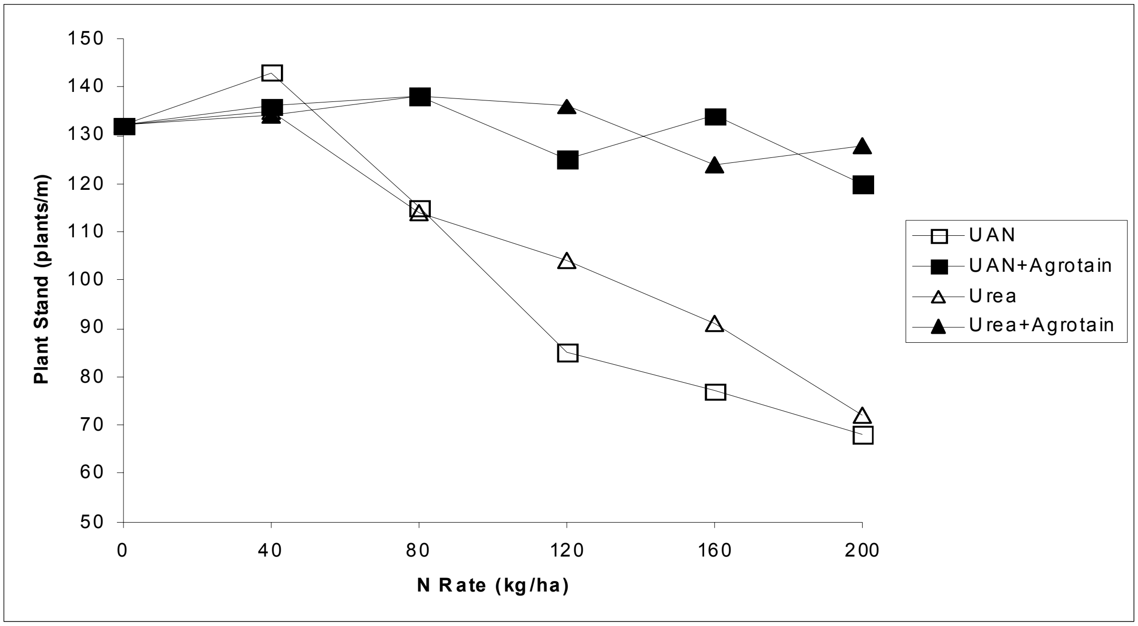

Figure 3. Effect of urea and UAN fertilizer, side-banded with and without Agrotain, on stand density of canola on a clay loam soil (average of three years).

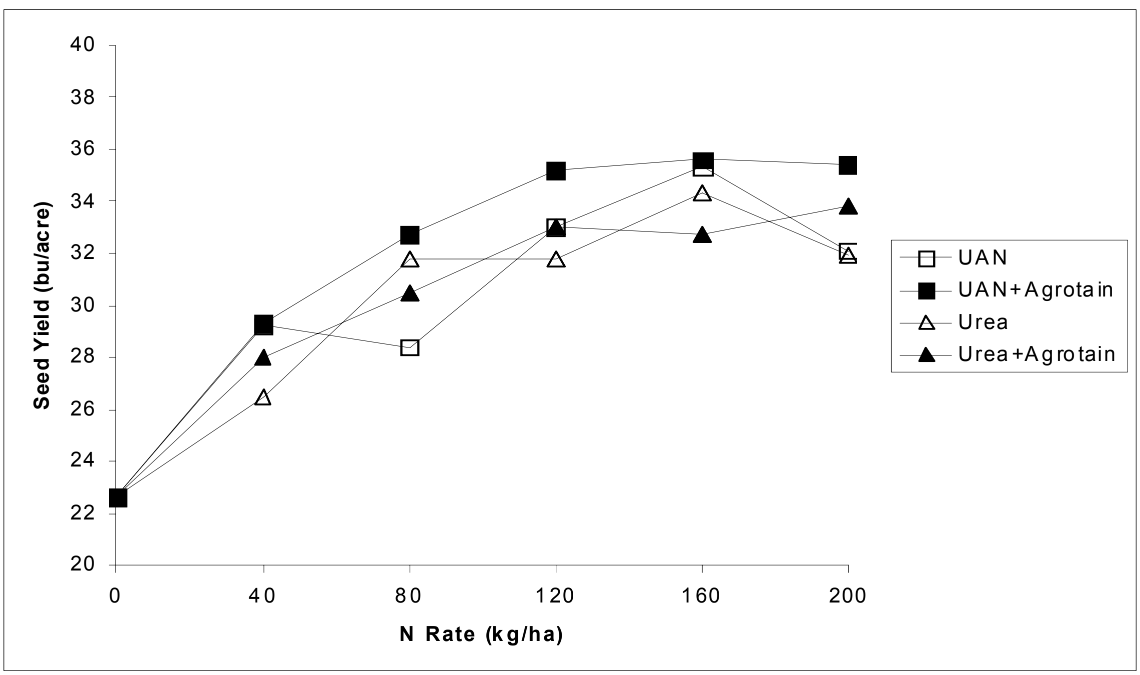

Figure 4. Effect of urea and UAN fertilizer, side-banded with and without Agrotain, on seed yield of canola on a clay loam soil (average of three years)

Fertilizer is often side-banded banded away from the seed to try to avoid seedling damage in a one-pass seeding and fertilizing system. However, damage may still occur if the target placement between the seed and fertilizer is too close or if the separation between seed and fertilizer fails, particularly with high fertilizer rates, wide row spacing and sensitive crops. In field studies over three years, stand density of canola was reduced on a clay loam soil when either urea or UAN was side-banded with a narrow hoe opener on 20 cm row spacing (Figure 3). Agrotain was able to reduce seedling damage with both urea and UAN. Canola has a good ability to recover from seedling damage, so the effect on final seed yield was less than the effect on stand density (Figure 4). However, there was a yield advantage to use of Agrotain with urea and UAN at the highest rate of N application.

CROP YIELD AND N USE EFFICIENCY

Controlling the release or hydrolysis of fertilizer will not increase crop yields and N recovery under all circumstances. Reducing volatilization losses from surface-applied urea-containing fertilizers will only increase yield if: a) Nitrogen fertility is limiting to crop yield and b) Volatilization losses from the applied fertilizer are sufficient to reduce crop yield. Similarly, reducing seedling damage will only increase yield if the damage is sufficient to reduce crop growth and competitiveness, or to delay maturity. Maximum benefits of either Agrotain treatment or controlled release fertilizers can therefore be expected where crop yield potential is high, soil N levels are low and soil and environmental conditions promote extensive nitrogen losses or seedling damage. Potential for N losses by volatilization will be greater if the fertilizer is broadcast and left unincorporated, as might be done under reduced tillage systems.

Studies at Brandon compared broadcast, banded and seed-placed applications of 50 kg N ha^{-1}, with and without the addition of Agrotain under zero (ZT) and conventional (CT) tillage management in barley on two soil types near Brandon (Table 4). A relatively low rate of N (50 kg N ha^{-1}) was used to ensure that the crop would be under N stress, so differences in efficiency would be apparent. Therefore, crop yields were generally low, as the N level was restricting yield.

On the clay loam soil, grain yield increased by 20 to 30% with N application (Table 4). Under ZT, grain yield tended to be higher with the use of Agrotain than in its absence, with the greatest effects when the fertilizer was broadcast or fall banded. Use of the Agrotain with fall–banded fertilizer on the clay loam soil may slow conversion to ammonium and then to nitrate, reducing potential for denitrification losses over the winter and early spring. This would be more important if soils are slow to cool in the fall, as may occur under ZT. Under CT, there was no significant effect of use of Agrotain. Under CT, highest grain yields were obtained with seed-placed or fall band applications, while under ZT, highest grain yields were obtained with fall-band or broadcast applications, if Agrotain was used. On the fine sandy loam soil, barley yield was increased by N application on both the CT and the ZT, but the effect was much greater under ZT, where yield potential was apparently increased by the extra moisture conservation. Grain yields tended to be reduced on this soil when Agrotain was used with banded fertilizer applications and increased when used with surface urea applications, particularly under CT. The increase in yield with use of Agrotain with broadcast urea was greater under ZT than CT.

Table 4: Grain yield (T ha^{-1}) of barley as affected by placement of 50 kg N ha^{-1} as urea, with and without Agrotain under conventional (CT) and zero tillage (ZT) on a clay loam and fine sandy loam soil (1994-96)

	Clay Loam				Fine Sandy Loam			
	CT		ZT		CT		ZT	
Treatment	No Agrotain	Agrotain	No Agrotain	Agrotain	No Agrotain	Agrotain	No Agrotain	Agrotain
Control	2573	2573	2298	2298	2019	2019	2125	2125
Broadcast	3086	2934	2937	3265	2053	2145	2325	2694
Pre-Plant Band	3083	3068	3006	3025	2244	2024	2819	2664
Seed-placed	3238	3083	2920	2948	2463	2064	2913	2648
Fall Band	3115	3119	2999	3207	2404	2257	3256	2839

Protein content and fertilizer use efficacy can be enhanced by use of Agrotain or controlled release fertilizers. In studies conducted in Saskatchewan, Mahli et al. (2003) found that use of Agrotain or CRU increased protein content and fertilizer use efficiency as compared to untreated urea when seed-placed (Table 5). This effect was likely primarily due to the reduction in seedling damage. However, slower release of N from the controlled release product could also have an additional benefit of "metering" the N to the plant over the growing season. If the N release is matched to crop uptake, losses of N by immobilization, denitrification and leaching should be minimized. Release of N during grain filling should also increase crop protein content. However, there may be situations when release of N from the controlled release product may be too slow and limit crop yield. This has occurred in some wheat studies. Blending some controlled release product with untreated urea may help provide sufficient N for early wheat growth while still maintaining the benefits of the slow N release. This would also lower the cost of the controlled release product.

Table 5: Effect of rate of urea, Agrotain-treated urea, and controlled release urea (CRU) on protein content and nitrogen uptake of durum wheat (Mahli et al. 2003)

N rate	Protein			Nitrogen Uptake		
	-------------------------(%)------------------------			---------------------(kg ha^{-1})--------------------		
Kg ha^{-1}	Urea	Agrotain	CRU	Urea	Agrotain	CRU
28	8.4	8.4	8.5	22.0	27.0	27.9
56	9.9	9.3	9.3	20.2	36.7	37.5
84	10.1	11.0	11.0	19.0	49.5	48.4
112	12.8	13.9	13.2	23.2	57.6	59.3
140	14.3	15.2	14.8	22.2	61.9	62.8
Mean	11.1	11.6	11.4	21.3	46.5	47.2

While the use of Agrotain shows promise in improving the fertilizer use efficiency of urea-containing fertilizers under no-till systems, it is not always effective. When fertilizers are banded under CT, Agrotain may be of no benefit, as shown in Table 4. Where environmental conditions are wet during seeding, losses of ammonia from surface applications may be minimal, and the Agrotain would not be required. Where dry conditions over the summer lead to very low crop yield, the requirement for N is decreased and conserving N from volatilization would not increase in crop yield. These conditions occurred in studies conducted from 1995 to 1997 on no-till wheat, at two locations near Brandon (Table 6). Treatments of UAN and urea were applied as broadcast or dribble-banded applications with and without Agrotain. Ammonium thiosulphate was also tested as a urease inhibitor in the UAN solution. On the fine sandy loam soil, where drought stress was severe, there was no response to N application at all. On the clay loam soil, banded application of urea or UAN was more effective than broadcast applications, particularly with UAN and particularly where no Agrotain was used. There was no overall benefit to using Agrotain in these studies, although use of Agrotain did improve the yields with broadcast UAN. Volatile losses of N from broadcast UAN were likely high because the UAN would begin volatilizing immediately upon application, as it was in solution already. Also, the UAN solution would adhere to surface residue, where urease activity is high and so rate of loss would be rapid initially. There was no benefit to using ammonium thiosulphate as an inhibitor in this study.

Table 6: Grain and straw yield of wheat as influenced by applications of urea or urea ammonium nitrate (50 kg N ha-1), with or without the use of Agrotain or ammonium thiosulphate as a urease inhibitor (1995-97).

	Grain Yield			Straw Yield		
	----------------------------t ha^{-1}			------------------------------------		
Treatment	FSL	CL	Mean	FSL	CL	Mean
1) Control	1.77	2.52	2.15	2.48	3.98	3.23
2) Urea, broadcast	1.95	2.85	2.40	2.72	4.91	3.82
3) UAN, broadcast	1.71	2.53	2.12	2.23	4.45	3.34
4) ATS, broadcast	1.68	2.67	2.18	2.44	4.04	3.24
5) Urea + Agrotain, broadcast	1.90	2.88	2.39	2.59	4.85	3.72
6) UAN + Agrotain, broadcast	1.88	2.97	2.43	2.69	4.65	3.67
7) UAN + ATS, broadcast	1.81	2.81	2.31	2.81	4.51	3.66
8) Urea, dribble	1.84	3.06	2.45	2.74	5.18	3.96
9) UAN, dribble	1.90	2.93	2.42	2.65	4.83	3.74
10) ATS, dribble	1.76	2.38	2.07	2.53	3.79	3.16
11) Urea + Agrotain, dribble	2.00	3.01	2.51	2.69	5.19	3.94
12) UAN + Agrotain, dribble	1.79	2.83	2.31	2.80	4.77	3.79
13) UAN + ATS, dribble	1.56	2.81	2.19	2.36	5.15	3.76
Mean	1.81	2.79	2.30	2.59	4.64	3.62

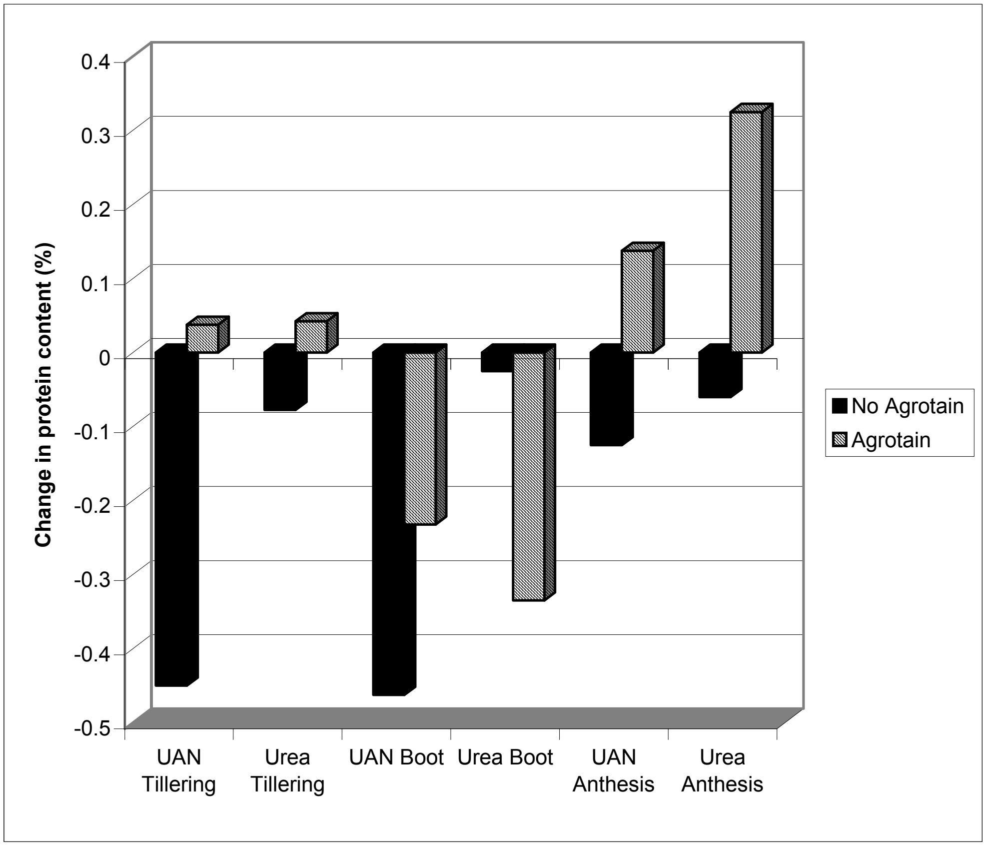

Figure 5: Difference in protein content between applying 75 kg N ha^{-1} at seeding and applying 60 kg N ha^{-1} at seeding and 15 kg N ha^{-1} as a foliar spray UAN or surface broadcast urea, with or without Agrotain, at various crop stages (Mean of 4 site years of data). Difference was calculated as protein with in-crop N minus protein with all N at seeding.

Environmental conditions are very important in determining volatilization losses and so in influencing the effectiveness of Agrotain with surface applications. Since weather conditions normally become warmer and drier as we get later in the spring, risk of volatilization losses and seedling damage increases as fertilizer applications and seeding operations are delayed to later in May or into June. Therefore, there is likely to be less benefit of using Agrotain early in the season and increasingly greater benefits as the season progresses.

Again, because of the effect of temperature and moisture, use of Agrotain may be beneficial when in-crop applications of fertilizer are being applied either to top-up fertilizer rates when growing conditions improve after seeding, or to enhance protein content of wheat in anticipation of a protein premium. Since these types of applications occur when the weather in generally hotter and drier, use of Agrotain may reduce losses and enhance the effectiveness of this type of application. In studies conducted on two soil types near Brandon, there was generally little advantage to applying some N in-crop as compared to all N at the time of seedling (Figure 5). However, addition of Agrotain with the in-crop application generally increased protein content, presumably by reducing the volatilization losses of the in-crop N.

CONCLUSIONS

Use of urease inhibitors or controlled release urea shows promise for use in crop production systems in the Canadian prairies. Where environmental conditions are conducive to NH_3 volatilization, delaying hydrolysis can reduce concentration of NH_3 at the soil surface, reducing the amount of fertilizer urea lost from surface applications. Immobilization of surface-applied urea may also be reduced, by allowing movement of urea below the surface residues, where it would be less prone to tie-up as the residues decomposed. In field studies near Brandon, use of the urease inhibitor Agrotain generally increased crop yield when applied with broadcast urea. Under CT or when the urea was banded, there was generally no benefit of Agrotain. Use of controlled release urea products may also reduce fertilizer losses, improve crop yield and enhance protein content by matching N release to crop requirements and uptake.

Damage from seed-placed urea-containing fertilizers can be reduced by use of Agrotain or controlled release urea. In studies with barley, stand density and grain yield were consistently higher when Agrotain was applied with high rates of seed-placed urea than in the absence of Agrotain. Agrotain also reduced seedling damage in canola from side-banded urea or UAN. Controlled release products tended to be more effective than the Agrotain in reducing seedling damage. A benefit from using either controlled release products or Agrotain will only occur where damage from seed-placed fertilizer is sufficient to produce a loss in yield, grade, maturity or competitiveness with weeds.

A benefit from use of Agrotain or controlled release urea cannot be expected every year, since volatile losses and yield response to N fertilizer are both greatly affected by environmental conditions. Increases in yield by the use of Agrotain with surface-applied urea-containing fertilizers will only occur where: a) N deficiencies are limiting yield; b) Volatile losses of urea-containing fertilizers would be significant; and c) The crop is able to respond to N preserved by reducing volatilization losses. Use of Agrotain is likely to be more beneficial under reduced tillage than conventional tillage systems.

Although benefits from use of Agrotain and controlled release urea, either with surface-applied or seed-placed urea-containing fertilizers, will not occur every year, due to variation in environmental conditions, they may be a useful tool in managing risk. Since we cannot effectively predict far in advance when environmental conditions will occur that will lead to volatilization losses or seedling damage, use of Agrotain and controlled release products may be a tool to help to reduce the risk of damage, if weather conditions become detrimental.