Surface versus banded nitrogen: Do new products close the gap?

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Introduction

An effective nitrogen management program plays an essential role in the economic production of a high-yielding, high quality crop. In-soil banding at or near the time is seeding is considered a best management practice for nitrogen fertilization on the prairies as it can reduce the risk of nitrogen losses by volatilization, immobilization, denitrification and leaching. However, with increasing farm size, many producers are moving away from in-soil banded nitrogen and using surface applications to increase speed of operations and reduce application costs. Various enhanced efficiency fertilizers are available that are designed to reduce nitrogen losses from surface applications and so improve nitrogen use efficiency and crop yield. But, are surface applied enhanced efficiency fertilizers as efficient as in-soil band applications?

Pathways of Nutrient Loss

Most chemical N fertilizers supply N as ammonium (NH_4^+), nitrate (NO_3^-), or as urea, which converts rapidly to NH_4^+ through the action of the urease enzyme. The four major pathways of nitrogen loss from the soil-pant system are volatilization, immobilization, leaching and denitrification, although nitrogen can also be lost through erosion and surface runoff (**Figure 1).**

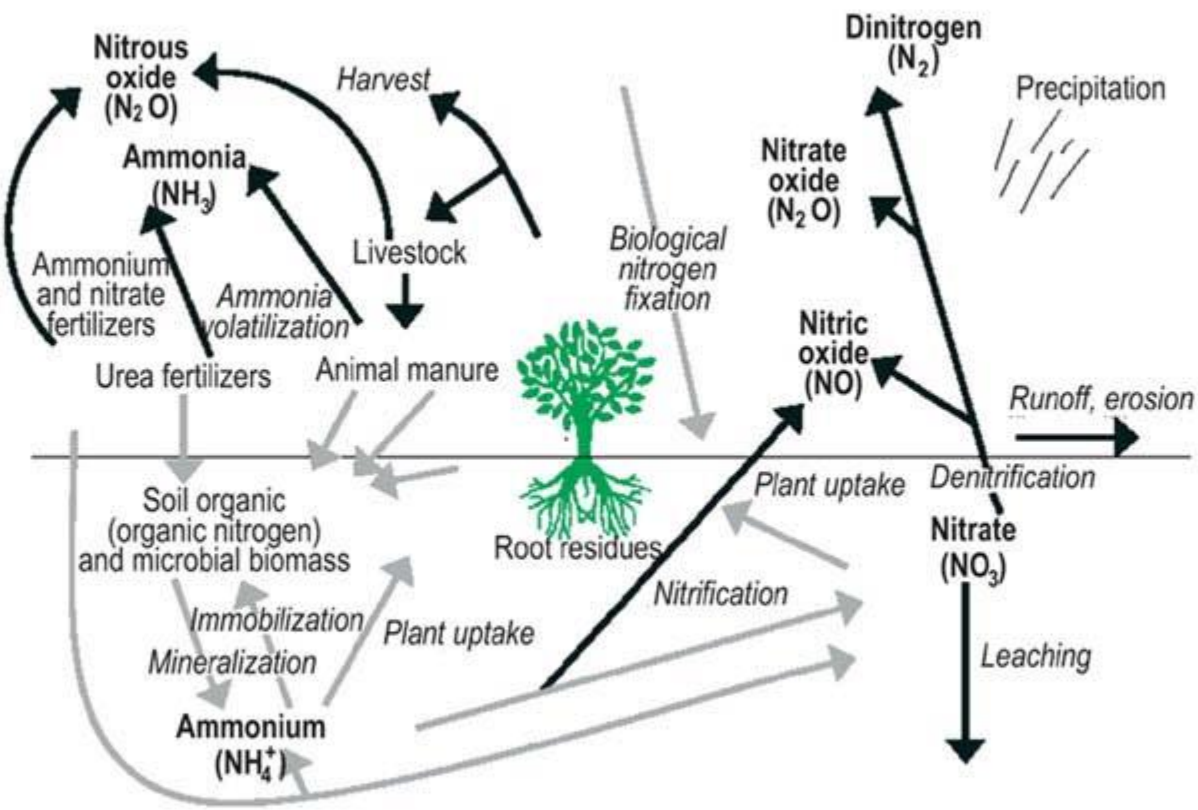

Figure 1: Simplified nitrogen cycle (Roy et al. 2003).

If ammonium or ammonium-producing fertilizers are applied on or near the soil surface, they may be lost from the plant-soil system through ammonia volatilization. Surface applications can also be at risk from erosion and run-off, especially during the spring snowmelt. Both ammonium and nitrate may be utilized by soil microorganisms and converted to organic forms through immobilization. Immobilization can be particularly high when the nutrients are in contact with low-nitrogen crop residues. Within the soil, the major pathways of loss are by denitrification and leaching (Harrison and Webb 2001). Nitrate nutrient sources can be lost by leaching and denitrification losses as soon as they enter the soil. However, if an ammonium or ammonium–producing source of N is used, such as anhydrous ammonia or urea, the ammonium must convert to nitrate before significant losses occur. As soil temperature and soil moisture increase, ammonium converts more rapidly to nitrate, thus increasing the risk of denitrification and leaching (Tiessen et al. 2006; Tiessen et al. 2008; Tiessen et al. 2005).

The greater the N loss from the soil-plant system, the lower is the N recovery in the crop. The potential magnitude and pathways of N loss will depend on the soil type and environmental conditions. Therefore, it is important to evaluate the soil and environmental conditions in a cropping system to determine the risk of losses by immobilization, volatilisation, denitrification, leaching, erosion and run-off to select a management package to minimize losses and optimise the economics of production.

Banding To Reduce Nitrogen Losses

Banding has long been recommended as a key management practice to minimise nutrient losses from the system, optimize nutrient use efficiency and increase crop yield and quality (Grant et al. 2002; Malhi et al. 2001). Nitrogen bands may be placed in the soil in the autumn before the ground freezes, in the spring prior to seeding, or at the time of seeding in a one-pass seeding. During the seeding operation, the N fertilizer bands may be placed directly with the seed, or in a separate band at varying distances from the seed-row, as long care is taken to avoid placing too much N fertilizer too close to the seed in the seed-row.

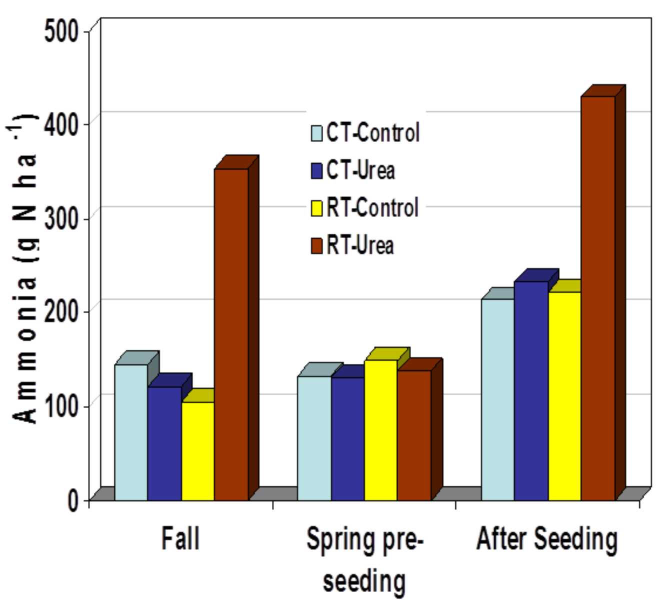

Figure 2: In-soil banding leads to very low volatilization losses from urea (Grant et al. unpublished)

In-soil banding of N fertilizer will reduce volatilization (Figure 2) and immobilization (Figure 3) losses, by placing the N below the soil surface and separated from crop residue (Grant et al. 2012; Malhi et al. 2001; Tomar and Soper 1987). In-soil banding also reduces the risk of loss by erosion and run-off by placing the fertilizer below the affected surface soil. Banding an ammonium source of N will also reduce denitrification and leaching losses, by creating a small zone with a high nutrient concentration that limits contact between the nutrient and the soil microorganisms, slowing the conversion from ammonium to nitrate. Under dry conditions, N fertilizer bands, even if applied in the autumn, can remain in the soil until plant uptake without significant losses, although under wet, warm conditions, losses may be considerable (Figure 4) (Tiessen et al. 2006; Tiessen et al. 2008; Tiessen et al. 2005). Therefore, banded applications of nitrogen tend to be significantly more efficient than broadcast applications for any particular time of application (Table 1).

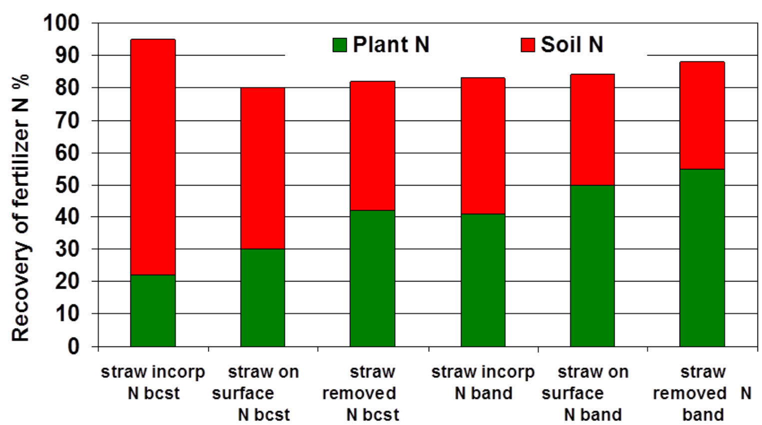

Figure 3: Banding reduces immobilization by limiting the contact between the fertilizer and the low-nitrogen crop residues (Tomar and Soper 1987)

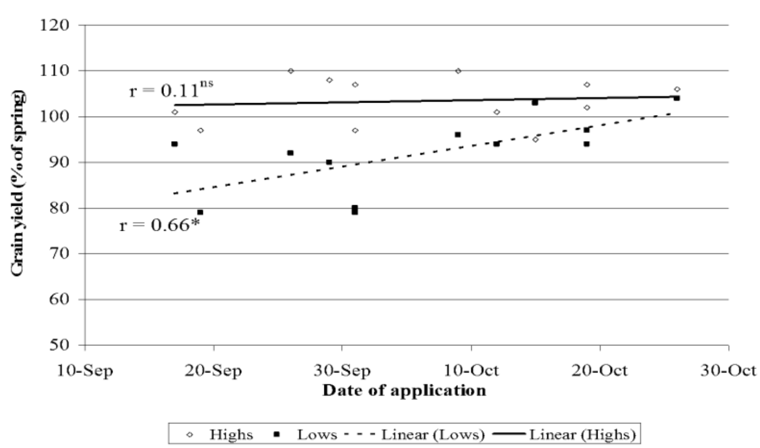

Figure 4. Grain yield as a percentage of that of spring-banded nitrogen for various timings of fall-banded application on upper and lower slope positions (Tiessen et al. 2005).

Table 1: Effect of timing and placement of urea application on relative nitrogen use efficiency (http://www.gov.mb.ca/agriculture/crops/soil-fertility/soil-fertility-guide/nitrogen.html#placement, accessed December 1, 2014).

Time and Method	Relative Values
Spring Broadcast	**100%**
Spring Banded	**120%**
Fall Broadcast	**80%**
Fall Banded	**100%**

While in-soil banding, especially at the time of seeding, is very effective at increasing nutrient use efficiency, it may create other operational problems. Farm sizes have been increasing over the years and with larger farms, operators feel the need to cover more acres in a shorter time. Surface applications can be much faster than in-soil banded applications. In particular, handling fertilizer during one-pass seeding and fertilizing can slow the seeding operation, and possibly mean that some fields are seeded late, or not at all. Under wet conditions, it may be possible to get on the field earlier without as much compaction if fertilizer is not being carried with the seeding equipment. Therefore, broadcast applications separate from the seeding operation can speed up seeding. In-soil applications also have greater draft requirements, higher equipment and fuel costs and greater soil disturbance than surface applications. There is also a school of thought that application of nitrogen to the growing crop can increase nutrient use efficiency and increase crop yield as compared to applying all of the nitrogen at seeding. In addition, there may be merit in midseason applications of N to increase protein content in a wheat crop that has higher than expected yield potential.

Role of Enhanced Efficiency Fertilizers with Surface Nitrogen Applications

A number of enhanced efficiency fertilizers are available that aim to improve the effectiveness of nitrogen fertilizer by reducing the exposure of the fertilizers to losses in the plant-soil system. These products can act on different parts of the nitrogen cycle by chemically stabilizing or inhibiting fertilizer reactions, or by physically slowing the release of the fertilizer into the soil solution.

Nitrification Inhibitors

Nitrification refers to the aerobic conversion of ammonia to nitrite (NO_2^-) and nitrate NO_3^-. Nitrification inhibitors interfere with the action of *Nitrosomonas* bacteria that convert NH_4^+ to NO_3^- (Frye 2005) slowing the conversion of ammonium to nitrate. This reduces the concentration of NO_3^- in the soil solution and decreases the risk of leaching, denitrification, and N_2O release (McTaggart et al. 1997). A number of nitrification inhibitors have been evaluated in Canada over the years, including ATC (4-amino-1,2,4-triazole hydrochloride) and thiourea (Malhi and Nyborg 1988a; Malhi and Nyborg 1988b). Ammonium thiosulphate, a fluid fertilizer source of N and S, has also been shown to limit nitrification to some extent (Goos 1985; Goos and Johnston 1992). A new product, 3,4-dimethylpyrazole phosphate (DMPP) also shows promising results in trials in other parts of the world (Pasda et al. 2001). However nitropyrin (2-chloro-6-trichloromethylpyridine) (N-Serve, eNtrench) and dicyandiamide (in SuperU and Agrotain Plus) are the two major nitrification inhibitors that have been evaluated and marketed in Canada.

Most of the research on the prairies with nitrification inhibitors assessed them with banded fertilizers rather than with broadcast applications. Nitropyrin ATC, and thiourea were all effective in inhibiting nitrification of fall-banded urea fertilizer under Alberta conditions where the fall applications were subject to nitrification losses (Malhi and Nyborg 1988a; Malhi and Nyborg 1988b). The inhibitors increased the amount of recoverable NH_4-N and NO_3-N in May, with approximately 30% of the N remaining as NH_4-N with the use of inhibitors, while nearly none was recovered as NH_4-N when inhibitors were not used. However, crop yields were not necessarily increased consistently with the use of the inhibitors. If fall fertilizer applications were banded late in the season when soil temperature was close to freezing, losses were minimal and use of the inhibitor provided no significant additional benefit. In North Dakota, both N-Serve and ammonium thiosulphate reduced nitrification from fall-applied aqua ammonia and increased yield of spring wheat after a winter with unusually high snow pack (Goos and Johnston 1999). In Manitoba, N-Serve applied with fall-banded urea and UAN increased canola yield and N accumulation, but there was no benefit when N-Serve was used with spring-applied fertilizer (Bailey 1990). In the Manitoba studies, the fall fertilizer applications occurred in mid-September, well before the soil temperatures reached freezing, which would increase the potential for benefit, as compared to where fertilizers were banded later in the season when soils were cold.

Agronomic and environmental benefits from use of nitrification inhibitors are greatest where potential losses are high. Losses by leaching and denitrification will be greatest under wet, warm soil conditions. Benefits are unlikely in dry or well-drained soils, where leaching and denitrification losses are limited. The longer the fertilizer remains in the soil before crop uptake, the greater the potential benefit for use of an inhibitor, so inhibitors have been of more consistent benefit with fall than with spring applications (Malhi and Nyborg 1988a; Malhi and Nyborg 1988b; Simek and Cooper 2002). Benefits have also been minimal when banding operations have been delayed application until late in the fall, when soils have cooled (Yadvinder-Singh and Beauchamp 1988). Nitrification inhibitors have not been widely used on the Canadian prairies mainly because they often do not provide a significant benefit above traditional practices (i.e. late fall application) in the prairie environment. However, nitrification inhibitors should help to reduce losses from broadcast applications of ammonium-producing fertilizers such as urea. The benefits would be greatest where the fertilizers were exposed to warm, moist conditions over an extended time, such as with fall applications or with long-season crops such as corn or potatoes.

Urease Inhibitors

While urea and urea-based fertilizers are commonly used in Manitoba, surface-applied urea or UAN can be lost via volatilization and immobilization volatilization (Watson 2005; Watson et al. 1994a; Watson et al. 1994b). Urea itself is not subject to volatilization loss, but urea rapidly converts to ammonia (NH_3) in a reaction catalyzed by the enzyme urease (Bremner 1995). Urease inhibitors can improve the efficiency of urea-based fertilizer by slowing the rate of hydrolysis and reducing the concentration of NH_4^+ and NH_3 in the soil solution (Watson 2005) Delaying urea hydrolysis provides time for rainfall to move the urea into the soil where the released NH_3 will be protected from movement to the atmosphere (Watson et al. 1994a, b) or for the urea to move away from the germinating seedling, reducing toxicity (Grant and Bailey 1999; Rawluk 2000; Rawluk et al. 2001). Koch fertilizers markets three formulations containing the urease inhibitor N–(*n*-butyl) thiophosphoric triamide (NBPT) Agrotain is a mixed solvent additive containing NBPT, to be used with urea or UAN. Agrotain Plus is a dry concentration containing both NBPT and the nitrification inhibitor dicyandiamide (DCD) that is designed to be added to UAN for surface applications. Super U is granular urea with DCD and NBPT. Use of both the nitrification inhibitor and the urease inhibitor should reduce the potential for losses by volatilization, denitrification and leaching.

In studies conducted on high pH soils in Manitoba, Agrotain reduced NH_3 emissions from surface applications of both urea and UAN (Grant 2014; Grant et al. 1996; Rawluk 2000; Rawluk et al. 2001). Ammonia losses and the potential benefit derived from use of Agrotain were higher when urea rather than UAN was the fertilizer source. Losses tend to be higher from urea than UAN because only a portion of the N in the UAN is in the form of urea and hence less is susceptible to losses. In addition UAN does not increase the pH surrounding the fertilizer to the same extent as urea, thus the ratio of ammonia to ammonium is lower with UAN than with urea. Volatilization will be reduced if rainfall occurs soon after fertilizer application, carrying the urea into the soil where it is protected from loss. Ammonia losses from surface-applied urea were reduced when simulated rainfall was applied to move the fertilizer into the soil, but the lowest loss occurred when use of Agrotain was combined with simulated rainfall (Figure 5) (Rawluk 2000).

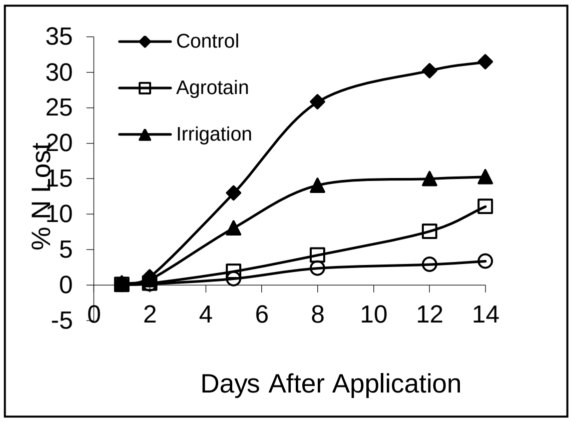

Figure 5: Effect of NBPT and simulated rainfall (2.0 cm on day 4 and day 7) on volatilization losses from surface applied urea fertilizer (Rawluk 2000)

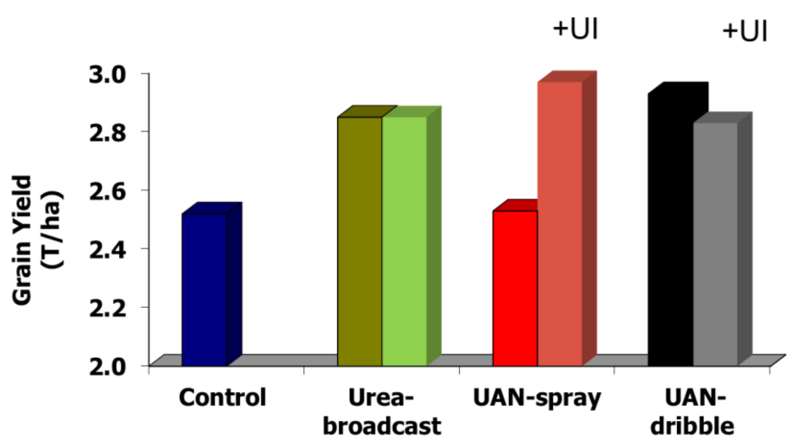

Figure 6: Agrotain did not increase spring wheat yield with broadcast urea or dribble-banded urea, when volatilization was low, but increased yield with spray-applied UAN, presumably by reducing immobilization (Grant 2014).

Agrotain has been relatively consistent in reducing measured loss of NH_3 from surface applications of urea and UAN. However, yield increases have not been as consistent (Figure 6). For a yield increase to occur from use of a urease inhibitor the N supply must be limiting to crop production and the potential volatile losses of N from the urea must be high enough to restrict crop yield. Maximum benefits of urease inhibitors will occur when crop yield potential is high, soil N levels are low and soil and environmental conditions promote extensive volatilization losses. Potential volatilization, and hence potential benefits from the use of urease inhibitors, will be higher where the fertilizer is left on the soil surface, where there is little opportunity for urea to move into the soil with infiltrating water, or where the soil has a high urease activity because of lack of cultivation or the accumulation of organic material. In management systems where surface application is used, urease inhibitors may be effective in increasing fertilizer use efficiency and economics of production. Benefits may be particularly high under no-till where the fertilizer will not be incorporated and where surface residues are present that can increase volatilization and immobilization losses. For example, in field studies in Manitoba, barley yield was increased when NBPT was added to broadcast urea under no-till management, but under conventional till management yields with broadcast urea were similar with and without the inhibitor (Figure 7) (Grant 2003).

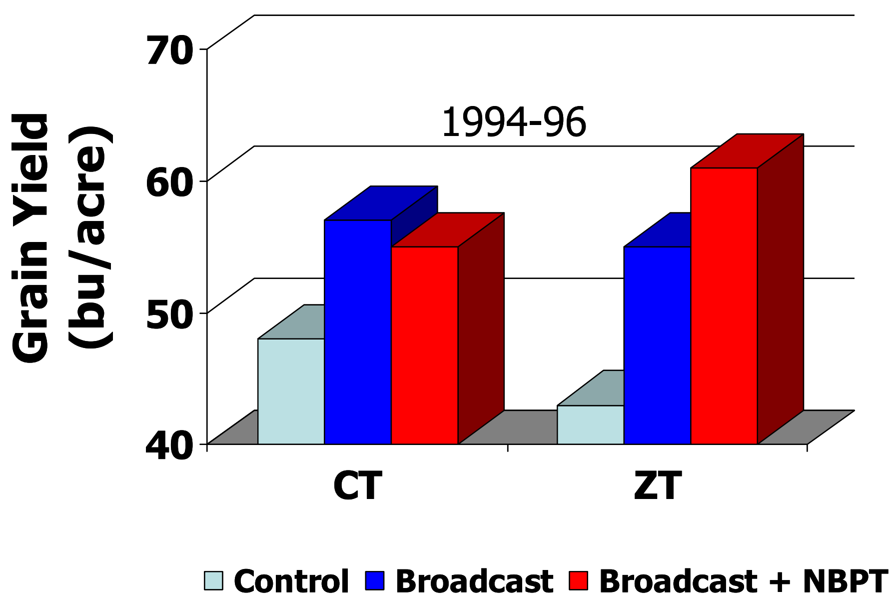

Figure 7: Effect of Agrotain on barley yield under conventional and reduced tillage management (Grant 2003).

Controlled Release Nitrogen

Controlled release N fertilizer products aim to reduce nitrogen losses by releasing the fertilizer gradually into the soil solution at a rate matched to crop uptake. Currently the major controlled release fertilizer product registered in North America is ESN (Environmentally Smart Nitrogen – Agrium), with a polymer coating that releases urea fertilizer into the soil solution at a rate limited by moisture, but controlled by soil temperature (Haderlein et al. 2001). Synchronising the N release into the solution with the uptake pattern of the growing crop minimizes the concentration of nitrate in the soil solution and the time the nitrate is in the soil solution before crop uptake which should reduce the risk of leaching and/or denitrification under wet, warm conditions. This may be particularly important with long-season crops such as corn or potatoes, where crop uptake of N occurs over a longer period than with shorter season crops such as wheat or canola (Table 2). It may also be beneficial with early fall applications of fertilizer. Studies in Alberta showed that crop yield could be increased by using fall broadcast ESN rather than fall broadcast urea if the fertilizer was applied early in the fall (Figure 8). Late fall applications showed no difference between sources. Late fall applications of ESN may be delayed in their release in the spring, leading to deficiencies in crops that have a high N demand early in the growing season. In addition, on sloping landscapes, surface applications of controlled release products could be at high risk of run-off loss during the spring snow-melt because they remain at the soil surface until the nitrogen is release over the growing season.

Table 2: Effect of enhanced efficiency fertilizers on potato yield (averaged over Carberry and Carman sites) (Tenuta et al. unpublished)

		Yield (cwt/ac)								Average Tuber
Treatment		< 3	3-6 oz	6-12 oz	> 12 oz	> 3 oz		Total		Size (oz)
1	Untreated Check	38.2	148.3	140.9	25.3	314.6	d	352.8	c	4.87
2	Urea at Plant	29.3	150.5	225.6	47.3	423.4	abc	452.8	b	5.74
5	Super-U split	39.3	136.5	239.2	38.7	414.4	c	453.7	b	5.48
6	Super-U split	31.0	142.1	233.1	41.6	416.8	c	447.8	b	5.67
7	ESN at Plant	29.3	152.0	237.3	59.5	448.7	a	478.0	a	5.89
8	ESN/Urea	27.7	143.3	222.5	51.6	417.3	c	445.1	b	5.93
LSD (P=.05)		ns	ns	ns	ns	25.5		23.0		ns
Treatment Prob(F)		0.0869	0.7225	0.0851	0.0831	0.0027**		0.0012**		0.1136

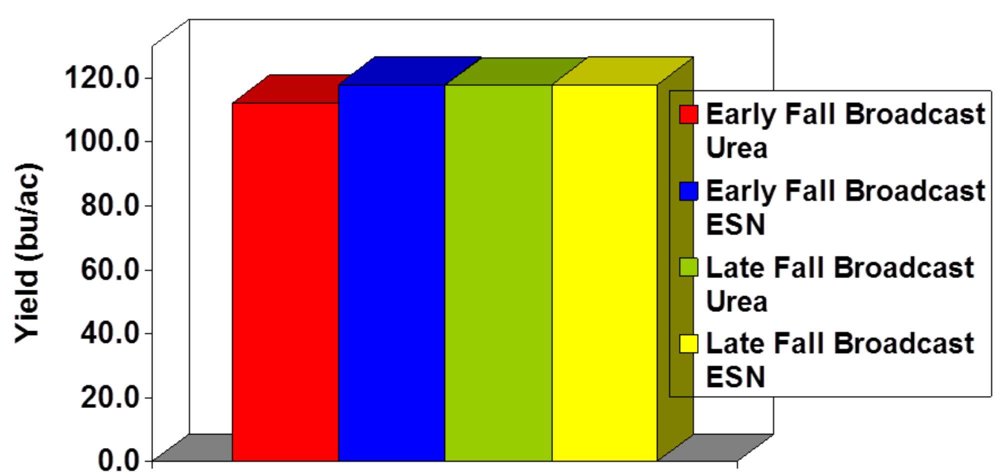

Figure 8: Yield of spring-seed cereals with fall broadcast ESN or urea – average of 6 site-years in southern Alberta. A difference of 5.5 bu/acre occurred with the early application. Early – last week of September; Late = last week of October. (McKenzie 2006-2008, unpublished).

The greatest benefit of coated urea appears to be in reducing denitrification and leaching losses. Therefore, benefits of controlled release urea will be greatest under warm, moist conditions that promote high losses by these pathways. There is also likely to be an environmental benefit due to the reduction in nitrous oxide emission (Halvorson et al. 2014). However, the impact on nitrous oxide emissions will depend on the timing of nitrogen release in relation to denitrifying conditions. There may be situations where release of nitrate into the solution can correspond to warm, wet conditions and increase nitrous oxide emissions (Figure 9).

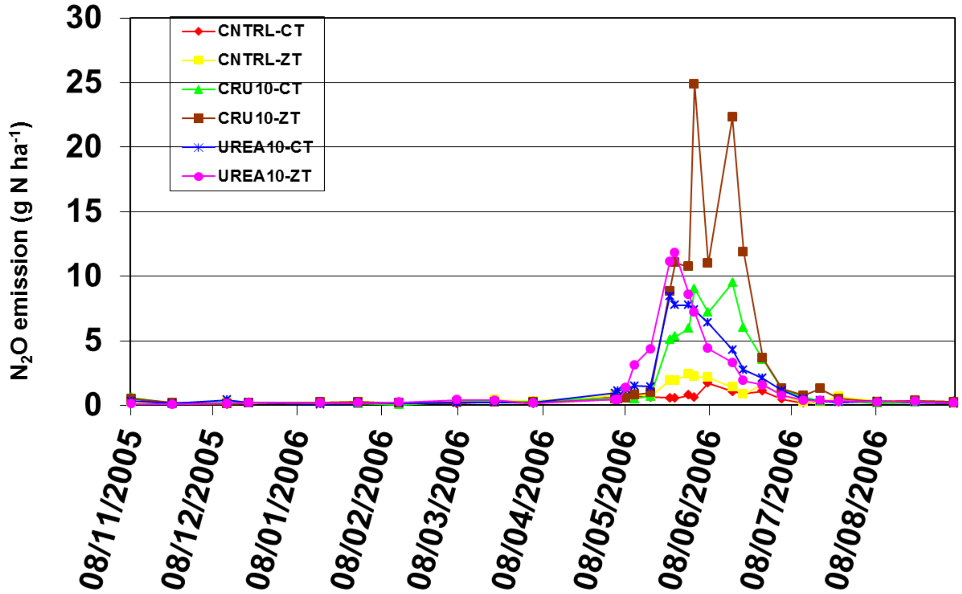

Figure 9: Nitrous oxide emission from broadcast urea and ESN under conventional and no-till management in corn at Agassiz, BC. (Shabtai Bittman)

As the major mode of action for controlled release products is reducing denitrification and leaching, potential benefits will increase with the length of time that the fertilizer is in the soil before crop uptake. Controlled release urea has not generally produced a significant advantage with spring broadcast fertilizer applications in winter wheat (Middleton et al. 2004; McKenzie et al. 2007). However, research on grassland in north-central Alberta has suggested that under conditions where volatilization led to poorer performance of surface-applied urea than ammonium nitrate, the effectiveness of the urea could be improved by using control release granular urea fertilizers (Malhi et al. 1998) most likely by preventing ammonia volatilization losses or possibly immobilization losses occurring from surface-applied urea on thatch layer under grassland. Similar benefits might be expected with surface applications on heavy residue in no-till. However, unpublished data from Tom Jensen (Alberta, 2006) showed that while ESN produced higher winter wheat yield than urea or ammonium nitrate when fall-banded at seeding, there was no advantage to the use of ESN over those sources when spring broadcast (Figure 10). The lack of benefit may be because the coated fertilizer will not be carried into the soil by rainfall and so would continue to be susceptible to volatilization and immobilization losses as it released over time (Figure 11). However, there may be some reduction in volatilization because of the lower concentration and possibly reduced pH effect caused by the gradual release.

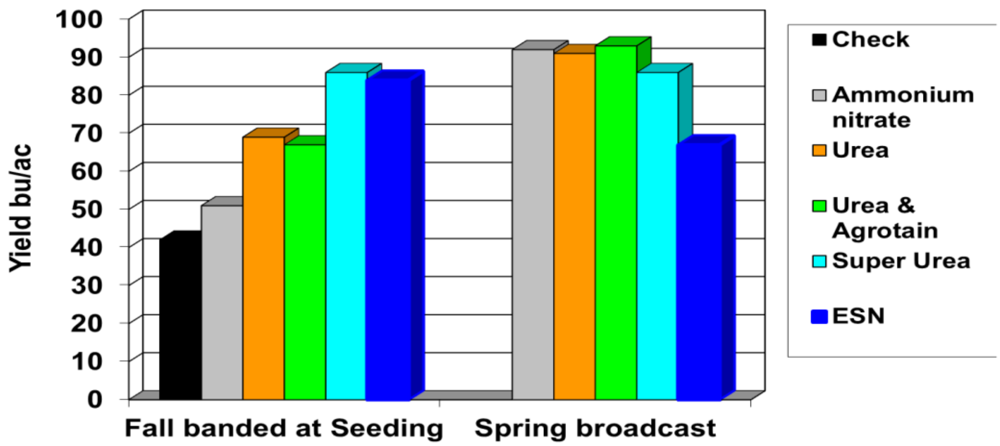

Figure 10: Impact of conventional and enhanced efficiency fertilizers on yield of winter wheat, when applied as a fall band or spring broadcast (Tom Jensen, unpublished – single site year- Alberta 2006).

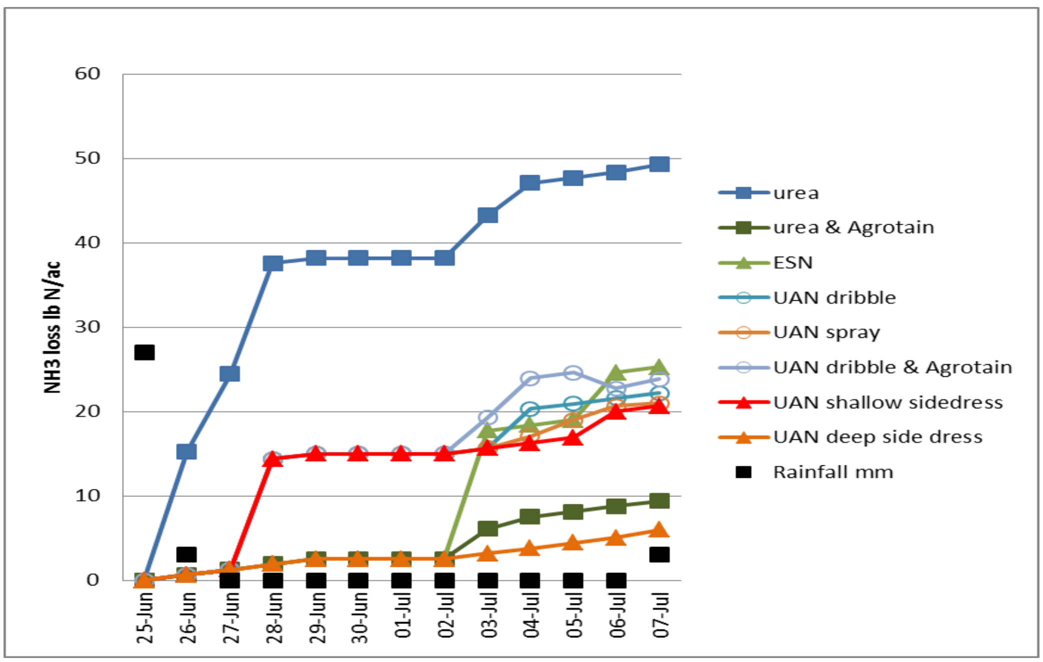

Figure 11: Volatilization from ESN was initially low, but increased over time as urea was released from the fertilizer granule (John Heard – unpublished data, single site year- Carman)

Do New Products Close the Gap Between Surface and In-Soil Banded Nitrogen

While the new products available can be effective in improving nitrogen use efficiency when used in the proper circumstances, they generally do not completely make up the difference between surface and in-soil banded applications. In-soil banding works to reduce the risk of all pathways of N loss, while the various enhanced efficiency products generally reduce only specific pathways of loss. In-soil bands have lower risk of volatilization, immobilization, erosion and run-off than broadcast enhanced efficiency products.

Controlled release products and nitrification inhibitors can reduce the risk of denitrification and leaching from fall applications but surface applications can still be susceptible to volatilization and immobilization. In addition, fall-applied surface applications will be subject to runoff during the snowmelt. However, there may be advantages to controlled release products or nitrification inhibitors over band applications of conventional sources at the time of seeding with long-season crops such as corn or potatoes; with these crops, controlled release of nitrogen or reduced nitrification over the growing season may reduce the risk of denitrification and leaching, particularly on wet soils or under irrigation.

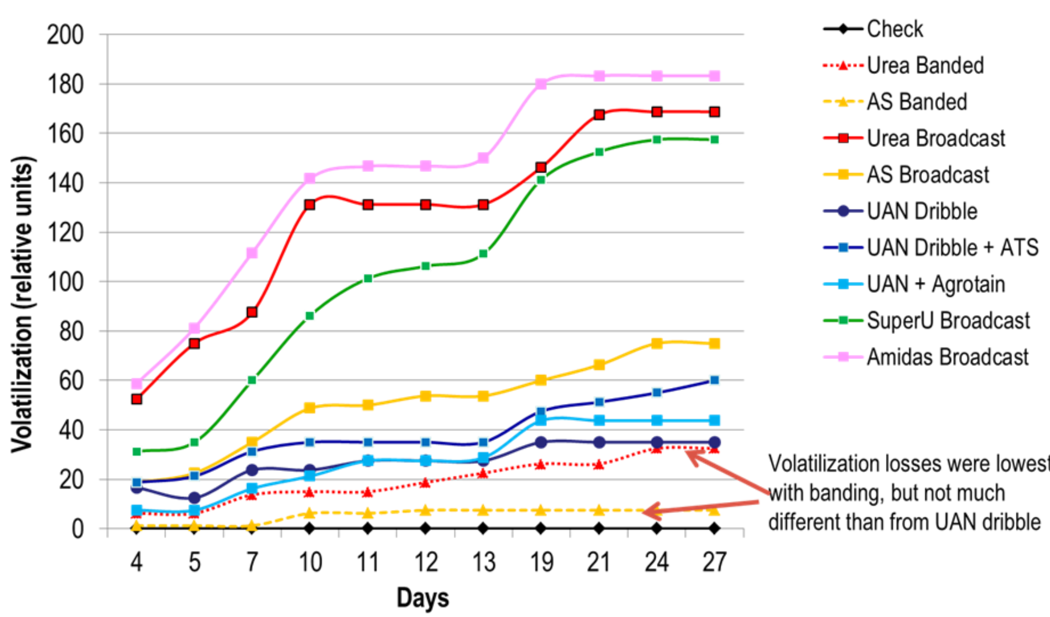

Figure 12: Comparative ammonia volatilization with different fertilizer sources and placements on a Newdale Clay Loam soil near Brandon in 2014 (Grant and Mohr – unpublished).

Urease inhibitors are effective at delaying conversion of urea to ammonia, buying time for the urea to move into the soil with rainfall where it will be protected from loss. Urease inhibitors may also have some benefit in reducing immobilization, if rainfall carries the urea away from the residue before it can be accessed by the soil microorganisms.

While use of urease inhibitors delay volatilization and reduce the risk of loss from surface application, in-soil banding is still more effective than use of enhanced efficiency products in reducing volatilization losses, particularly if rainfall does not occur to carry the broadcast fertilizer into the soil. In on-going studies at Brandon, volatilization losses over a 27 day period were extremely low with in-soil banded application of urea and much lower than they were with inhibited urea (Figure 12). Similarly in the work by John Heard (Figure 11), volatilization losses were lower with in-soil banded UAN than with inhibited surface applications, as long as the bands not placed too shallowly. In both studies, volatilization loss from uninhibited dribble-banded UAN was significantly lower than from urea and this could be a viable choice for surface applications.

In-soil banding is still the gold standard for nutrient use efficiency in Manitoba. While enhanced efficiency products do not close the gap between in-soil banding and surface applications, they can narrow the gap if used correctly. Surface applications will not normally be as good as in-soil bands from the perspective of nutrient use efficiency, but they may provide advantages in other areas of the farming operation, including more rapid seeding, reduced soil disturbance, less draft requirement, lower equipment and fuel costs and increased field trafficability. Delaying nitrogen applications until after seeding may also allow assessment of yield potential before the nitrogen is purchased, potentially reducing the inputs into a low-yielding crops or allowing greater N applications on a better than expected crop. In-crop applications may also play a role in protein management in high-quality wheat production.

The decision to use surface application rather than in-soil banding requires consideration of the potential costs and benefits of each method of application. This includes determination of how much nitrogen will likely be lost from the various pathways of and how effective use of enhanced efficiency products will be in reducing those losses. It also requires an assessment of how important savings in time, soil disturbance, draft requirements, fuel and equipment costs, or increased flexibility of timing of application are in contributing to crop yield potential or economics of production. While in-soil banding is still the gold standard for nutrient use efficiency, there may be situations where surface applications with the use of enhanced efficiency fertilizers may be contribute to whole farm efficiency. A sound understanding of agronomic and nutrient management principles will help to ensure that the best decisions are made for the overall farming operation.

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