# Nitrogen Fertilizer Management in Small Grain Production

C.A. Grant
Agriculture and Agra-Food Canada - Brandon Research Centre
Box 1000A, R.R. #3, Brandon, MB, and Canada, R7A 5Y3

Nitrogen is the most commonly limiting nutrient in agricultural systems. Therefore, effective nitrogen management is a critical component in crop production, not only to improve financial returns, but also to maintain soil quality and reduce the likelihood of damage to the environment. Effective nutrient management must ensure that an adequate supply of nitrogen is present in a position where the crop can access it at the time that it is needed by the crop. Excesses must be avoided, as they reduce financial returns and increase the risk of environmental damage.

## Manage to Balance Supply and Demand

Nitrogen management balances the needs of the crop for optimum economic yield and quality and the N supply that the plant can access as needed. Nitrogen supply from the soil includes the residual soil N that is present at seeding, the N released from mineralization over the growing season, and for legume crops, N that is symbiotically fixed through the legume-rhizobium interaction. Nitrogen supply is reduced by the losses of N that occur through the season. Nitrogen fertilization should make up the difference between the demands of the plant and the supply from the soil.

## Use Management Tools to Optimize Efficiency

Effective N management must consider a number of factors including the crop, the soil and environment conditions and the specific economic, logistical and personal needs of the particular farm. Nitrogen management tools that we can use include:

1. Rate: Selected to optimize economic yield and quality, but not lead to negative effects on crop or environmental quality
2. Source: Suited to the time and method of application
3. Timing: Selected to ensure that adequate amounts of nutrient are available when required by the crop, losses are minimized and operation is efficient in terms of time management
4. Placement: Placed where nutrients are available to the crop when required for plant growth, losses are minimized and crop damage is avoided

Source, timing, placement and rate options can be combined into many effective management packages. Our goal is to improve fertilizer use efficiency by reducing the losses of N to the environment and optimizing the amount of N that is being used by the plant. This both improve the economics of fertilizer use and minimize the risk of negative environmental effects. The "best" fertilizer management package for a particular farm will vary, depending on crop grown, environmental conditions and other constraints within the overall production systems.

## Determining Nitrogen Application Rate

To be able to choose our N application rate, we need to estimate how much N the crop needs for optimum economic yield and how much N will be available from the soil for the crop to use. Nitrogen supply will include both the N in the soil at seeding and the N released during the growing season. With legume crops, it also included N fixation. Fertilizer N rate should be enough to make up the difference between the crop requirement and the soil supply, keeping in mind that N losses will occur from both the soil and the fertilizer we add.

N fertilizer = Crop demand - N in soil - N released + N losses from soil and fertilizer

## Crop Demand

The amount of N needed to produce a crop depends largely on the yield potential of that crop. For example, a wheat crop needs about 2 to 3 lbs of N to produce a bushel of wheat, so a 60 bu/acre crop will need substantially more N than a 30 bu/acre crop. Crop N requirement can therefore be estimated by selecting a reasonable target yield. In many areas of the Great Plains, target yield is primarily determined by the available moisture, including stored soil moisture and anticipated precipitation. However, target yield will also be influenced by a wide range of factors including soil characteristics, target protein content, management practices, crop rotation, length of growing season, and likelihood of weed, disease and insect problems. Deficiency of nutrients other than N will reduce yield potential and should be corrected, so that the target yield is based on yield restriction imposed by factors that can not be economically controlled. Past experience will help in setting a reasonable target yield. Nitrogen supply should be selected to support that yield and quality goal.

## Soil Supply

In an ideal world, N supply would be measured using a soil test combined with an effective predictor of potential seasonal N mineralization. However, in reality, few producers actually soil test and a quick and effective predictor of N mineralization is not available. Therefore, N supply often is estimated based on experience.

Where an effective soil test is in place, soil testing is still the best tool to estimate available soil N. However, considering input and removal of N from the soil system can help an agronomist develop an estimate of N supply from the soil in the absence of a soil test or fine-tune a recommendation if a soil test is available.

Crop Removal in Preceding Year: Each bushel of wheat at 14% protein removes approximately 1.5 lb of N from the system in the grain. With high crop yields in the preceding year, crop removal will likely have depleted reserves of soil N, leading to a reduced supply of available N for the current crop. This is particularly true if the crop also contained high protein content, which will increase N removal.

Cropping Intensity: Moving from cropping systems that include fallow to continuous cropping systems will increase annualized crop yield and so total nutrient removal with continuous cropping will be substantially higher than with a fallow cropping system. With increased nutrient removal, responses to fertilizer applications become more likely. Therefore, in intensive cropping systems, N fertilization becomes increasingly more important.

While crop removal of nutrients is increased by cropping intensification, the amount of organic residues returned to the system is enhanced by more frequent cropping, which can increase the potential for nutrient release from organic matter residues, particularly in fertilized systems. Nitrogen returned to the system via crop residues from previous years of cropping serves to replenish the organic nutrient pool in the soil. Historically, fallow systems have relied upon N mineralized from the soil organic matter to provide N for the succeeding crop. Over time, insufficient crop residues were returned to the soil to compensate for the loss in N supplying capacity of the soil due to fallowing. This, combined with the soil erosion associated with fallowing, led to soil organic matter depletion and an overall decline in the capacity of the soil to mineralize N. Therefore, although continuous cropping will reduce the amount of residual mineral N in the soil, in the long-term it may increase the potential ability of a soil to supply N to a crop via mineralization during the growing season. There is still some question as to how many years of good management it will take before the potential for greater N mineralization will be reflected *in situ*.

<u>Crop Rotation</u>: A diversified crop rotation can increase yield potential, which will increase the crop nutrient demand. However, crop rotations may also influence the supply of nutrients to the growing crop. Crops differ substantially in the amount of N returned in the crop residue for use of subsequent crops, since N supplied will depend on the amount of crop residue, primarily, and on the concentration of N in the residue. Nitrogen concentration in the residue will determine the net balance between immobilization and mineralization. Jay Goos suggested that if the N concentration in the residue is below approximately 20-24 g N $kg^{-1}$, immobilization will exceed mineralization and the decomposing residues will tie up N rather than release it.

Over the long term, as decomposition proceeds, all residues will eventually release the minerals they hold. The time required for this to occur will increase as the initial N concentration in the residue decreases and the C/N ratio widens. In studies by Janzen and Kucey at Lethbridge, that N concentration of lentil, rape and wheat residue had a dominating influence on rate of residue decomposition and nutrient release. Increasing the N concentration of the residue by fertilization increased rate of residue decomposition. Straw from a well-fertilized wheat crop will decompose more rapidly and release more N to the following crop than will an N-deficient crop. Therefore, species and nutrient management of the preceding crop will influence its nutrient content and the amount of nutrient it will release to the subsequent crop. Placement of residues and method of termination of the crop will also influence N release. Soil incorporation of residues reduces N loss by volatilization, enhances mineralization and increases the short-term supply of plant-available N.

Annual legumes, such as soybean, field pea, or lentil, are often included in rotation and can increase the amount of available N for the following crop. Legume crops can symbiotically fix N in association with *Rhizobium spp*. If the legume crop is used as a green manure, considerable amounts of N can be supplied to the succeeding crop as the legume residue decomposes. With legume pulse crops, such as soybean, field pea or lentils, where the seed is harvested and removed from the field, N fixation will reduce the fertilizer N requirement for optimum yield of the legume crop. The amount of N removed in the seed is generally similar to the amount of symbiotic N fixation. Despite this, N requirements are generally reduced in crops following pulse crops, indicating that pulse crops increase the available N for subsequent non-legume crops. Estimates of N contributions to following crops ranges widely (less than 10 to greater than 70 lb/acre) and will depend on legume yield, management practices and environmental conditions. Legume residues contain considerable amounts of N and have a relatively low C:N residue, leading to more rapid release of N than lower N-containing cereal residues. Work by Sawatsky and Soper at the University of Manitoba indicated that up to 44% of N fixed by legumes remained in the soil after roots was physically removed from the soil, and was presumably present in irrecoverable root material, or lost from the plant root by sloughing and exudation. Some of this fixed N remaining in the soil would become available for subsequent crops. Increased N availability to crops following legumes may also be due to reduced immobilization, as legume crops generally produce lower amounts of crop residue than do cereal crops.

Past N management: Both residual soil N and the potential release of N from mineralization will be influenced by long-term N management. Long-term crop production in the absence of adequate N applications will reduce soil organic matter, potentially mineralizable N and residual soil N. In contrast, long-term cropping with N applications designed to optimize crop yield potential, combined with return of crop residue to the system, can slow the loss or possibly even lead to increases in soil organic matter over time. Therefore, a long-term history of effective N management and good residue management will lead to a greater ability of the soil to supply N for crop growth. Application of high N organic amendments such as manure or green manures will also increase the supply of N from the soil and reduce the rate of N required for crop production.

Tillage System: Tillage tends to increase release of N from the soil. Organic matter in the soil is frequently inside of soil aggregates, where it is protected from decomposition. Tillage exposes this protected organic matter, enhancing its decomposition. With reduced tillage, residue from previous crops is left on the soil surface, rather than incorporated into the soil. Surface residue tends to break down more slowly than incorporated residue, because contact between the residue and the soil microorganisms is restricted, conditions at the surface are less favourable for decomposition than in the soil, and the high C:N ratio of the straw may slow microbial action. Therefore, release of N from the residue is slowed.

The surface mulch under no-till moderates changes in soil temperature, making the soil slightly cooler during the spring and summer, but warmer during the fall and winter. This may shift mineralization of organic matter in the soil to later in the growing season. If N is released after crop uptake of N ceases, the N may remain in the soil after harvest and be more prone to loss in the fall and early spring period. The mulch and standing stubble will reduce evaporation and may increase water retention, so soil moisture content is generally higher under reduced tillage than under conventional tillage. This may lead to enhanced microbial activity, increasing mineralization, immobilization and possibly denitrification and leaching. The balance between nutrient release and tie-up will depend on the environment, and whether temperature and moisture conditions are limiting to microbial activity. Generally, at least in the initial years of a reduced tillage system, tie-up of N in the soil organic matter increases and the N available for crop growth declines. Therefore, it may be necessary to compensate for this by increasing fertilizer rate or improving the efficiency of fertilizer management.

Expected Efficiency of Fertilizer Application: The more efficiently N fertilizer is used by the crop, the less N fertilizer is needed. Therefore, if the source, timing and placement package and the environmental conditions combine to produce high N efficiency, rate of application can be reduced. In contrast, if a less efficient management package is selected because of other management constraints on the farm, or to improve operational efficiency in another area of the production package, the reduced efficiency can be compensated for by increasing fertilizer rate.

## Improving N Efficiency with Fertilizer Source, Timing and Placement

By improving N use efficiency, we can reduce the amount of fertilizer required to optimize yield and quality. We do this by ensuring that as much N as possible is used by the plant and as little as possible is lost to the environment. Understanding how N is lost from the soil and how our N management practices influence N losses can help us determine the most effective N management package for a particular farming system.

Nitrogen can be removed from the cropping system by four major pathways. These are volatilization, immobilization, denitrification and leaching.

**Volatilization** is the loss of N to the atmosphere as ammonia gas. Ammonium and ammonium-producing sources, such as urea, are readily lost by volatilization when left on the soil surface, while nitrate sources are not. The ammonia travels in the water stream, so volatilization losses increase with factors that increase evaporation, such as high air and soil temperatures and wind. Applying the fertilizer when temperatures are cool, winds are light and there is a good likelihood of receiving rain in the near future would help to reduce volatilization losses.

Table 1. Conditions that Affect Volatilization Losses of N Fertilizer

| High Loss Potential | Low Loss Potential |
|---|---|
| moist conditions, followed by rapid drying | dry conditions, followed by rainfall |
| high soil temperatures | low soil temperatures |
| high soil pH (> pH 7.5) | low pH (>7.5) |
| high lime content in surface soil | no lime at soil surface |
| coarse soil texture (sandy) | fine textured soil (clay) |
| low organic matter content | high organic matter content |
| high amount of surface residue (Zero Till) | conventional tillage |

**Immobilization** refers to the "tie-up" of N in the soil microorganisms as they use the N for their growth and reproduction. Both ammonium and nitrate can be used by microorganisms and lost through immobilization. This is a temporary loss, since the N will recycle when the microorganisms die and decompose, but it restricts N availability in the year of application.

**Denitrification** is the conversion of nitrate-N to gaseous forms of N, which can be lost to the atmosphere. Denitrification occurs when available oxygen in the soil is limited. This can occur under flooded conditions or when the soil is very compacted. Losses are therefore higher on fine-textured soils and on soils subject to water-logging, such as bottom-slope positions. Even when the soil is not completely flooded, there will be microsites in the soil where oxygen availability is limited and denitrification can occur. Rate of denitrification will be faster when soil temperatures are warm, because the activity of the microorganisms that cause denitrification increases with increasing soil temperature.

**Leaching** is the movement of N in the soil water down through the soil profile. When the N moves below the rooting depth, the plants can no longer reach the N, so it is lost for crop use. Ammonium-N is normally bound to soil particles and so protected from leaching losses. Therefore, N in the nitrate form is much more susceptible to leaching losses is the ammonium form. Leaching will increase with increasing precipitation and is higher on light-textured soils with lower water holding capacity.

The potential for N loss from these pathways will depend on soil type and environmental conditions. In order to build a N management package, the soil and environmental conditions should be evaluated to assess the relative risk of losses by volatilization, immobilization, denitrification and leaching. Nitrogen source, timing and placement can be then be manipulated to minimize N losses and maximize fertilizer use efficiency.

## Selecting Nitrogen Sources

Nitrogen fertilizer supplies N in the form of ammonium, nitrate, urea (which rapidly converts to ammonium in the soil), or as a blend of these ions. Both nitrate and ammonium sources are subject to immobilization losses. However, ammonium and nitrate sources differ in their susceptibility to losses by volatilization, denitrification and leaching.

Ammonium and urea sources are more prone to volatilization losses than are nitrate sources. This is because they convert to ammonia gas, which can be lost to the environment. Therefore, these sources should be applied where volatilization potential is low, or placed in a way that reduces volatilization losses.

Nitrate sources are more prone to leaching and denitrification losses than are ammonium sources. Therefore, under conditions where leaching or denitrification is likely, ammonium or urea sources are preferable to nitrate sources. However, microorganisms in the soil convert ammonium to nitrate through nitrification, with the rate of conversion increasing with optimal moisture conditions and increasing soil temperature. So, over time, ammonium and urea will also become susceptible to losses as they change to nitrate. Placing these fertilizers in a way to slow the conversion to nitrate will improve efficiency.

## Nitrogen Timing and Placement

**Broadcast and surface applications**: With surface applications, N can be lost by volatilization until it is incorporated or moves into the soil with precipitation. If the N is in close contact with crop residues, it may also be subject to immobilization as the residues decompose, since with high C:N ratio residues microorganisms will use N from the soil or fertilizer as they break down the residue. Because of the high potential for volatilization and immobilization losses, surface applications of N tend to be less efficient than in-soil banded applications. Efficiency of surface applications tends to improve in higher rainfall areas, since precipitation will move the fertilizer into the soil, reducing the risk of loss and of stranding at the soil surface. Efficiency is lower on high pH soil, since high pH encourages the production of ammonia gas.

Use of a source containing a relatively high proportion of nitrate, such as ammonium nitrate, may reduce volatilization losses, since nitrate is not subject to volatilization. Urea is particularly subject to volatilization losses if surface applied without incorporation, since the concentration of ammonium released from urea is high. The presence of crop residues at the soil surface may increase volatilization, since the residues contain the urease enzyme, which breaks down urea and makes it subject to loss as ammonia gas. The crop residue may also increase immobilization, since the raw organic matter, with a high C:N ratio will tie up N as the residue decomposes. Therefore, separation of the crop residue and the N, by placing the fertilizer below the residue may be even more important under reduced as compared to conventional tillage.

In studies by Malhi and Nyborg in Alberta, yield of barley grown under no-till was lower than under conventional tillage if the urea was broadcast, but the yield was equal if the fertilizer was side-banded or placed below the seed. While yield increased when N was banded as compared to broadcast under both no-till and conventional tillage, the increase was greater under no-till. The residue left on the surface under no-till led to high losses by volatilization and/or immobilization, increasing the benefits from seed-placement or side-banding under no-till.

Similar results were obtained in studies with durum, conducted on a clay loam and a fine sandy loam soil in Manitoba (Table 2). Under conventional tillage, spring banded applications of urea produced similar yields to broadcast urea. Under reduced tillage, the in-soil spring banded application produced higher yields than the broadcast applications, in spite of the extra soil disturbance associated with the banding action.

Table 2: Yield of durum grown under conventional tillage (CT) and zero tillage (ZT) with varying placements of 55 kg N $ha^{-1}$ as urea (1992-95) (Grant, Brown, Racz and Bailey, 2001- In Press).

| Method of Placement | Clay Loam CT | Clay Loam ZT | Fine Sandy Loam CT | Fine Sandy Loam ZT |
|---|---|---|---|---|
| | ----------bu per acre---------- | | | |
| Fall Banded | 44 | 30 | 43 | 42 |
| Spring Banded | 44 | 41 | 39 | 40 |
| Dribble Banded | 45 | 34 | 37 | 41 |
| Broadcast[1] | 45 | 33 | 41 | 38 |
| Control | 33 | 22 | 28 | 25 |

1. Broadcast without incorporation for reduced tillage and with incorporation for conventional tillage

In spite of the potential for loss of surface applied N, broadcast application may be a practical choice, since it allows for application of large amounts of fertilizer without investment in specialized equipment or high cost of field operations. While a higher rate of fertilizer may be required to compensate for the reduced fertilizer use efficiency, this may be a practical compromise, particularly for producers who are not willing or able to purchase specialized equipment for in-soil fertilizer placement.

Ammonium nitrate is generally considered more efficient than urea when broadcast, since ammonium nitrate is less subject to volatilization. However, under the right conditions, surface applications of urea can be as effective as surface applications of ammonium nitrate (Table 2).

Volatilization losses will be minimized by application of the fertilizer early in the growing season when air and soil temperatures are cool. In conventional tillage systems, incorporation immediately after application will minimize losses. In no-till systems or on perennial forages, where incorporation is not an option, rainfall soon after application will wash the fertilizer into the soil, reducing losses. Use of ammonium nitrate or urea ammonium nitrate (UAN) dribble bands as post-seeding treatments up to the 4th leaf stage of the crop may also produce good results. Fall broadcast applications of N tend to be inefficient. Fall application leaves the fertilizer in the soil for a long time, while broadcasting provides good contact between soil microorganisms and generally places N close to crop residues, which provide a carbon source for microbial activity. This combination of factors creates a high likelihood of N loss.

Use of urease inhibitors such as Agrotain (NBPT) in the urea fertilizer can also reduce volatilization losses. Urease inhibitors slow the conversion of urea to ammonium ions. This allows more time for the urea to move into the soil before release of ammonium ions leads to a high risk of ammonia volatilization. Also, with slower release of the ammonium ions, concentration of ammonia at the soil surface would be reduced, which reduces the rate of volatilization. In studies where N volatilization over a two week period was measured using polyfoam traps in tubes set in the field, volatilization was reduced to a far greater extent by use of Agrotain than by application of 1.5 inches of water as irrigation treatments split at day 4 and day 7 (Table 3). However, the benefit of this will depend on the cost of the product relative to potential losses.

Table 3: Cumulative losses of N over a two week period from surface broadcast urea applications with and without irrigation or Agrotain application (Rawluk, 2000)

| | N Volatilization (%) | | | | | |
|---|---|---|---|---|---|---|
| | Day 1 | Day 2 | Day 5 | Day 8 | Day 12 | Day 14 |
| No irrigation | 0.23 | 1.13 | 12.97 | 25.80 | 30.22 | 31.45 |
| No irrigation + Agrotain | 0.08 | 0.24 | 1.92 | 4.22 | 7.58 | 11.07 |
| Irrigation | 0.30 | 0.77 | 8.06 | 14.07 | 14.98 | 15.25 |
| Irrigation + Agrotain | 0.05 | 0.16 | 0.90 | 2.37 | 2.90 | 3.37 |

**In-soil banded or nested applications:** By placing N fertilizers as bands or nests in the soil, problems with volatilization are reduced substantially. Once in the soil, nitrogen is more readily lost from the nitrate form than the ammonium form. This is because both ammonium and nitrate can be immobilized by soil microorganisms, but nitrate is also subject to losses by denitrification and leaching. Therefore, in-soil applications of N tend to be more efficient when a larger proportion of the N is in the ammonia/ammonium form. With spring applications, where plant uptake will begin soon after application, source of N may not be particularly important. But, if the fertilizer will be in the soil for an extended period of time prior to plant uptake, use of ammonium or ammonium-producing sources may improve fertilizer use efficiency.

Fall Banding: On most of the Canadian prairies, soils are essentially frozen from mid-November to mid-March and losses of N from frozen soils will be minimal. In addition, there is generally a relatively low risk of having a prolonged period with the combination of warm temperatures and saturated conditions. Therefore, fertilizer N can be banded in the fall. A fall banding operation allows for spreading of the workload, by shifting the fertilization operation to late in the fall, rather than during seeding in the spring. Fertilizer costs may also be lower in the fall as compared to the spring and for those producers concerned about taxes, there may be a benefit to purchasing fertilizer in the fall. Applying the fertilizer in a separate operation from seeding removes the requirement for specialized and costly seeding equipment, with banding capabilities. However, a separate banding operation will increase time, labour and equipment costs, as well as causing extra soil disturbance and increased weed density. In some cases, the soil disturbance from the fall band is considered a benefit, on wetter, colder soils in terms of helping the soil to dry slightly and warm up more readily in the spring.

With fall applications, fertilizer N will be subject to losses from the time of application until the soil freezes in the fall and from spring thaw until plant uptake. To minimize losses from denitrification and leaching, it is desirable to apply the fertilizer when surface soil temperatures have cooled below about 5 to 10 C, so that reaction of the N in the soil will be limited. The most efficient sources are generally ammonia or urea, rather than sources containing a higher proportion of nitrate (Table 4). Also, one would wish to maintain the fertilizer in the urea or ammonia/ammonium form for as long as possible. Placing the fertilizer in a band reduces the contact between the fertilizer and the soil microorganisms, reducing immobilization of both ammonium and nitrate. Banding also slows the conversion of urea to ammonium and ammonium to nitrate, which can reduce losses by denitrification and leaching. Applying the fertilizer as late as possible in the fall, when soil temperatures are low, would also reduce losses of the N through microbiological activity.

Table 4: Effect of fertilizer source, timing and placement on yield of durum wheat on a clay loam and fine sandy loam soil, under conventional (CT) and reduced tillage (ZT) management 1993-95 (Grant, Brown, Racz and Bailey, 2001 In Press ).[1.]

Cla

| | ZT | CT | ZT | CT |
|---|---|---|---|---|
| Fall Bands | -------------------------bu acre$^{-1}$-------------------------- | | | |
| $NH_3$ | 38 | 53 | 41 | 39 |
| UAN | 29 | 43 | 36 | 41 |
| Urea | 29 | 46 | 38 | 41 |

| | | | | |
|---|---|---|---|---|
| Spring Bands | | | | |
| $NH_3$ | 42 | 47 | 43 | 39 |
| UAN | 43 | 49 | 38 | 35 |
| Urea | 43 | 47 | 36 | 37 |
| UAN nested | 35 | 48 | 37 | 40 |
| UAN dribbled | 36 | 48 | 39 | 38 |
| Am. nitrate dribbled | 31 | 45 | 35 | 36 |
| Am. nitrate broadcast | 33 | 46 | 37 | 40 |
| Urea broadcast | 33 | 43 | 36 | 38 |
| Control | 25 | 36 | 28 | 31 |

1. Phosphorus applied as monoammonium phosphate with the seed.

Fall application of N may be less desirable with reduced rather than conventional tillage systems (Table 4). Under reduced tillage, the soil tends to be moister and somewhat more compacted than under conventional tillage, which would reduce aeration. Also, with reduced tillage, the soil is slower to cool in the fall. The warmer soil temperatures, higher moisture and reduced aeration may increase N losses from denitrification and possibly from leaching. Under reduced tillage, the conservation of moisture from fall applications would be of less benefit than under conventional tillage, while the soil disturbance may be of more concern, although the soil disturbance from fall banding may aid early seeding in wet years. These factors could combine to reduce the benefits experienced from fall banding.

<u>Spring Banding:</u> The benefits of banding vary greatly with environmental conditions. Banding of N generally has greater benefits when moisture level, yield potential and N use are high. Therefore, on the Black, Dark Grey and Grey soil zones of the Canadian prairies, banding of N may have a large advantage over broadcast applications (Tables 2 and 4). Under drier conditions, such as on the Brown and Dark Brown soils, the soil disturbance caused by banding may lead to loss of moisture and seed-bed quality great enough to reduce yields. Since the level of N required to optimize yield under dry conditions may be relatively low, seed-placed N may be the best option in many of the drier areas of the prairies.

Nitrogen fertilizer can be pre-plant banded in the spring, side-banded during seeding, seed-placed (which is also a form of banding), and injected or nested into the soil near the time of planting or later in the growing season. Once fertilizer N is in the nitrate form, it is mobile in the soil and will move out from the band relatively quickly. This is why one rarely notices much "striping" from anhydrous ammonia bands, even when they are placed 16 inches apart. Due to the ability of the N to move through the soil, the precise location of the band is not critical and the various in-soil banding methods are generally equally effective in terms of N use efficiency. Therefore, seed-placed, side-banded or pre-plant banded N fertilizer will be equally effective, as long as the rate is not high enough to produce seedling damage. This is shown in Table 5, where at 50% of the recommended rate, these placements produced similar yields. As the amount of fertilizer applied increased, the yield obtained with seed-placed urea decreased in comparison to that obtained with the pre-plant band or the side-band, until at 150% of the recommended rate, yield with the seed-placed urea was lower than with the 50% rate.

Table 5: Grain yield of Argyle barley under reduced tillage as influenced by fertilizer source and placement, at 50%, 100% and 150% of recommended application rates (3 years data)(Unpublished data-Ag. Quest)

| Method of Application | 50% | 100% | 150% |
|---|---|---|---|
| | --------------------kg per hectare | ------------------ | |
| Fall banded urea | 65.7 | 83.9 | 94.7 |
| Spring banded urea | 62.6 | 80.7 | 92.3 |
| Side-banded urea | 61.3 | 79.8 | 88.9 |
| Seed-placed urea | 60.3 | 77.0 | 52.9 |
| Broadcast urea | 57.9 | 74.0 | 89.7 |
| Injected UAN (28-0-0) | 60.8 | 81.3 | 86.5 |

A banding operation will generally lead to some soil disturbance, which may or may not be a problem. Seed-placed N is effective, but as mentioned previously, care has to be taken to avoid exceeding the levels that can be tolerated by the emerging seedling. A number of openers and seeders are on the market that have the ability to side band the fertilizer away from the seed. This is an efficient form of placement (Table 5). However, there have been problems with achieving sufficient seed-fertilizer separation with some of the openers, leading to severe problems with crop emergence. Some newer seeders available do a good job of side banding, but there is frequently a large price tag attached to these machines. Also, there can be an increase in draft requirement and often in seed-bed disturbance associated with a side-band operation.

Table 6: Effect of source and rate of side-banded N fertilizer and herbicide application on stand density (plants m$^{-2}$) at two weeks of canola (2000)

| N Rate | Herbicide | | | | No Herbicide | | | |
|---|---|---|---|---|---|---|---|---|
| kg ha$^{-1}$ | UAN | UAN+UI | Urea | Urea+UI | UAN | UAN+UI | Urea | Urea+UI |
| 0 | 101 | 101 | 101 | 101 | 120 | 120 | 120 | 120 |
| 40 | 123 | 108 | 98 | 123 | 109 | 131 | 106 | 128 |
| 80 | 110 | 121 | 118 | 105 | 99 | 138 | 111 | 141 |
| 120 | 84 | 124 | 113 | 121 | 105 | 110 | 108 | 128 |
| 160 | 84 | 99 | 89 | 113 | 93 | 119 | 90 | 121 |
| 200 | 66 | 108 | 85 | 125 | 68 | 118 | 83 | 119 |
| Mean | 95 | 110 | 101 | 115 | 99 | 123 | 103 | 126 |

Table 7: Effect of source and rate of side-banded N fertilizer and herbicide application on seed yield (bu/acre) of canola on a clay loam soil (2000)

| N Rate | Herbicide | | | | No Herbicide | | | |
|---|---|---|---|---|---|---|---|---|
| kg ha$^{-1}$ | UAN | UAN+UI | Urea | Urea+UI | UAN | UAN+UI | Urea | Urea+UI |
| 0 | 25.1 | 25.1 | 25.1 | 25.1 | 12.9 | 12.9 | 12.9 | 12.9 |
| 40 | 29.3 | 25.3 | 22.2 | 28.6 | 24.6 | 20.6 | 21.5 | 22.3 |
| 80 | 19.1 | 27.9 | 30.6 | 29.9 | 21.5 | 24.1 | 28.3 | 25.9 |
| 120 | 25.5 | 27.7 | 29.4 | 30.0 | 25.5 | 23.6 | 23.2 | 25.5 |
| 160 | 28.7 | 28.7 | 26.1 | 26.8 | 23.2 | 29.7 | 22.5 | 25.8 |
| 200 | 19.1 | 27.7 | 21.2 | 31.7 | 18.7 | 29.9 | 17.7 | 26.2 |
| Mean | 24.5 | 27.1 | 25.8 | 28.7 | 21.0 | 23.5 | 21.0 | 23.1 |

Even when seed-fertilizer separation is maintained, seedling damage may occur (Table 6). Many seeders are designed to place the fertilizer an inch to the side and an inch below the seed. With wide row spacings, high fertilizer rates, or sensitive crops, this spacing may be insufficient and damage may occur in situations that promote seedling toxicity. Risk factors include high pH carbonated soils, soils with low cation exchange capacity (i.e. coarse textured soils, soils with low organic matter content), drying conditions after seeding, and application on sensitive crops, such as canola or flax. If the seed-fertilizer separation is not maintained, risk of damage will also be higher. Seedling damage will not always translate into a reduction in crop yield at the end of the growing season, but yield may be reduced depending on the growing season (Table 7). Where risk of damage is considerable, it may be advisable to increase the separation between seed and fertilizer band, to use a less-damaging fertilizer source, or to consider an alternate method of fertilizer application.

Seed Placement: Placement of fertilizer in the seed-row is a popular option, since it eliminates an extra pass for fertilizer application. If the fertilizer is placed directly with the seed, it eliminates the extra expense, draft requirements and soil disturbance required to side-band the fertilizer requirements. Seed-row placement is a form of banding, so is efficient in terms of reducing N losses. However, applying excess nitrogen with the seed can lead to seedling damage, reduced crop yields, reduced response to nitrogen fertilizer and reduced nitrogen use efficiency.

The amount of seed-placed fertilizer that can be safely applied depends on a number of factors including environmental conditions, crop grown, soil type, width of the seed/fertilizer band, row spacing and fertilizer source. Use of air seeders with wide sweeps allows for increased levels of seed-placed fertilizer, since the concentration of fertilizer in contact with the seed is reduced as the seed and fertilizer are spread over a wider zone. Rate applied with the seed must be decreased with light textured soils, low soil organic matter, cool growing conditions, low soil moisture, in the presence of salts or free lime, or with the use of wide row spacing. Small seeded crops such as flax or canola are more sensitive to seedling damage than crops such as wheat or barley. With cereal crops, urea tends to be more damaging than ammonium nitrate, while urea ammonium nitrate (UAN) tends to be intermediate, since it is a blend of urea and ammonium nitrate. With canola, there seems to be less difference between urea and UAN in seedling damage (Tables 6 and 7). The amount of damage from seed-placed fertilizer can vary greatly from year to year, depending on the specific conditions at seeding, so a rate that caused no problems one year may cause significant damage the next. A reasonable compromise may be to apply a portion of the fertilizer with the seed and broadcast the remainder.

Table 8: Effect of seed-placed urea, with (UI) and without (NI) the urease inhibitor NBPT, on stand density (plants $m^2$) of Bedford barley on a clay loam and fine sandy loam soil, from 1994 to 1996.

| | Clay Loam | | | | | | Fine Sandy Loam | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N | 1994 | | 1995 | | 1996 | | 1994 | | 1995 | | 1996 | |
| kg ha$^{-1}$ | NI | UI | NI | UI | NI | UI | NI | UI | NI | UI | NI | UI |
| 0 | 107.5 | | 163.1 | | 131.9 | | 107.5 | | 127.5 | | 140.6 | |
| 20 | 85.0 | 92.5 | 156.9 | 156.2 | 122.5 | 140.0 | 104.4 | 109.4 | 140.0 | 141.2 | 147.5 | 155.0 |
| 40 | 86.2 | 99.4 | 133.8 | 160.6 | 131.2 | 128.1 | 89.4 | 89.4 | 133.1 | 142.5 | 136.9 | 147.5 |
| 60 | 80.0 | 90.0 | 128.1 | 159.4 | 123.1 | 125.0 | 65.0 | 83.1 | 120.6 | 125.6 | 113.1 | 143.8 |
| 80 | 60.0 | 76.2 | 112.0 | 166.2 | 111.2 | 140.0 | 48.8 | 87.5 | 117.5 | 121.2 | 119.4 | 142.5 |
| 100 | 51.2 | 66.9 | 78.8 | 144.4 | 111.2 | 131.2 | 49.4 | 78.8 | 90.0 | 138.8 | 90.0 | 148.8 |

Use of urease inhibitors may increase the level of urea that can safely be applied with the seed. Since urease inhibitors will slow the conversion of urea to ammonium/ammonia, the concentration of toxic salts and ammonia in contact with the seedling will be reduced and the urea will have a greater opportunity to diffuse away from the seed before causing injury. Field studies have shown that this can increase stand density and vigour at high rates of urea application, leading to a higher final yield (Tables 8 and 9).

Table 9: Effect of seed-placed urea, with (UI) and without (NI) the urease inhibitor NBPT, on grain yield (bu/acre) of Bedford barley on a clay loam and fine sandy loam soil, from 1994 to 1996.

| | Clay Loam | | | | | | Fine Sandy Loam | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N | 1994 | | 1995 | | 1996 | | 1994 | | 1995 | | 1996 | |
| kg ha$^{-1}$ | NI | UI | NI | UI | NI | UI | NI | UI | NI | UI | NI | UI |
| 0 | 53.2 | | 46.8 | | 56.7 | | 38.7 | | 30.0 | | 62.5 | |
| 20 | 53.1 | 54.6 | 46.4 | 45.7 | 55.1 | 54.9 | 45.6 | 46.6 | 31.8 | 28.0 | 57.9 | 60.0 |
| 40 | 54.7 | 65.6 | 40.3 | 42.4 | 61.0 | 58.6 | 37.7 | 40.0 | 38.8 | 42.9 | 62.1 | 70.1 |
| 60 | 61.7 | 69.1 | 49.5 | 51.0 | 50.0 | 41.8 | 36.1 | 40.3 | 37.8 | 34.0 | 61.6 | 68.3 |
| 80 | 60.7 | 68.7 | 37.8 | 57.7 | 61.5 | 61.4 | 31.9 | 41.2 | 45.7 | 39.6 | 60.2 | 67.1 |
| 100 | 69.6 | 69.2 | 36.5 | 48.8 | 29.7 | 50.8 | 27.5 | 49.9 | 33.7 | 45.3 | 65.2 | 73.0 |

Post-seeding Applications: Nitrogen fertilizer can be top-dressed, dribbled, spoked or injected after crop emergence. Generally, where soil levels of N are low, early applications will have the most benefit, since crop yield potential is determined early in crop growth. Ideally, N should be applied to cereals at or before the 3-5 leaf stage and prior to canola bolting. As adverse weather may delay post-seeding applications, some N should be applied at seeding, where available soil N is low

Surface applications will be subject to the same considerations as with surface applications prior to seeding, so nitrate sources will generally be more efficient than ammonium or urea sources. Losses will be higher on high pH soils. There may also be an enhance risk of stranding of N at the soil surface with prolonged dry weather. Spoke-wheel or coulter application may reduce N losses and the risk of “stranding” but if there is substantial soil disturbance, problems may occur with stand damage and moisture loss. Likelihood of a benefit from post-seeding applications increases with the likelihood of receiving significant in-season precipitation. This is both because the crop is more likely to be able to access and take up the applied N and because in areas where yield is primarily limited by available moisture, in-season rainfall increases yield potential and response to applied N.

Late applications for protein enhancement: Late applications of N are frequently applied to enhance grain protein content. Late applications of N generally affect protein more than yield. Since there is little impact of the late application on crop yield, there is less dilution of the protein produced, unlike with early applications where concurrent yield increases dilute protein. Nitrogen accessed later in the season may be more effectively channelled to the grain, as it is not immobilized in vegetative parts. However, timing of N supply must still be early enough in plant development to allow sufficient time for plant uptake and translocation. Applications from the boot stage until slightly after anthesis have been effective in increasing protein content in wheat, with the largest increases occurring when N was applied close to anthesis.

In-crop “foliar” applications of urea ammonium nitrate or urea solutions are frequently used to increase grain protein content, in the belief that N is absorbed more efficiently through the leaf than from soil. In reality, very little of the foliar-applied N is normally taken up through the leaf (Table 10) and the majority of the “foliar-applied” N is accessed by roots once the fertilizer washes off and reaches the soil. Soil-applied dribble-banded or broadcast in-crop N tends to be more effective than foliar application, if there is sufficient time and moisture for the N to be dissolved and moved into the root zone (Table 11). Soil application of in-crop N will also reduce the risk of crop damage due to leaf burn. The small amount of N that is absorbed through the leaf with foliar applications may still be able to increase protein content under dry conditions or late in the season, where the crop may not be able to utilize soil-applied fertilizer.

Table 10: Uptake of soil and foliar applied urea (%) as affected by NBPT and Agral 90 in two growth chamber experiments (Rawluk et al. 2000)

| Treatment | Experiment 1 | Experiment 2 |
|---|---|---|

| | | |
|---|---|---|
| Soil | 37.0 | 67.7 |
| Soil + NBPT | 57.0 | 67.1 |
| Foliar | 7.8 | 11.3 |
| Foliar + NBPT | 9.4 | 10.6 |
| Foliar +Agral 90 | na | 26.7 |

Table 11 : Effect of timing and source of addition of 15 kg N supplement to base rate on protein content (%) of hard red spring wheat (Melfort, 1997)

| | All N banded at Seeding | 60 kg N $ha^{-1}$ at seeding plus 15 kg N $ha^{-1}$ as foliar UAN | 60 kg N $ha^{-1}$ at seeding plus 15 kg N $ha^{-1}$ as broadcast ammonium nitrate |
|---|---|---|---|
| 60 kg N $ha^{-1}$ | 10.5 | -- | -- |
| 75 kg N $ha^{-1}$ | 11.1 | -- | -- |
| N at Tillering | -- | 10.9 | 11.7 |
| N at Boot | -- | 11.2 | 12.1 |
| N at Anthesis | -- | 12.0 | 11.4 |

For soil-applied in-crop applications of N, ammonium nitrate may be a better source than urea or urea ammonium nitrate, as it is less subject to volatilization loss than ammonia- and ammonium-producing sources such as urea. Efficiency of broadcast urea can be improved by use of a urease inhibitor or with irrigation or significant rainfall after fertilizer application.

While in-crop applications of N can be used to increase protein content, there are some problems associated with this technology. In-crop applications of N will not always increase protein content. Increases are less likely when initial levels of N for the crop are relatively high or when growing conditions reduce the yield potential and hence the N requirements of the crop. Granular applications of N on dry soil will be ineffective if rainfall does not occur and the fertilizer is stranded on the soil surface. Foliar applications can cause leaf burn and lead to a yield decrease. In-crop applications require another operation with extra labour and expense.

If initial applications of N at or prior to seeding are high enough to ensure optimal yield, then protein levels should be in the range of 13-14%, for Canadian Hard Red Spring wheat. A similar level was suggested by Dan Long and Rick Engel for Hard Red Spring wheat in Montana, while Jay Goos found a range of 11-12% for winter wheat in Colorado. If higher levels of protein are desired, it may be more beneficial to increase early season N application, where there may be an impact on yield and protein content, rather than to rely on in-crop N applications. This is especially true if protein levels have been low in this past, as this may be an indication that insufficient N has been applied to optimize crop yield. Fertilization for a reasonable target yield and use of “best management practices" for N management to minimize N loss and optimize fertilizer use efficiency are key steps in production of high protein wheat.

## **Pulling the Package Together**

Balancing crop N requirements with N supply requires an understanding of the factors driving crop yield potential, N inputs into the systems and fertilizer use efficiency. The farm operator must then take this information and make it work with the goal of improving the efficiency of his entire farming system.

Ultimately, any N fertilization package has advantages and disadvantages. In selecting the optimum fertilizer management system, the balance between rate of application, cost and availability of equipment, soil disturbance, seed-bed quality, moisture conservation, time and labour constraints and fertilizer use efficiency must be considered against the backdrop of the other demands in the overall operation. The objective is to improve farm management not just fertilizer management. With competing demands within the operation for time, labour, equipment and financial resources, flexibility in nutrient management is an important consideration. Often losses in efficiency in one area can be compensated for by improvements in efficiency in another. The "best" management system is not fixed, but will depend on the major limiting factors on each individual farm.