Understanding Nutrient Cycling and Maximizing Fertilizer Efficiency

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Crops require a number of different nutrients. There are at least 16 elements known to be essential for plant growth. Carbon (C), hydrogen (H), and oxygen (O) are derived from carbon dioxide (CO_2) and water (H_2O). Nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca), magnesium (Mg), boron (B), chlorine(Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo) and zinc (Zn) are normally derived from the soil in the form of inorganic salts. Ninety-four to 99.5 per cent of fresh plant material is made up of carbon, hydrogen and oxygen. The other nutrients make up the remaining 0.5 to 6.0 per cent.

Macronutrients refer to those elements that are used in relatively large amounts, whereas micronutrients refer to those elements that are required in relatively small amounts (Table 1).

TABLE 1. Essential Plant Nutrients

Supplied from air and water	Supplied from soil and fertilizer sources	
	Macronutrients	**Micronutrients**
Carbon (C)	Nitrogen (N)	Zinc (Z)
Hydrogen (H)	Phosphorous (P)	Copper (Cu)
Oxygen (O)	Potassium (K)	Iron (Fe)
	Sulphur (S)	Manganese (Mn)
	Calcium (Ca)	Boron (B)
	Magnesium (Mg)	Chlorine (Cl)
		Molybdenum (Mo)
		Cobalt (Co)

Nitrogen (N) is often the most deficient of all the plant nutrients. Most crops are very sensitive to insufficient nitrogen and very responsive to nitrogen fertilization. This paper will focus on soil N cycling and factors affecting N fertilizer utilization.

Factors Influencing Crop Response to Nitrogen Fertilizer

The utilization of applied nitrogen fertilizer depends on the availability of soil nitrogen and the potential losses of applied nitrogen. Various other agronomic factors can cause a poor response to applied nitrogen including:

Cultivar

Varieties with higher yielding potential will respond to higher rates of applied nitrogen than those with lower yield potential, providing that other factors are not limiting.

Available Soil Nitrogen

Available soil nitrogen at planting time is one of the main factors that will influence crop response to fertilizer nitrogen. The nitrogen status of a field can be estimated from the previous cropping history, but is more accurately determined by a soil test. Soils that have low plant available nitrogen will require more fertilizer nitrogen.

Delayed or Late Seeding

Late seeding usually results in a lower yield potential and therefore reduced response from nitrogen fertilizer due to moisture/heat relationships. Also, there is greater risk of crop loss from increased disease pressure, insects, frost and poor harvest conditions.

Weed Competition

Weeds compete with crops for moisture, nutrients and light. Applied nitrogen fertilizer may stimulate the growth of weed seedlings almost to the same extent as wheat. It is therefore important to control weeds in order to minimize the competition between weeds and wheat plants. Banding fertilizer or placing fertilizer with the seed makes it less accessible to weeds during the early growing season. However, if too much fertilizer is seed-placed injury to the seedling will reduce emergence resulting in higher weed competition.

Disease Infestation

Well nourished, healthy plants provide a measure of resistance to many disease organisms. Inadequately nurtured plants seem to be predisposed to certain diseases such as common root rot. Some diseases are reduced such as take-all root rot when wheat absorbs ammonium nitrogen and is increased when the plants take up excessive amounts of nitrate nitrogen.

Soil Moisture

In lower rainfall soil zones, soil moisture reserves must be considered when choosing fertilizer rates. On medium textured (loam) soils in the brown and dark brown soil zones, moist soil to a depth of 75 cm (30 in) and 68 cm (27 in) respectively is considered adequate for re-cropping stubble land. On fine textured (clay) soils in the brown and dark brown soil zones, moist soil to a depth of 55 cm (22 in) and 50 cm (20 in) respectively is considered adequate for re-cropping. When soil moisture exceeds these levels, higher rates of nitrogen will generally give economic returns. If the entire rooting zone (90-120 cm) (35-47 in) is moist, rates up to twice those normally recommended can be profitable.

The risk of crop damage or failure is higher on poorly drained or flood prone fields. Lower nitrogen fertilizer applications are advised on these fields if adequate drainage cannot be provided. Although well fertilized crops usually withstand more water, if water stands for more than 2 or 3 days causing saturated conditions, considerable crop damage or complete failure may result.

Coarse textured soils with water tables deeper than 1.2 to 1.8 m (4 to 6 ft) below the surface are often droughty. Yield potential to a large extent is restricted by lack of moisture. High rates of nitrogen fertilizers are generally not recommended in these soils.

Nitrogen Immobilization and Losses

It is very important to understand how nitrogen can be added or lost from the soil. There are a number of terms used to define N additions and losses.

Volatilization

Nitrogen from fertilizers containing ammonia or urea can be lost through volatilization as ammonia gas to the atmosphere. Ammonia volatilization increases with increasing soil pH, soil carbonate content and pH of the added fertilizer. These types of losses are far greater with urea (46-0-0) than with ammonium nitrate fertilizers (34-0-0) and ammonium sulphate (21-0-0-24).

Losses are greater in alkaline (high pH) soils than from acid soils and are higher under dry as compared to wet soil conditions.

The losses from course sandy soils are usually higher than from fine textured clay soils and are greater at high temperatures than at low temperatures. Greatest volatile losses can occur where there is just enough moisture to put fertilizer into solution, but not enough to move it in to the soil, followed by hot, dry windy conditions. Loss due to ammonia volatilization can be eliminated or greatly reduced if fertilizer is banded or well incorporated into the soil.

Ammonium fixation

The ammonium (NH_4^+) form of nitrogen can be temporarily retained by some clay minerals. Much of this nitrogen can be used by the plants at some time during the growing season. Ammonium fixation is generally not considered to be a major factor by which fertilizer nitrogen availability is reduced.

Erosion

Nitrogen fertilizer can be lost in runoff waters and through soil erosion caused by either wind or water. Runoff losses of applied fertilizers can be reduced by banding fertilizer into the soil. Cultural methods to control wind and water erosion should be used to minimize N losses. Generally, it is not advisable to apply fertilizer to frozen soils.

Leaching

Leaching refers to the movement of nitrate nitrogen in the soil solution through and out of the root zone. When leaching occurs, nitrogen is lost from the root zone, thereby reducing the utilization of nitrogen by wheat plants. Losses of this nature are minimal during winter and the growing season. However, nitrate leaching can occur during late fall or early spring, in particularly sandy soils or irrigated soils. Leaching can also be a significant problem on summerfallow land. Generally, nitrate leaching is a less serious concern in clay soils. Leaching losses of nitrogen applied in the spring close to the time of seeding are minimal on most soils. Leaching losses are also reduced by using ammonium fertilizers banded into the soil.

Immobilization

Immobilization refers to the conversion of plant available nitrogen to organic nitrogen by soil micro-organisms. This nitrogen is not lost but is tied up temporarily and is released slowly for crop use through mineralization. It is important to remember that soil microbes compete with growing crops for applied nitrogen fertilizer, which may result in reduced crop growth.

Immobilization of ammonium nitrogen is slightly greater than immobilization of nitrate-nitrogen. Considerable amounts of inorganic nitrogen are removed by immobilization (20 to 40%) from the available form. Higher nitrogen immobilization in surface soil under minimum and zero till management may reduce available nitrogen to crops in the early part of the growing season. Banding of nitrogen rather than broadcast incorporation is effective to decrease nitrogen losses by immobilization.

Denitrification

This process results in the reduction of nitrate-nitrogen to nitrogenous gases such as nitrogen (N_2) and nitrous oxide, which are lost to the atmosphere. Considerable nitrate-nitrogen may be lost by denitrification when soils are temporarily wet (early spring or after heavy rainfall). This is because the micro-organisms that convert nitrate to nitrogenous gas work optimally under high moisture or saturated soil conditions.

Areas of the province, such as west central Alberta, that tend to be saturated for extended periods in the spring are the most prone to significant denitrification losses. For this reason, nitrogen fertilizer should not be applied in the fall to areas that are subject to saturated soil conditions in the spring or to low lying land subject to flooding. Because of possible denitrification losses, it is generally recommended that fall applied nitrogen be banded in the ammonium form and applied as late as possible when the soil is cold, so that the nitrogen will remain in the ammonium form. Denitrification losses do not occur as long as the fertilizer nitrogen is present in the ammonium form. On summerfallow fields, the available nitrogen is present in the nitrate form, and is, therefore quite vulnerable to losses under excess moisture conditions.

Some recent studies in Saskatchewan have shown that there is a greater potential for losses of nitrogen through denitrification under minimum and zero-till cropping conditions than when conventional tillage is practiced because soil is moister.

Nitrogen Fertilizer Application in Fall versus Spring

Farmers frequently ask about the relative effectiveness of fall versus spring nitrogen fertilizer applications. In a nutshell, fall fertilization can range from very effective to disastrous depending on soil moisture, the form of nitrogen used and how it is applied. To understand why we must understand the fate of fertilizer N in soil.

Fertilizer N is applied to soil in the form of urea ($CO(NH_2)_2$), anhydrous ammonia (NH_3), ammonium (NH_4^+), or nitrate (NO_3^-) depending on the product used. Urea and anhydrous ammonia quickly convert to ammonium. It is the ammonium and nitrate forms that are taken up by plants. If the soil is warm, moist and well aerated, ammonium is rapidly oxidized to nitrate through the nitrification process. This is a biological process performed by highly specialized soil bacteria.

Banding slows the nitrification process by creating an environment near the band that inhibits the activity of the bacteria converting ammonium to nitrate. Therefore, if urea or anhydrous ammonia is banded in late fall, most of the N is retained in the ammonium form until the soil warms up in the spring. If the fertilizer is broadcast or banded in early fall, likely most of the ammonium will be converted to nitrate prior to freeze-up, large losses can occur when soils are water saturated during and just after snow melt in early spring. The losses are caused by an anaerobic process called denitrification, which converts nitrate to nitrogen and oxygen gases.

TABLE 2. Efficiency of nitrogen fertilizer application.

Fall-Applied N as a Percent of Spring Broadcast and Incorporated				
	Soil Climate Categories			
Application Method	Dry	Medium	Wet	Irrigated
Spring Broadcast and Incorp	100	100	100	100
Spring Banded	120	110	105	110
Fall Broadcast and Incorp	90	75	65	95
Fall Banded	120	110	85	110

Dry-Well drained soils, which are seldom saturated during spring thaw.

Medium-Well to moderately drained soils that are occasionally saturated during spring thaw for short periods.

Wet-Poorly to moderately drained soils that are saturated for extended periods during spring thaw.

Irrigated-Well drained soils in southern Alberta that are seldom saturated during spring thaw.

(Source: Agdex 542-7)

Research has also shown that denitrification will occur in virtually all of our agricultural soils. This is not surprising since denitrification is not a particularly specialized function. Many different types of soil bacteria use denitrification as an alternative form of respiration when oxygen is in short supply.

What this means in terms of fertilizer management is that no soil type or region of the province is 100% safe when it comes to losses of fall-applied N. The risk of over winter N loss is highest in regions with moister climates such as west central Alberta. There is less risk in regions that tend to be drier such as southeastern Alberta, but even in these regions N losses can be high during a wet spring. In general, however, N losses through denitrification in the drier regions are normally small and fall banded N is equal to spring banded N (Table 2). In cases where spring banding causes a significant loss of seedbed moisture, fall banding can be superior to spring banding.

Also keep in mind that denitrifying bacteria are less than 2 millonths of a meter in size. They could care less about the regional climate or moisture level during a given spring. They only respond to what is happening in their tiny corner of your field. What does this mean? It means micro-climate is also important. Even during dry springs, there are localized wet areas such as depressions where denitrification can occur. Think about this in terms of your own fields. Are they uniformly flat and well drained? Not likely. There are always spots that are wetter than the rest. Where runoff accumulates after a rain or spring snow melt. Over winter N losses can vary greatly over a short distance. Fall-applied N can be very effective on upland and totally ineffective in a depression just a short distance away.

It is important to remember fall-application always puts your fertilizer N at risk. The level of risk is generally assessed at the regional level, but whether or not losses occur is a function of very local conditions.

General rules about application methods and timing:

- Generally spring banded is the most effective method of application and fall broadcast the least effective.
- Fall banded N will be as effective as spring banded if there is no extended period of saturation in the spring.
- Fall banded N may be more effective than spring banded when lack of seedbed moisture is a concern.

With this information in mind here are a few tips to consider before fertilizing in fall:

- If your soils tend to be saturated with water for extended periods in the spring, then fall-application is probably not a good option. However, if saturated soil conditions are normally not a problem, then you should get good results from fall banding.
- Soil test to determine the optimum rates of fertilizer required. Producers should sample 0-6, 6-12, and 12-24 inches to determine the cumulative N to two feet.
- Apply a conservative rate, say 75% of soil test recommendation, or 75% of what you would expect to apply, if you haven't got your soil test results back at time of application. This conservative fall rate is a hedge against such things as high soil test N levels, or low spring moisture or low crop prices. If conditions look favorable in spring, additional N can be drilled with the seed. Take note however that the amount of additional N that can be drilled with small seeded crops like canola is only 10 pounds with a disk drill and 20 – 35 lbs. with an air seeder.
- Select a fertilizer formulation that is right for your conditions. Generally under low risk conditions such as in southern Alberta, anhydrous ammonia (82-0-0), urea (46-0-0), ammonium nitrate (34-0-0), or liquid nitrogen (28-0-0) perform equally well when fall banded. However, soils in southern Alberta tend to be alkaline and losses through ammonia volatilization can occur if the bands are too shallow or the soil is dry and cloddy.
- Avoid the use of the nitrate containing products 34-0-0 and 28-0-0 on soils that tend to be saturated in the spring. Nitrates are subject to both denitrification and leaching losses under wet spring conditions.

- Apply N in late fall after the soil temperature has dropped below 7 C and the nitrification process has slowed down.
- Band, don't broadcast. Banding restricts the contact between soil and fertilizer and as a result over winter losses are lower.

As you can see there are a number of agronomic factors to consider before fall application of N fertilizer. You may want to consult with a soil fertility specialist while you're setting up your fall fertilizer program.

Other management factors should also be considered in deciding to fall fertilize including:

- Fall fertilization can improve your time management. By applying fall-fertilizer a field operation can be eliminated in the spring and allow earlier planting.
- Fertilizer prices and payment schedules tend to be more favorable in the fall, making it economical to fall apply.
- Availability of product and application equipment is often better in the fall than during the peak demand periods in spring.
- Soils tend to be drier in the fall, so N application equipment is less likely to cause soil compaction.

This covers the major points to keep in mind when deciding to fertilize in the fall. It is always a good idea to get several opinions and consider all the factors before you make your final decision.

Nitrogen Fertilizer Placement

The method of placement and time of application can have significant effect on the efficiency of nitrogen fertilizer by increasing yield and/or protein. Methods of application include:

1. Drilling in with the seed
2. Sideband placement
3. Banding into soil prior to seeding
4. Broadcast and incorporated into the soil
5. Broadcast without incorporation
6. Foliar application

There are a number of factors which will influence the magnitude of wheat response to N fertilizer and its placement. These include:

1. Rate of fertilizer - the higher the rate, the less impact placement will have.
2. Soil test levels - the higher the soil test level, the less impact placement will have.
3. The higher the rainfall, the less impact placement has.
4. Ammonium nitrate is less sensitive than urea based fertilizer to placement. Anhydrous ammonia (NH_3) has to be banded.
5. Crop rotation - legumes in rotation with cereals can reduce the impact of placement.

Drilled in with the seed

Drilling N with the seed is one of the most effective means of adding nitrogen fertilizer. The safe rates of N fertilizer that can be seed-placed is provided in Table 3. If seedbed moisture conditions are favorable, up to 45 kg N/ha (40 lb/ac) can be applied with the seed. More than 20 kg N/ha (18 lb/ac) when applied with a double disc drill can cause seedling damage and reduce yield increases. Higher rates of urea can be used with seeding equipment which spread the seed and fertilizer in a wider band. Many air seeders are capable of creating a band 4-8 inches wide.

TABLE 3. Safe rates of seed-placed fertilizer

Crop	Soil texture	Seedbed soil moisture	Phosphate	*Double disc or narrow hoe drill		**Pneumatic seeder 50% spread	
				Urea	Ammonium nitrate	Urea	Ammonium nitrate
				lb/ac of Nitrogen (N)			
Wheat Barley Oats	Medium to fine	Good Poor	50 50	30 20	45 30	45 30	65 45
	Coarse	Good Poor	50 50	20 15	30 20	35 25	55 35
Small seeded crops	All textures	Good Poor	10-20 0-10	10 0	20 10	20 10	35 25

Sideband placement

Sideband placement of N is equal in effectiveness to N drilled with the seed, however, it has the advantage that higher amounts can be used. Attachments for side banding are only available on some types air seeders and direct seeding equipment. Therefore, this type of N placement has limitations to fertilize spring wheat. A form of side banding which has been developed in recent years is the paired row system, where fertilizer is placed between two seed rows. Certain hoe drills and air seeders can be adapted for this purpose. An advantage of side banding is that fertilizer is more selectively available, favoring the crop more than the weeds.

Banded into soil prior to seeding

Banding N into soil, prior to seeding is about equal in effectiveness to side banding or seed placement. Nitrogen fertilizer is applied in a band behind a shank or disc at depths of 7.5 to 10 cm (3-4 in). Generally, seeding can take place immediately after fertilizer application. In the past, it was recommended that seeding be delayed for two days after banding anhydrous ammonia (NH_3). However, in many soils as long as the NH_3 is placed 5- 7.5 cm (2-3 inches) away from the seed, NH_3 can be applied at the time of seeding. Seed damage from NH_3 is most likely to occur under dry conditions on sandy soils when there is insufficient separation from the seed. Placement of fertilizer nitrogen should be deeper in sandy soils than in loams or fine textured clay soils. Narrow band spacing 25 to 30 cm (10-12 in) is better than wider band spacing particularly under low moisture conditions. Research has shown that with low soil moisture, in cool spring conditions, narrower spacing are more effective in minimizing temporary or season long N deficiency.

Broadcast and incorporated into the soil

Generally, this method does not result in a yield and/or protein increases as large as those obtained by band placement. To minimize volatilization losses, urea and liquid or dry fertilizer containing urea should be well incorporated into the soil. Shallow incorporation of these fertilizers may result in ammonia volatilization. In cases where incorporation is not desirable due to moisture or soil conservation reasons, losses are reduced by applying fertilizer at a soil temperature of less than 5°C or by applying ammonium nitrate fertilizer which is not subject to volatilization losses.

Broadcast without incorporation

This method is the least efficient use of fertilizer nitrogen. When urea is used, ammonia volatilization losses can be appreciable resulting in lower yield and/or protein content than obtained when the fertilizer nitrogen is incorporated or banded. The use of ammonium nitrate is the preferred source of nitrogen for surface broadcast application due to its low volatilization potential.

Foliar nitrogen application

Nitrogen in liquid form has been foliar applied at heading to the soft dough stage with some success to increase wheat protein content. Applications are generally in the range of 7 to 15 kg/ha (6 to 14 lb/ac) of N. Rates above 20 kg/ha can potentially cause some tissue burning resulting in crop injury

Fertilizer Recommendations

Fertilizer recommendations are based on the results of the soil test analyses and on the nutrient requirement of the crop to be grown. Recommendations on time and method of fertilizer application are also included. Each soil testing lab has its own philosophy for making fertilizer recommendations. Two examples are:

1. Recommendations which indicate the nutrient requirements and yield potentials for optimum economic production based on moisture conditions of the field. In the example below are Economic returns of N fertilizer with barley in Thin Black soil zone with 6” Stored Water and average growing season precipitation with a soil N level of 40 lb/ac:

N Fert:	0	10	20	30	40	50	60	70	80	90	100
Ex Yield:	43.3	49.6	54.8	59.3	63.1	66.5	69.5	72.1	74.4	76.5	78.4
Yield Inc.		6.2	5.2	4.5	3.9	3.4	3.0	2.6	2.3	2.1	1.9
Fert Cost: $0 .42/lb		4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20
Barley @ $2.00		12.40	10.40	9.00	7.80	6.8	6.0	5.20	4.60	4.20	3.80
Fert Cost: $0 .32/lb		3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20
Barley @ $3.00		18.6	15.60	13.5	11.70	10.20	9.00	7.80	6.90	6.30	5.70

In the example above, with high soil moisture, 50-60 lb N/ac of fertilizer would be most economic if fertilizer was 42 cents/lb and barley was worth $2.00/bu. However, if fertilizer cost was 32 cents/lb and barley was worth $3.00/bu, then 90 lb N/ac would be economic.

2. "Target Yield Recommendations" which indicate the nutrient requirements for a range of various lower and higher yield potentials under the same moisture conditions. With this information the producers have the flexibility of selecting a fertilizer application rate or target yield that best suits their individual situation.

Summary

Producers must keep in mind that optimum yields of high quality crops cannot be obtained without adequate fertilization, and most soils are deficient in essential elements. Fertilization, however, will neither increase yield or quality of a crop if other management inputs and cultural practices are not optimal, nor will it increase yield if the added nutrients are not required. Therefore, the most successful fertilizer program will be based on knowledge of soil nutrient status combined with optimum crop and fertilizer management practices.

For further information on optimizing N or other fertilizers contact the Alberta Ag-Info Center at 1-800-882-7677.