Manitoba
Soil Fertility Guide

REVISED 2007

COVERING NEW GROUND
Manitoba Agricultural Sustainability Initiative

Manitoba

Guidelines in this publication are based upon traditional recommendations developed by the Manitoba Soil Fertility Advisory Committee, and updated through new research findings.

When possible, concepts and recommendations are referenced to the source of the original research or review of that research.

Table of Contents

Tables

Figures

Appendix:

INTRODUCTION

Providing an adequate supply of essential plant nutrients has a major impact on crop yields and is one crop production factor that can be readily managed.

The purpose of this guide is to provide an overview of soil fertility practices in Manitoba and general fertilizer use considerations. Producers are encouraged to use this information in conjunction with reliable soil tests, their own experience and, when required, the assistance of a professional agronomist to develop effective, environmentally sound and economically viable fertilizer management practices.

Five key practices must be implemented to achieve this goal:

- apply only those nutrients that will result in economic yield increases
- apply appropriate nutrient rates
- apply appropriate sources of fertilizer nutrients
- apply nutrients at appropriate timing
- apply using the most effective and practical application techniques

Practices that are economically effective and practical will serve to minimize potential adverse effects on the quality of soil and water resources.

Nutrient requirements and crop responses on Manitoba soils

At least 16 elements are essential plant nutrients. An insufficient supply of any one or more of these nutrients can have a detrimental effect on plant growth and, ultimately, crop yields. All but three of these nutrients, carbon, hydrogen and oxygen, are derived mainly from the soil. Only four nutrients - nitrogen, phosphorus and, to a lesser degree, potassium and sulphur - are likely to be of any concern for crop production on mineral soils in most areas of Manitoba.

Table 1 lists the amount of nutrients typically removed with the harvest portion of several Manitoba crops[1]. The soil often supplies the entire crop requirement for most nutrients.

Table 1. Field crop nutrient uptake and removal in typical Manitoba crops (lb/ac)[1]

Crop and yield	Crop Portion	Nitrogen N	Phosphate P_2O_5	Potassium K_2O	Sulphur S
Spring wheat 40 bu/ac	Uptake† Removal‡	76-93 54-66	29-35 21-26	65-80 16-19	8-10 4-5
Winter wheat 75 bu/ac	Uptake† Removal‡	91-111 71-86	41-51 35-42	96-117 23-29	13-17 9-12
Barley 80 bu/ac	Uptake† Removal‡	100-122 70-85	40-49 30-37	96-117 23-28	12-14 6-8
Oats 100 bu/ac	Uptake† Removal‡	96-117 55-68	36-45 23-28	131-160 17-20	12-14 4-5
Corn 100 bu/ac 5 t/ac silage	Uptake† Removal‡ Removal‡	138-168 87-107 140-172	57-69 39-48 57-70	116-141 25-30 181-222	13-16 6-7 12-14
Canola 35 bu/ac	Uptake† Removal‡	100-123 61-74	46-57 33-40	73-89 16-20	17-21 10-12
Flax 24 bu/a	Uptake† Removal‡	62-76 46-56	18-22 14-17	39-48 13-16	12-15 5-6
Sunflower 2000 lb/ac	Uptake† Removal‡	67-82 48-59	23-28 14-18	33-44 11-13	8-9 4-5
Peas 50 bu/ac	Uptake† Removal‡	138-168 105-129	38-46 31-38	123-150 32-39	11-14 6-7
Dry beans 1800 lb/ac	Uptake† Removal‡	N/A 75	N/A 25	N/A 25	N/A 5
Soybeans 35 bu/ac	Uptake† Removal‡	160-200 130-140	28-35 28-30	84-155 48-50	12 4
Potatoes 400 cwt/ac	Uptake† Removal‡	205-251 115-141	60-73 33-40	268-327 194-238	16-20 11-13
Alfalfa 5 ton/ac	Removal‡	261-319	62-76	270-330	27-33
Grass hay 3 ton/ac	Removal‡	92-113	27-33	117-143	11-14

† Uptake refers to total nutrients contained in the crop

‡ Removal refers to nutrients removed in harvested portion of the crop (e.g. seed, tuber)

The difference of uptake and removal is straw or vines left in the field.

Values are based upon the yield in the first column. Values can be adjusted for different yields, by scaling according to the base yield.

NITROGEN (N)

Plants use both the ammonium (NH_4^+) and the nitrate (NO_3^-) forms of nitrogen (N) in the soil - but primarily the nitrate form. Nitrate-nitrogen (NO_3-N) levels vary considerably from field to field and year to year because of differences in soil types, climatic conditions and management practices.

Stubble fields generally contain inadequate N levels for optimum crop production. Residual nitrate tends to be higher in fields following the more heavily fertilized row crops, such as potatoes and corn, than the solid-seeded cereal and oilseed crops[2] (Table 2).

Table 2. Residual soil NO_3-N levels in Manitoba as affected by previous crop and growing conditions.

Previous crop	Soil nitrate-N lb/ac in 0-24 in. depth	
	Drought years (1988-89)	1990-2006
Wheat	102	50
Barley	76	49
Canola	79	45
Flax	88	44
Corn	107	73
Potatoes	94	71

Fields that have been heavily manured, repeatedly fertilized with high rates of N and/or affected by drought, or some other factor that has severely restricted yields, often contain higher than average residual nitrate levels. Extremely high N levels were encountered in the fall of 1988 and 1989 following droughts throughout a large part of the province.

Sometimes fallow fields contain enough available N for crop production. Fields where a green manure crop was "worked in", or fields in which a crop was "ploughed-down" because of drought, severe insect damage or hail, usually contain higher nitrate levels than stubble fields, but lower than fallow.

Following legume breaking (breaking after first cut of forage), soils will release considerable quantities of N, which may satisfy all the N requirements of the crop. Grass and grass-legume breaking provide a lower, but substantial level of N for following crops. The amount of N available is determined by the time of legume forage crop termination and density of the legume stand (Tables 3 and 4)[3]. Manitoba research indicates that either tillage or herbicide termination of the stand are equal in releasing N for subsequent crops.

Nitrogen

Table 3. Nitrogen contributions from alfalfa for following crops.

Termination Time	N Contribution to following crop (lb N/ac)
Before July	90
July – August	70
Fall	45
Spring	30

This N contribution is based on a full stand of alfalfa. The N contributions should be adjusted for lesser alfalfa stands accordingly to Table 4.

Table 4. The reduction in N credits from alfalfa based on alfalfa crown density.

Alfalfa crowns/sq. foot	N Credit
>5	Full credit
3-4	2/3 credit
1-2	1/3 credit
>1	0 credit

Pulse Crop Nitrogen Contributions

It is recognized that N requirements for crops may be reduced following pulse crops. Traditionally N recommendations were not reduced for crops following pulse crops in Manitoba since the greater yield potential that frequently occurs following pulse crops required similar N rates as when crops follow cereals[4]. In addition to the higher yield potential, wheat often has higher protein concentration following pulse crops.

Recent research has evaluated N contributions from field peas, soybeans, chickpea and dry beans harvested for grain[5]. Apparent N credits are small (10 lb N/ac or less) for soybeans and dry beans. Field peas provided the most consistent N benefit of some 25 lb N/ac. Field peas are traditionally harvested in early fall and under moist conditions, mineralization and N release are detected by the late fall nitrate soil test.

Summerfallowing has a detrimental effect on soil quality and leaves the soil susceptible to erosion. Therefore, except for certain emergency situations, summerfallowing is NOT a recommended practice in Manitoba. Any tillage should leave sufficient stubble cover to prevent soil erosion. Poorly maintained summer fallow or fields that have been broken or ploughed down late in the season usually contain available N comparable to, or lower than stubble fields.

Nitrogen contributions are greater when forage or grain legume crops are grown as a green manure crop. Under such production the crop is destroyed at vegetative stage and nitrogen returned to the soil. For legume or pulse crops, every 1000 lb of vegetative material contains some 30 lb of nitrogen. Half of this plant nitrogen is available to the following crop, with some 15% being available in year 2. Typical amounts of nitrogen produced in Manitoba studies are shown in Table 5.

Table 5. Typical nitrogen contributions from green manure crops in Manitoba [6, 7].

Green manure crop	Amount of available nitrogen (lb/ac)		
	Year 1	Year 2	Year 3
Full season growth			
Alfalfa (4 year stand)	70	25	7
Sweet clover	55	20	
Chickling vetch	75	5	
Indian Head lentil	70	10	
Relay seeded with winter cereals			
Annual alfalfa	45-55	5	
Red clover (spring terminated)	20-25	5	
Double cropped after winter cereals			
Chickling vetch	25-40		
Indian Head lentil	20-35		
Summerfallow	55	-4	

Fertilization of Annual Crops

Effects of nitrogen and moisture supply on crop yield and quality

Most non-legume crops respond well to fertilizer N when the available soil levels are low. N fertilizer is effective in increasing both yield and protein content of crops on deficient soils. On soils low in available N, applications of moderate rates of N usually result in yield increases. When soil levels are high or high rates of N are applied, both yield and protein content are increased, as well as the risk of lodging.

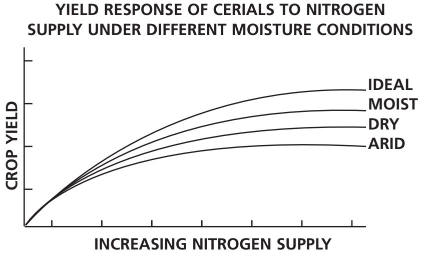
Growing season moisture conditions also have a significant effect on crop response to available soil N and applied fertilizer N (Figure 1).

Generally, higher moisture availability results in higher yields at comparable N supply levels, as well as a greater response to applied fertilizer N. Lower moisture availability not only restricts response and yield potential, but also results in higher crop protein contents, particularly at higher levels of available N.

High protein Canadian western red spring wheat can be grown in all areas of Manitoba if sufficient N is available to the crop from the soil and/or applied fertilizer. To determine if sufficient N was present for high yield, the grain protein content can be checked. If spring wheat protein content is less than 13.5%[8] (11.5% for winter wheat[9, 10]), insufficient N was added to optimize crop yield.

For a recommended malting barley to be acceptable for malting grade, the grain should contain 10.5 to 13% protein. Protein levels in barley are determined by the amount of available N, seeding date, growing season moisture and temperature. Late seeding, high rates of N and/or limited growing season moisture may result in protein content above acceptable levels.

Figure 1.



Very high levels of available N may have a negative impact on growth and, in some crops, quality. A heavy, lush crop resulting from high N levels may be prone to lodging and more susceptible to disease under certain climatic conditions. Seed set may also be reduced and maturity may be delayed. In oilseed crops, oil content tends to decrease as protein content increases in response to high N and/or low moisture conditions.

Nitrogen Fertilizer Efficiency

Fertilizer N efficiency is significantly influenced by certain soil properties, climatic conditions and the time and method of placement. The efficiency gained in N management is primarily through reducing N losses from the following processes:

Denitrification occurs under flooded or saturated soil conditions when soil bacteria convert nitrate-nitrogen to nitrogen gas (N_2O and N_2). It is the most common way that N is lost and occurs slowly at soil temperatures slightly above freezing, becoming very rapid at temperatures above 15°C. Losses in spring flooded soils may be 2-4 lb N/ac/day. Losses in poorly drained fields between June and October can result in the loss of much of the available N in several days. Denitrification can be greatly limited by providing good field drainage and using fertilizer management practices that retain N in the ammonium form (e.g. subsurface banding).

Immobilization refers to the temporary loss of N as soil organisms work to decompose crop residues that have a low concentration of N (e.g. cereal straw). Nitrogen becomes available again when the organisms die and decompose. Immobilization can be limited by subsurface banding N fertilizer, which makes N more available to the crop and less available to soil organisms.

The C:N ratio of crop residue plays an important role driving the rate at which nitrogen is cycled by soil micro-organisms (Table 6)[11]. If the C:N ratio is less than 20:1 then mineralization or the release of nitrogen occurs. If the C:N ratio is greater than 20:1 then immobilization or nitrogen is tied up within the field. The C:N ratio of crop residue declines as the residue decomposes (i.e. C is released as CO2). Nitrogen is temporarily tied up in residues having high C:N ratios (e.g. wheat straw or corn residue) however, as the C:N ratio declines to 20:1 mineralization (N release) can occur. The magnitude of immobilization is directly related to the quantity of crop residue. High residue crops such as grain corn or cereals immobilize more N than low residue crops such as dry beans (Table 8).

Table 6. Typical C:N ratios and yield of crop residues in Manitoba.

Crop residue	C:N Ratio Mean (Range)	Typical residue amounts t/ac
Wheat straw	60:1 (35-85:1)	1-1.5
Flax straw	55:1 (45-65:1)	0.5
Corn stover	82:1 (65-95:1)	3
Sunflower stover	60:1	2
Soybean residue	65:1	1.5
Dry bean residue	34:1	0.5-1
Potato vines	31:1	1.2

Nitrate leaching is the downward movement of the nitrate form of N by water moving through the soil profile. Nitrates are water-soluble and move readily since they are not held by soil particles. Nitrate leaching occurs most readily on coarse textured soils following significant precipitation. Nitrate leaching can be minimized by applying only enough N fertilizer to meet crop needs, applying fertilizer as close as possible to the time of crop uptake and using moisture efficiently. Nitrate leaching during the growing season is highly unlikely even in very sandy soils under dryland conditions. Irrigation of sandy soils can often lead to leaching even during the growing season unless special management is practiced (*i.e.* split applications of nitrogen or via irrigation water).

Ammonia volatilization occurs when the ammonium-N from broadcast urea, urea-ammonium nitrate solutions (UAN) or manure converts into ammonia gas and dissipates into the atmosphere. Factors that increase volatilization losses are higher temperatures, a moist soil followed by drying conditions, high soil pH and high levels of free lime or calcium carbonate. Ammonia volatilization can be limited by subsurface banding N fertilizers (especially urea) into the soil or incorporating broadcast applications. The urease inhibitor, Agrotain, will delay volatilization from urea and UAN solutions for up to 14 days. Refer to manufacturer's directions for more information.

Methods of nitrogen fertilizer placement

Nitrogen

Banding

There are several types of band applications:

- drilled with the seed
- side banded
- mid-row banded
- sub-surface banded into soil prior to seeding
- surface banded
- nested

Drilled with the seed – This method consists of placing the fertilizer with the seed in the seed row. Drilling fertilizer with seed in excess of recommended rates can cause seedling damage and reduce yields. Depending upon the equipment used, there can be a large variation in the concentration of fertilizer adjacent to the seed. Greater spreading of the fertilizer and seed and lower rates of fertilizer, reduce the likelihood of seedling damage. A double disc press drill places the seed and fertilizer close together in a narrow furrow. A discer, air seeder or hoe drill can scatter the seed and fertilizer, depending on the opener used. Wider spacings between rows increases the concentration of fertilizer in each seed row.

Placing fertilizer with cereal seed optimizes efficiency. However excessive rates of nitrogen fertilizer may lead to reduced germination and seedling damage due to ammonia toxicity or salt burn. Table 7[12] contains guidelines for safe rates of N placed with the seed of cereals and canola. For more details refer to the Manitoba Agriculture, Food and Rural Initiatives (MAFRI) fact sheet, *"Guidelines for Safely Applying Fertilizer with Seed"*. Factors affecting safe N rates include crop type, row spacing, seed and fertilizer spread, soil texture, N source and soil moisture.

For canola, ammonium nitrate and ammonium sulphate are just as damaging to the seedlings as urea. For cereals only, suggested N rates can be safely increased by about 20 lb N/ac when ammonium nitrate is used. UAN solution is 50% urea and 50% ammonium nitrate, so would be intermediate in toxicity between the two granular products. The urease inhibitor, Agrotain reduces seed toxicity from seed-placed urea[13]. Suggested N rates for cereals and canola may be safely increased by 40-50% when urea is treated with Agrotain. Refer to manufacturer's instructions for specific information.

Where seedbed moisture is low or when weather is hot and windy, reduce the rates in Table 7 by approximately 50 per cent.

Table 7. Rates of urea nitrogen (lb N/ac) safely applied with cereal and canola seed if seedbed soil moisture is good to excellent.

Soil texture	1 in. spread† (disc or knife)‡			2 in. spread† (spoon or hoe)			3 in. spread† (sweep)		
	Row spacing								
	6″	9″	12″	6″	9″	12″	6″	9″	12″
	SBU*								
	17%	11%	8%	33%	22%	17%	50%	33%	25%
CEREAL SEED									
Light (sandy loam)	10	0	0	20	15	10	30	20	15
Medium (loam to clay loam)	20	15	10	30	25	20	40	30	25
Heavy (clay to heavy clay)	25	20	10	40	30	25	50	40	30
CANOLA SEED									
Light (sandy loam)	0	0	0	10	0	0	20	10	0
Medium (loam to clay loam)	0	0	0	20	10	0	30	20	10
Heavy (clay to heavy clay)	10	0	0	30	20	10	40	30	20

† Width of spread varies with air flow, soil type, moisture level, amount of surface crop residue and other soil conditions, so it must be checked under field conditions.

‡ Some openers give less than 1″ spread. Urea should not be applied with the seed on light soils when a double disc opener is being used.

* SBU, seedbed utilization, is the amount of the seedbed over which the fertilizer has been spread. Thus, it is a reflection of the relative concentration of fertilizer. SBU (%) is the width of spread, divided by the row spacing, multiplied by 100. For example, if the seeding implement has a 6″ spacing and spreads the seed and fertilizer over 2″, the SBU would be 33 per cent (2/6 X 100 = 33). The higher the SBU, the more fertilizer that can be safely spread with the seed. Although some openers spread the seed and fertilizer vertically, SBU does not take this into account since it is generally recognized that all seed should be placed at an even depth for even germination and emergence.

Side band placement - This method consists of placing the fertilizer in a narrow band 2 to 3″ to the side and/or 2 to 3″ below the seed during seeding. The efficiency of side banding is equivalent to placement with seed and higher rates can be used safely.

Nitrogen requirements of most crops can be met without causing seedling damage when solution or dry fertilizer is placed at least **2″ from the seed row.**

Anhydrous ammonia cannot be placed in or near the seedrow. However, equipment has been modified to allow anhydrous ammonia to be applied at seeding time in a band or other arrangement that is separated from the seed. The anhydrous ammonia should be separated from the seed by at least 2-3″ and placed below and to the side of the seed or to the side of the seed. It should not be applied directly below or above the seed. The anhydrous ammonia tends to follow the furrow upward, so attempts at placing it below the seed will likely lead to seed damage.

Mid-row banding - This method places fertilizer between every second seed row as part of the seeding operation. The fertilizer is banded with knives, discs or coulters to a depth of 3 to 4”. This system is an efficient method of N placement, which allows the application of high rates without risk of damage to germinating seedlings.

Banding into soil prior to seeding - This method places the fertilizer below the soil surface in a band behind a shank at a depth of 3 to 6” It is often referred to as “deep banding”.

Band spacings should not exceed 18” when applying nitrogen fertilizer. The efficiency of this method of N placement in spring is equal to side banding or seed placing fertilizer.

Anhydrous ammonia should be applied only when soil conditions permit a good seal behind the applicator shanks. Seeding can be done immediately after anhydrous ammonia application, provided there is at least a 4” vertical separation of the injection point and the seed[14]. Crop emergence may be slightly reduced directly over the anhydrous bands, particularly for small seeded crops and if soils are sandy or dry. However, plants will tiller or branch and yield will not be affected. The ammonia bands should be perpendicular to the direction of seeding.

Surface banding - This application method places a band or stream of liquid fertilizer on the soil surface. The equipment used include fertilizer floaters and field sprayers outfitted with dribble nozzles or streamer bars. Surface banding improves nitrogen efficiency as compared with broadcast methods because volatilization and contact with residues and possible immobilization, are reduced. The liquid stream also penetrates a crop canopy better than a broadcast application and as a result, more fertilizer reaches the soil surface.

Nesting - This method uses a spoke wheel injector to place regularly spaced pockets or nests of liquid fertilizer into the soil. N losses by volatilization and immobilization are avoided. Disturbance of soil and crop residue is minimal and post-seeding applications may be made into the growing crop.

Broadcast

Broadcast and incorporated -

Granular or solution fertilizer is broadcast on the soil surface and incorporated into the soil with a tillage implement. Nitrogen fertilizers, especially urea and liquid or dry fertilizers containing urea, should be incorporated as soon as possible to minimize gaseous losses by volatilization.

Broadcast without incorporation

This method usually results in the least efficient use of fertilizer N. Fertilizer left on the soil surface increases the risk of loss by runoff, erosion, ammonia volatilization (especially with fertilizers containing urea) and immobilization by crop residue. This is the most commonly used method to fertilize established pasture or hay land and is frequently used in zero tillage production.

Ammonium nitrate (34-0-0) is a better N source than urea (46-0-0) for broadcast applications without incorporation. Losses of urea are higher than losses of ammonium nitrate under conditions favouring volatilization (*e.g.* high temperatures and high soil pH). Loss of urea can be minimized by applying during periods of low temperature or just before it rains. Treating urea with urease inhibitor, Agrotain will delay volatilization losses for up to 14 days.

Time of nitrogen fertilizer application

At or near time of seeding -

Nitrogen fertilizer applied at or near time of seeding is usually the most effective for increasing yields.

After seeding - Under moist conditions, applying N up to two weeks after emergence is a good alternative to applying nitrogen in the fall. However, if N fertilizer is broadcast without incorporation on dry soils, N utilization may be delayed. If urea (46-0-0) is used, gaseous N losses may occur. Ammonium nitrate (34-0-0), while not readily available is the preferred N source for broadcast application after seeding.

Leaf burn may occur if N solution is sprayed onto leaf surfaces. Canola, flax, corn and sunflowers are particularly susceptible to damage. In trials, cereals at seedling stages have been sprayed with N solution at 40 lb N/ac with minimal damage and no reduction in yield[15]. Leaf burn is minimal under cool, wet conditions. Rain or irrigation immediately following N application washes all leaf surfaces free of fertilizer and results in little or no damage. Broadcasting granular fertilizers does not cause damage unless the foliage is wet.

N fertilizers can be applied to row crops following crop emergence and is usually referred to as "side dressing". Fertilizers banded into the soil should be applied at least 6 to 8" from the row in order to minimize root pruning. Use care so that plants are not damaged by equipment. Applying N fertilizer between every second row (similar to mid-row banding) is referred to as "skip row application".

The application of N fertilizer after seeding is a method to hedge on costs until you have a better idea of crop price and growing conditions[16]. Mid-season applications of N fertilizer can also be used to increase the protein content in grain. Nitrogen application to the growing crop through irrigation water has greater efficiency than placing all the nitrogen at the time of seeding.

Fall-applied nitrogen does not usually give yield and/or protein increases as great as those obtained when equal amounts are added in spring. However, in many cases, the differences in yield between fall and spring applications are small, particularly under dry soil conditions. Losses due to leaching, volatilization, denitrification, immobilization and weed growth are usually higher for fall-applied N and account for differences in yield and protein content.

Relative efficiencies of nitrogen applications

The relative efficiency of N fertilizers, as affected by the time and method of application, varies greatly with factors such as soil moisture, soil temperature, soil type and weed growth. Average relative values for Manitoba based on time and method of placement, when spring broadcast N is given a value of 100, have been calculated as follows in Table 8[17].

Nitrogen

Table 8. Nitrogen efficiency based on application time and placement.

Time and Method	Relative Values
Spring broadcast	100%
Spring banded	120%
Fall broadcast	80%
Fall banded	100%

Efficiency values are calculated based on N uptake by plants. Broadcast values assume urea-based N carriers are incorporated, where necessary, to minimize losses through ammonia volatilization. This is particularly important on soils with a high pH or which contain free lime in the surface.

Banded values are based on any subsurface band application. This includes with-the-seed band, as long as the rate applied does not exceed the safe limit at which damage to germination and seedling emergence may occur. For maximum benefit, bands should not be disturbed prior to or during the seeding operation.

Nitrogen losses due to leaching, gaseous loss, immobilization and weed growth are probably higher for fall-applied than for spring-applied nitrogen. These losses may be greater if the nitrogen is applied too early in the fall (prior to mid-September) or when soil temperatures at the 4" depth are greater than 5°C. Loss of N accounts for much of the difference in efficiency between fall and spring applications. Under dry soil conditions, the efficiency of nitrogen banded in late fall can approach that of spring banded because potential losses due to leaching or denitrification are low. Efficiency of fall-applied N can be substantially lower than those indicated in Table 8 under excessive moisture conditions in spring or fall and/or an early fall application before soils have cooled to 5°C.

Poorly drained soils or depressions, including "microdepressions" in the generally level landscape of the Red River Valley have high potential for loss of nitrate-N. These losses have been shown to be minimized in management studies through proper placement and timing of nitrogen[18]. (Figure 2)

In a practical sense, time and method of application should be based not only on the needs of the crop and potential losses from the soil, but also on coordination of the soil fertility program with an efficient overall farm management system. Select a time and method of N application that permits preparation of a good seed bed, conserves soil moisture, aids in prevention of soil erosion, allows for timeliness of operations and maximizes net returns.

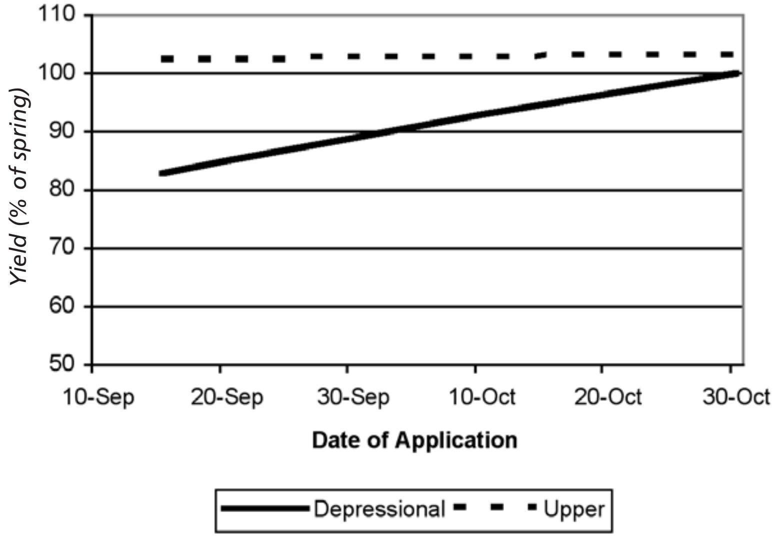


Figure 2. Effect of date of fall N application on wheat grain yields from fall-banded urea relative to spring-banded urea at depressional and upper slope positions at three sites near Winnipeg and one site near Brandon (2001-2002).

Fertilization of forage grasses

Nitrogen rates

Forage grasses respond well to N fertilization. Unfortunately hayfields in Manitoba often receive little to no fertilization, which can limit the protein content and yield potential of the crop. In Manitoba, the optimum amount of N recommended for established stands of grass hay is in the range of 90 to 110 lb/ac. It is likely that these rates of N application are too low with good rainfall and too high when moisture is limiting.

Manitoba studies show that moisture availability in the soil and the selling price of baled hay are key factors in determining the most profitable rates of N application. In these studies, the level of N supply that gives maximum profit is called "the economic optimum N supply" and can vary with different grass species and moisture conditions. By subtracting soil test values for nitrate-N from the values for economic optimum N supply, producers can determine the most profitable rates of N-fertilizer application.

Forage yield and nitrogen removal may be very high under the combination of high moisture conditions and nitrogen supply. Growers choosing to use manure to supply nitrogen to forage grasses must be aware that phosphorus will be supplied at levels above that required and soil P levels will increase. Current manure regulations may limit the amount that can be applied to forage.

Recommendations based on the soil test are listed in Appendix Table 14, 15 and 16.

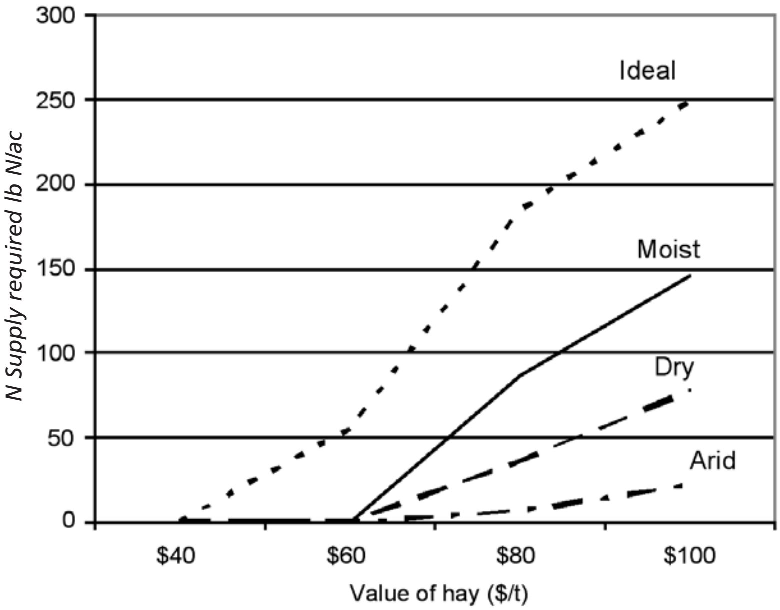


Figure 3. Economically optimum nitrogen requirement for smooth bromegrass/ intermediate wheatgrass under various moisture conditions and hay selling prices.

Assumes fertilizer at $0.41/lb N and hay cutting and handling cost of $25/t.

Optimum N supply is soil nitrate-N to 24" plus fertilizer N.

In Figure 3[19], Manitoba soils are categorized into four groups according to the amount of available moisture, which modifies the yield response to N fertilizer.

Ideal soils occur under irrigation or when yield is not limited by lack of rainfall.

Moist soils are typical of the clay soils of the Red River Valley and the Grey Wooded soils which have high water holding capacity or are in the cooler soil areas but are subject to periodic dry conditions.

Dry soils include the sandy soils in southwestern Manitoba and are intermediate in water-holding capacity and are subject to dry weather conditions.

Arid soils are well drained, coarse-textured soils that have a poor ability to hold water and are subject to dry conditions on a regular basis. Most soils in the province are in either the moist or dry category.

The timothy hay export market is a new opportunity for Manitoba hay producers. Recommended N rates may be lower than required for optimum hay or seed yield due to quality concerns. The primary quality factor for export hay is greenness. High N rates tend to promote lodging and leaf disease, which reduce the green colour. Studies[20] have shown that 100 lb of total N/ac (fertilizer and soil N) will optimize yield with acceptable quality (Appendix Table 14). Growers have also observed improvements in quality when N is split (half in early spring and the remainder 4-6 weeks later in June) or injected directly into the stand in June with disk or spoke injection.

High nitrogen rates are usually required for forage grass seed and vary by species (Table 9)[21, 22, 23, 24].

Table 9. Nitrogen rates for grass seed production in Manitoba.

Grass species	Nitrogen (lb/ac)
Intermediate wheatgrass Slender wheatgrass Western wheatgrass Smooth bromegrass Meadow bromegrass	70-80
Tall fescue Timothy	70-90
Reed canary grass	75-100
Perennial ryegrass	80-100
Kentucky bluegrass	100-150

Sources of Nitrogen

Ammonium nitrate is generally 10-15% more efficient than urea in increasing yield of the first cut of early season grasses. Manitoba studies have found that under conditions of minimal volatilization loss, urea forms are equal or superior to ammonium nitrate for fertilizing late season grasses in multiple harvest systems and grass pasture. In these instances, hay or pasture grasses fertilized with urea have higher crude protein levels than those fertilized with ammonium nitrate[25].

Supplies of ammonium nitrate are limited, so growers will need to consider alternative practices. Options include broadcast urea, ammonium sulphate or UAN solution applied through injection or surface dribble banded. Under high risk conditions for urea volatilization, consider treatment of urea and UAN with Agrotain.

Volatilization losses of surface applied N may be very high if rainfall is not received soon after application. Volatilization losses are greatest when urea is applied to a moist thatch cover, followed by warm, windy weather.

Broadcast N solutions are not satisfactory for established forages. To increase efficiency, N solutions should be surface or dribble banded or injected into the soil with equipment such as the spoke wheel applicator.

Time of application

Grass for hay or pasture: The relative efficiency of broadcasting granular N fertilizer on established grass is as follows (Table 10):

Table 10. Relative efficiency of broadcasting granular N fertilizer on established grass.

Time of Application	Month	Relative Efficiency
Spring	April to early May	100%
Fall	October	78%

The efficiency of split-rate N applications (applying one-half the required N in the spring and the other half immediately following the first cut) is similar to a single spring application[26]. The split-application technique has the added advantage of equalizing the production of forage with a relatively high protein content during the growing season. It is also useful for pasture production where rotational grazing is practiced. Split application of less than 45 lb N/ac is not recommended.

Grass for seed production: Timing of N fertilizer application for grass seed production is very important and varies with species (Table 11). Nitrogen promotes the growth of tillers and by stimulating the growth of larger seed heads in those tillers that will form seed heads. Tillers must have grown enough to be induced to form seed heads by the correct daylength and temperature for each species. Since the period of the year when this physiological change occurs differs among grass species, the timing of nitrogen need changes.

Table 11. Nitrogen timing for grass seed production[27, 28, 29, 30]*.*

Grass species	Nitrogen timing
Kentucky bluegrass Meadow bromegrass Smooth bromegrass Intermediate wheatgrass Slender wheatgrass Western wheatgrass	Mid September to early October
Reed canary grass Perennial ryegrass Tall fescue Timothy	Late fall or very early spring

PHOSPHORUS (P)

The majority of Manitoba soils cannot supply adequate phosphorus (P) for optimum yields. In recent years, some 25% of fields are rated as very low and low in P[31]. Unlike nitrogen, phosphorus levels do not change from year to year in response to climatic conditions, most crop rotations or crop management practices.

Losses of P into surface water will decrease water quality. Beneficial management practices (BMPs) to manage P include:

- Regular soil testing and appropriate fertilizer applications
- Soil conservation practices such as conservation tillage, forages and buffer strips where losses are related to particulate P from soil erosion

The P content of seedling plants need to be high in order to achieve maximum yields. Placing P fertilizer where developing roots can access it rapidly is critical in attaining these high P levels in young plants. Additionally, the high pH calcareous soils that predominate in Manitoba tend to "fix" or reduce the availability of applied P and slow the build up of soil test levels. For this reason, P use is most efficient when soil contact with fertilizer is limited, such as by banding.

Phosphorus efficiency is greatest when applied with the seed, providing the amount does not injure the germinating seedling[32]. Some crops, such as oilseeds and pulse crops, are sensitive to seed-placed phosphate, whereas cereals can tolerate their total fertilizer P requirement placed with the seed (Table 12).

Monoammonium phosphate (11-52-0) has a low salt index and does not produce much ammonia, so it has relatively low toxicity to seedlings.

Phosphate fertilizer banded near the seed (beside and/or below) results in the greatest yield increase per unit of P when recommended rates exceed that tolerated with seed-placed application. Such side-banded applications are recommended for most oilseeds, annual legumes and row crops.

Deep banding phosphate at the 4-6″ soil depth and in spacings of 12″ or less before seeding or mid-row banding during seeding are more effective in increasing yields than broadcast and incorporation methods. Banding nitrogen with the phosphate will increase fertilizer P availability. Band these fertilizers together when both N and P are needed. Application of 10 to 15 lb P_2O_5/ac with or near the seed may also be required to ensure adequate P supplies for early growth before roots can proliferate in the fertilizer bands. Application of additional phosphate with or near the seed may be especially beneficial when soils are cold and/or very deficient in P or when the phosphate is dual banded with a high rate of urea N in spring.

Broadcast and incorporated phosphate results in the lowest yield increase per unit of P fertilizer. Broadcast application of P may be uneconomical on many soils, since the amount required in the first few years is two to four times that of seed-placed P to achieve similar yield increase.

Table 12. Maximum safe rates of actual seed-placed phosphate (P_2O_5) fertilizer as monoammonium phosphate[†].

Crop	Actual P_2O_5 (lb/ac)[‡]
Cereals	50
Canola*, peas*, fabebeans, buckwheat, flax[33]	20
Dry beans[34], soybeans (narrow rows**)	10
Dry beans, soybeans (wide rows**)	0

[†] Divide values in table by 0.51 or multiply by 1.96 to calculate lb of 12-51-0 per acre.

[‡] Rates are based on disk or knife openers with a 1″ spread, 6 to 7″ row spacing and good to excellent soil moisture.

[*] When P soil test values are medium to high, no phosphorus should be placed with canola or pea seed.

[**] A low rate of seed-placed phosphorus is safe for beans and soybeans when seeded in row widths of 15″ or less. Similar rates may cause unacceptable stand reductions in wider rows.

Crops such as flax may suffer reduced stands and yield when high rates of phosphorus are seed-placed. Recent studies demonstrate that modest rates of P can be seed-placed with flax without reducing yield. This rate of 20 lb P_2O_5/ac is sufficient to meet the crop removal of a 30 bu/ac flax crop.

Most crops will respond to properly applied fertilizer phosphate when the available soil P level is low. The probability and degree of response, as well as the amount of fertilizer P required, will decrease as the level in the soil increases. Up to a third of the time, cereal crops will respond to a small amount (*e.g.* 10 lb/ac) of seed placed phosphate even when the soil test level is relatively high.

This is commonly called the "pop-up effect" and occurs particularly under cold, dry soil conditions at seeding time.

Repeated applications of relatively high rates of phosphate fertilizer may slowly increase available P content of some soils. Manured fields tend to have higher P soil test values, often related to the frequency, amount and type of manure applied.

A seed-applied inoculant called JumpStart (Registration #900025A, #920064A, *Fertilizers Act*) is a natural occurring fungus (*Penicillium bilaii*) that grows on plant roots and makes residual soil P more available for plant uptake. It is registered for use on wheat, peas, lentils, dry bean, chickpea, canola, mustard, sweet clover and alfalfa. When used on soils testing low or medium in P, accompanying fertilizer phosphate rates should not be reduced. On high to very high P testing soils, JumpStart may be used in place of the starter phosphate fertilizer. JumpStart is not residual and needs to be applied annually.

A beneficial fungus called mycorrhizae (or "fungus root") occurs naturally in our prairie soils. This fungus colonizes the roots of most plants and through fungal strands or hyphae, assists in the interception and uptake of immobile nutrients, especially phosphorus and zinc. This fungus contributes substantially to early season P uptake in crops such as corn, flax, sunflower and soybeans. However mycorrhizae do not colonize members of the Brassica family (*i.e.* canola, mustard) and the population is quite low following these crops or after fallow. Consequently, succeeding crops may suffer an impaired ability to take up phosphorus and have reduced growth and yield. Crops such as cereals are often sown with phosphate fertilizer close to the seed and do not appear to suffer as greatly from the lack of effective mycorrhizae following canola or fallow.

Mycorrhizae appear to be more effective in taking up phosphorus on low P soils and on undisturbed soils such as zero till where mycorrhizal hyphae remain intact.

POTASSIUM (K)

Most Manitoba soils contain adequate amounts of available potassium (K) for crop production. Soils likely to be low in K are coarse-textured sands, sandy loams and organic soils. Potassium may be required on about 6% of arable Manitoba soils for maximum production of commonly grown annual crops such as cereals, canola and flax. About one-third of Manitoba soils require additional K for the production of special crops such as corn, potatoes and small fruit or vegetable crops.

Potassium enhances winter hardiness and spring growth of forages. Further information regarding fertilizing forage stands, consult the MAFRI publication, "*Fertilizing Alfalfa Forage*".

Like phosphorus, K levels do not change significantly from year to year in response to climatic conditions or crop management practices. An exception would be when high yields of forage are repeatedly removed from coarse textured soils (Table 1).

Where required, applied potash (KCl) can increase crop yield and quality. Depending on the type of crop, it may also increase frost and disease resistance, palatability, storage quality and other characteristics.

For most efficient use by cereal crops, K fertilizer should be placed with the seed. For most row crops, potash should be side-banded to the side and/or below the seed. The efficiency of broadcast and incorporated potash is about 50% that of potash banded with the seed or side-banded[35]. If potash is broadcast, the recommended rate for seed placement or side banding should be doubled to obtain equal crop response. Broadcast K fertilizer should also be incorporated into the soil.

SULPHUR (S)

Low levels of available sulphate-S may occur in any non-saline soil in Manitoba. Sulphur (S) deficiencies are most frequently found on well-drained and grey wooded soils. Soil testing is the best available tool for determining S fertilizer needs. Testing should be done to a 24" depth to account for sulphate not at the surface, but still available for crop use.

Sulphate concentrations within a field can vary, depending upon soil type and slope position. On rolling land, sample hilltops, mid-slope positions and low-lying areas separately. Sandy, coarse textured soils should be sampled separately from heavier soils. This is important since it is not uncommon for low lying, heavy soils to contain many times more sulphate-S than light-textured hilltops. Sampling a variable field as a whole would typically result in a recommendation that no S fertilizer is needed, yet crops in some areas may be highly S-deficient. For this reason an "insurance application" of S fertilizer may be advisable on variable soils or where high value, high S-demanding crops, such as canola, are to be grown.

Available sulphate levels are often low following the breaking of a perennial legume or grass-legume stand, due to their high S removal rates (Table 1).

Sulphate forms of S fertilizer, primarily ammonium sulphate and liquid ammonium thiosulphate, are equally effective when applied as a surface application, banded or incorporated. Elemental S must be oxidized by soil micro-organisms to form sulphate before plants can use it[36]. Elemental S should be applied at least one year before it is needed by the crop and left on the surface as long as possible before incorporation, as rainfall and weathering help disperse the fertilizer granule and speed the conversion to the sulphate form.

MICRONUTRIENTS

Seven of the 16 essential plant nutrients are referred to as micronutrients; not because they are less important for plant growth and development, but because they are required in relatively small amounts (Table 13.). They include: chloride (Cl), boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo) and zinc (Zn). Table 13 also includes typical amounts of the secondary nutrients calcium and magnesium.

Table 13. Micronutrient and secondary nutrient uptake and removal by typical Manitoba crops [37, 38]†.

Crop (Yield)		**Calcium (Ca)**	**Magnesium (Mg)**	**Zinc (Zn)**	**Manganese (Mn)**	**Copper (Cu)**	**Boron (B)**	**Iron (Fe)**
		lb/ac						
Spring wheat	Uptake	8	7	0.31	0.18	0.02	0.15	0.74
(40 bu/ac)	Removal	0.1	4	0.14	0.09	0.01	0.04	0.32
Barley	Uptake	9	6	0.22	0.11	0.03	0.24	0.62
(80 bu/ac)	Removal	0.2	4	0.15	0.08	0.03	0.12	0.36
Oats	Uptake	13	7	0.22	0.23	0.03	0.23	2.00
(100bu/ac)	Removal	2	4	0.15	0.15	0.02	0.12	1.53
Canola	Uptake	43	12	0.28	0.13	0.05	0.29	1.58
(35 bu/ac)	Removal	5	5	0.10	0.07	0.01	0.08	1.11
Flax	Uptake	13	9	0.17	0.09	0.05	0.16	0.29
(24 bu/ac)	Removal	3	5	0.13	0.03	0.01	0.04	0.14
Peas	Uptake	24	8	0.18	0.08	0.04	0.17	0.51
(50 bu/ac)	Removal	0.2	3	0.14	0.03	0.02	0.05	0.22
Corn	Uptake	7	16	0.27	0.24	0.04	0.10	0.67
(100 bu/ac)	Removal	-	7	0.21	0.03	0.01	0.03	0.17
Sunflowers	Uptake	55	38	0.12	0.19	0.07	0.28	0.53
(20 cwt/ac)	Removal	3	7	0.08	0.04	0.04	0.04	0.08
Soybeans	Uptake	71	24	0.14	0.35	0.04	0.19	1.04
(35 bu/ac)	Removal	4	6	0.09	0.06	0.02	0.06	0.55
Dry beans	Uptake	55	13	0.07	0.18	0.01	0.07	0.78
(18 cwt/ac)	Removal	7	4	0.05	0.03	0.007	0.02	0.10
Potatoes	Uptake	48	36	0.70	1.80	0.14	0.28	3.10
(400 cwt/ac)	Removal	0.4	12	0.33	0.09	0.12	0.13	1.28

† Crop nutrient removal is not equal to crop requirements. Crops often take up larger amounts of nutrients than are required (i.e. K and Cl).

In Manitoba, most soils are adequately supplied with micronutrients. However, the following soil and environmental conditions may reduce micronutrient availability:

- soils low in organic matter (B, Cu and Zn)
- sandy soils (coarse texture) are more likely to be deficient than clay soils (fine textured) (Cl, Cu, Zn, B and Mo)
- peat soils or soils with over 30% organic matter (Cu, Mn and B)
- cool, wet soils reduce the rate and amount of micronutrients that can be taken up by the crop
- high soil pH reduces micronutrient availability (for all except for Mo and Cl)
- highly calcareous, high lime content soils (Zn and Fe)
- soils with exposed subsoil due to erosion or a result of land leveling (Zn)
- soils with excessive phosphorus levels (Zn)

Certain crops and even varieties may vary in sensitivity to micronutrient deficiencies. Table 14 lists crops in their response to micronutrient fertilizers when a deficiency occurs.

Table 14. Response of crops to micronutrient fertilizers.

Crop	Boron	Copper	Manganese	Molybdenum	Zinc
Alfalfa	High	High	Medium	Medium	Low
Barley	Low	High	Medium	Low	Medium
Canola	High	High	Medium	Low	Medium
Clover	Medium	Medium	Medium	High	Medium
Corn	Low	Medium	Low	Low	High
Oats	Low	High	High	Medium	Low
Peas	Low	Low	High	Medium	Low
Rye	Low	Low	Low	Low	Low
Wheat	Low	High	High	Low	Low
Potatoes	Low	Low	High	Low	Medium

Highly responsive crops often respond to micronutrient fertilizer if the micronutrient concentration in the soil is low. Medium responsive crops are less likely to respond and low responsive crops do not usually respond even at the lowest micronutrient levels. In Manitoba studies, the frequency of crop response to micronutrients on mineral soils has been small.

Chlorosis in flax and soybeans

Frequently Manitoba flax[40] and soybean[41] crops exhibit chlorosis or leaf yellowing due to reduced iron availability under wet soils. Chlorosis appears as yellowing of upper leaves while veins remain green. Under severe conditions growth is stunted and yield loss occurs. These symptoms may result from a number of soil and environmental factors. Contributing factors are:

- cool, wet growing conditions
- saturated soil
- high levels of carbonates or "free lime" in the soil
- salinity
- compacted soil

Under such saturated soil conditions, iron uptake is limited when the iron ion is converted to a less available form while other minerals are increased in availability and compete for plant uptake. Application of iron micronutrients is not economical to correct this condition. Cultivars of flax and soybeans differ in their ability to tolerate chlorotic conditions; cultivar selection and improved drainage offer the best management options on suspect soils.

Chloride (Cl)

Yield response to chloride has been observed in North and South Dakota. However, in research trials conducted in Manitoba, chloride fertilization has resulted in inconsistent responses, despite being conducted on soils considered deficient or marginal in chloride by American standards (< 30-40 lb Cl/ac in 0-24" depth). Increases in grain yield by spring wheat were not consistent from year-to-year, and varied among variety[39]. A deficiency of Cl in winter wheat is visible as physiological leaf spotting. Winter wheat responses to chloride vary according to variety, and yield increases are small. Chloride is best supplied as potash (KCl) which is approximately 50% Cl.

Diagnosing Micronutrient Deficiencies

The relatively high cost of micronutrient fertilization demands accurate identification of possible deficiencies. The following steps should be taken to determine if micronutrient fertilization is warranted.

- Eliminate other possible causes of poor growth (*e.g.* drought, flooding, salinity, disease, herbicide injury, shortages of nitrogen, phosphorus, potassium or sulphur).
- Determine if a particular soil or crop is likely to be deficient in a micronutrient. Critical levels for several micronutrients are listed in Appendix Table 20.
- Determine if crop visual symptoms are similar to typical deficiency symptoms for specific micronutrients.

- Take separate soil and tissue samples from both affected and unaffected areas. Submit samples to a reputable lab for complete nutrient analysis. For micronutrients, tissue sampling is generally superior to soil analysis to confirm deficiencies.
- When indications suggest a micronutrient deficiency, apply such nutrients in field test strips (Appendix Table 21). Evaluate crop recovery and yield compared to untreated areas.

Foliar micronutrient applications are often quite effective if deficiencies can be diagnosed early in growing crops. Refer to manufacturer's recommendations for rates and materials.

THE FERTILIZERS ACT AND QUALITY STANDARDS

In Canada, fertilizer and supplement products sold and/or imported are regulated by *The Fertilizers Act* and Regulations, which is under the jurisdiction of the Canadian Food Inspection Agency (CFIA). The primary purpose of this federal legislation is to ensure these products are safe, efficacious and properly labelled. This protects the farmer and the general public against potential health hazards and fraud in marketing.

Product Types and Requirements

Major (N, P and K) and lesser (Ca, Mg and S) nutrient fertilizers are not generally required to be registered, but are still regulated under *The Fertilizers Act*. These products are assessed to ensure that sufficient amounts of nutrients are delivered to the plant/crop according to label directions. Foliar applied major nutrients are subject to review. There is one form of major nutrient fertilizer which is an exception to the rule and is required to be registered; low analysis farm fertilizers (%N + %P_2O_5 + %K_2O is less than 24%) that are not customer requested.

Micronutrient (B, Cl, Cu, Fe, Mn, Mo and Zn) fertilizers require registration and must demonstrate that they meet label claims for guaranteed nutrients. A fertilizer containing micronutrients may not need to be registered if the purpose of the fertilizer is to supply N, P and K with only trace amounts of micronutrients.

Fertilizer-pesticide combination products require registration and must demonstrate that the product is in compliance with the Compendium of Fertilizer Use Pesticides. The pesticide component must also be registered under *The Pest Control Products Act* (under the jurisdiction of Health Canada).

Supplements are those products which are intended to improve the physical condition of the soil and/or to aid in plant growth or improve crop yields. Products represented for use in improving the physical (*e.g.* organic matter) and chemical (*e.g.* liming materials) condition of the soil are not subject to registration, but are regulated. However, there are other forms of supplement products, such as; microbial products (*e.g.* inoculants and pre-inoculated seed), synthetic substances and plant growth regulators (*e.g.* hormones) which are required to be registered under *The Fertilizers Act*.

Product Labelling

For those products that are required to be registered, they must also display the registration number on the product label, in the form of:

Registration Number
YYYYNNNX *Fertilizers Act*

Where;

YYYY= year (e.g. 2006) (products registered prior to 2000 only have 2 digits here)

NNN = numerical value assigned to product according to the number of products registered in that year (012 value would indicate that it was the 12th product registered in that year) (products registered prior to 2000 have 4 digits here)

X = letter value assigned based on product type (A = supplement, B = micronutrient, C = fertilizer-pesticide)

(*e.g.* Registration Number 2006012A *Fertilizers Act*)

The guaranteed analyses for fertilizer/supplement products indicate the amount of each active ingredient (*e.g.* nutrient and/or supplement activity) expressed as a percentage of the total weight of the fertilizer/ supplement product. Some supplement guarantees do not conform to this measure, but still carry guarantees which are based on the weight of the product.

The grade (which forms part of the name) of the fertilizer is reflective of the total nitrogen (N), available phosphoric acid (P_2O_5) and soluble potash (K_2O) and is expressed as $\%N - \%P_2O_5 - \%K_2O$.

In the case of supplement products, the guarantees are varied, but specific to the product type. For example, a compost will generally carry guarantees for organic matter and moisture content, as well as any applicable nutrient guarantees. On the other hand, an inoculant will carry a guarantee for the active microorganism(s) in the formulation with units of measurement being viable cells per gram of product or viable cells per seed (after inoculation has occurred).

Market Monitoring

The CFIA performs product evaluations and registrations, as well as market monitoring of all fertilizer and supplement products. Sampling of products to ensure compliance is random in nature, with annual targets based on the industry sector found in that region (largely agricultural in Manitoba).
The CFIA also relies on the industry and consumers to identify products which may be out of compliance with *The Fertilizers Act* and Regulations.

Manufacturers and blend producers of major nutrient (N, P and K) fertilizers are part of the Canadian Fertilizer Quality Assurance Program (CFQAP). Fertilizer samples are voluntarily submitted to accredited labs and the CFIA summarizes the results in the annual publication of the Canadian Fertilizer Quality Assurance Report. A customer can request a supplier's CFQAP rating directly from the supplier or from the CFIA.

Additional Information

Additional information can be obtained from the Fertilizer Section, Canadian Food Inspection Agency, 2 Constellation Cr., Nepean, Ontario K1A 0Y9, or on the website at http://www.inspection.gc.ca/english/plaveg/fereng/ferenge.shtml.

CALCULATING FERTILIZER RATES FROM NUTRIENT RECOMMENDATIONS

Soil test recommendations are given in lb/ac or kg/ha of nutrients. To determine the fertilizer rate for a particular nutrient, multiply the rate of the desired nutrient by 100 and divide by the percentage of the nutrient in the fertilizer.

Example 1

Recommended rate of N is 80 lb/ac

Using 46-0-0, the rate of fertilizer required is:

(80 x 100) / 46 = 174 lb/ac

Example 2

Recommended rate of P_2O_5 is 40 lb/ac.

Using 11-52-0, the rate of fertilizer required is:
(40 x 100) / 52 = 77 lb/ac

77 lb/ac of 11-52-0 would also supply (11/100) x 77 = 8.5 lb/ac of N.

Example 3

Recommended rate of K_2O is 15 lb/ac.

Using 0-0-60, the rate of fertilizer required is:
(15 x 100) / 60 = 25 lb/ac

Converting fertilizer prices into price per unit of nutrient

The cost of a fertilizer is related to its plant nutrient content. If a nitrogen fertilizer such as 34-0-0 is being purchased, the cost should be about three-quarters that of 46-0-0. When buying fertilizer, one should compare prices on the basis of cost per pound of "actual" nutrient, not the price per tonne of fertilizer material.

Example 1

If urea (46-0-0) costs $367/tonne, the cost per pound of nitrogen (N) is calculated as follows:

Nitrogen in one tonne (1,000 kg or 2,204 lb) of 46-0-0 (containing 46% N): (46/100) x 2,204 = 1,014 lb

Cost per lb of N is: $367/1,014 = $0.362

Example 2

(Based on 11-52-0 at $391/tonne)

In order to calculate the cost of phosphate in 11-52-0, the value of nitrogen must first be subtracted.

Nitrogen in one tonne (1,000 kg or 2,204 lb) of 11-52-0 is (11/100) x 2,204 = 242 lb

The value of nitrogen is 242 x $0.362 = $88 (from example 1, which calculated the value of N to be $0.362lb)

Cost of phosphate per tonne is $391 - $88 = $303

Phosphate in one tonne (1,000 kg or 2,204 lb) of 11-52-0 is: (52/100) x 2,204 = 1,146 lb

Cost per lb of P_2O_5 is: $303/1,146 = $0.264

FALL/SPRING FERTILIZER PRICE DIFFERENCES

Generally, fertilizer prices are lower in fall than in spring. Producers should take these price differences into consideration when planning their fertilizer program. Another factor to consider if purchasing in the fall is the interest and storage cost for carrying over to spring. Table 15 summarizes the provincial average price comparisons between fall and spring for the major phosphorus and nitrogen fertilizer products.

Table 15. Average prices of fall versus spring purchased nitrogen and phosphate fertilizer (Fall 2001- Spring 2006).

Fertilizer	Cents/lb N	
	Fall	Spring
Urea (46-0-0)	34.8	39.0
Anhydrous ammonia (82-0-0)†	28.2	33.2
UAN Solution (28-0-0)	37.9	40.5
	Cents/lb P_2O_5	
Mono ammonium phosphate (11-52-0)	25.5	27.2
Ammonium polyphosphate (10-34-0)	36.4	36.8

† FOB Dealer

Fertilizer application costs

Table 16 provides a general summary of costs related to fertilizer application. It includes the major fertilizer forms as well as method of application.

Table 16. Custom fertilizer costs† (2004 values)

Application method	Custom Applied $/ac
Anhydrous ammonia banding	$8.00
Liquid surface broadcast or dribble	$4.80
Granular broadcast	$4.80
Liquid in-soil banding	$8.50
Granular in-soil banding	$8.50
Spoke wheel liquid injection	$8.00

† This includes equipment, fuel, delivery and labour cost.

COMMON FERTILIZERS AND THEIR CHARACTERISTICS

Table 17 summarizes common fertilizers used and their characteristics.

Table 17. Common fertilizers and their characteristics

Name	Nutrient	Physical Properties	Comments
Fertilizers used primarily as sources of nitrogen:			
Anhydrous Ammonia	82-0-0	Compressed gas High affinity for water Pungent odour Corrosive	Must be placed at 4-6" depth. Hazardous (safety precautions are required). High pressure equipment required.
Urea†	46-0-0	Granular	Applied prior to or after seeding. Much less corrosive than other nitrogen fertilizers. Avoid mixing with ammonium nitrate as attraction for moisture causes mixture to turn to slush. More subject to volatilization losses than ammonium nitrate when not incorporated in the soil. Volatilization losses are enhanced when urea is broadcast without incorporation under warm and windy conditions on alkaline, calcareous or drying soils.
Polymer Coated Urea (ESN)	44-0-0	Granular	A polymer coating covers a urea granule. Release of urea is intended to coincide with the crop uptake. This results in decreased nitrogen in a form prone to losses. ESN stands for "environmentally smart nitrogen"
Nitrogen Solution (UAN)	28-0-0	Solution 50% of the nitrogen is in the urea form and 50% is in the ammonium nitrate form contains 0.79 lb N/litre or 3.57 lb N/imperial gallon	Can be applied prior to or after seeding but may be injurious to crops when applied after emergence. Can be applied with certain pesticides. Urea portion is subject to volatilization losses when nitrogen solution is surface-applied and not incorporated. Losses are enhanced when solution is surface-applied without incorporation under warm and windy conditions on alkaline, calcareous or dry soil.

Name	Nutrient	Physical Properties	Comments
Ammonium Nitrate[†]	34-0-0	Granular Prilled	Larger amount than urea can be applied with the seed of cereal crops. Can be applied prior to or after seeding. Avoid mixing with urea as attraction for moisture causes mixture to turn to slush. Less subject to volatilization losses than urea when broadcast without incorporation. Supplies of ammonium nitrate are limited.
Fertilizers used primarily as sources of phosphorus:			
Monoammonium Phosphate (MAP)	11-52-0 12-51-0 10-50-0	Solid, granular, does not absorb moisture during storage, fairly resistant to breakdown during handling.	Most commonly used high analysis dry phosphorus fertilizer.
Diammonium Phosphate (DAP)	18-46-0	Solid, granular	Phosphorus availability to plants similar to monoammonium phosphate. More toxic than MAP when placed with the seed.
Ammonium Polyphosphate Solution (APP)	10-34-0	Liquid contains 0.31 lb N and 1.06 lb P_2O_5/litre or 1.42 lb N and 4.83 lb P_2O_5/imperial gallon	Phosphorus availability to plants similar to monoammonium phosphate.
Phosphoric Acid	0-54-0	Liquid contains 1.87 lb P_2O_5/litre or 8.50 lb P_2O_5/imperial gallon	Burns skin upon contact. Requires specialized delivery systems which can withstand corrosiveness of product. Primarily used for dual band applications with nitrogen fertilizers.
Triple Super Phosphate	0-45-0	Solid Granular	Phosphorus availability less than for phosphorus fertilizer containing ammonium.

Fertilizers used primarily as sources of potassium:			
Potassium chloride (Potash)	0-0-60 0-0-62	Crystalline Hygroscopic Soluble	Most commonly used potassium fertilizer in Manitoba. Can be mixed with other fertilizers. Contains chloride which is a nutrient and may help to reduce the incidence of some plant diseases.
Fertilizers used primarily as sources of sulphur:			
Ammonium Sulphate	21-0-0-24 20-0-0-24 19-2-0-22	Crystalline Granular Granular	Applied prior to seeding. Contains sulphur in the sulphate readily available form. Corrosive. A highly acidifying fertilizer, which should not be used continuously or at high rates on acidic soils.
Ammonium Thiosulphate	12-0-0-26 15-0-0-20	Liquid contains 0.35 lb N and 0.76 lb S/litre or 1.60 lb N and 3.46 lb S/imperial gallon contains 0.43 lb N and 0.57 lb S/litre or 1.96 lb N and 2.62 lb S/imperial gallon	Non-corrosive. Contains sulphur in a readily available form.
Elemental Sulphur	0-0-0-90	Can be blended with most dry fertilizers except ammonium nitrate.	Must be oxidized to sulphate before the plant can use it. Apply one year in advance of crop use.
Combination or blended fertilizers: Note: When blending fertilizer, it is important to use fertilizer sources with evenly matched particle sizes. Using inconsistently sized sources will result in segregation of different fertilizers and may result in lost productivity and crop damage.			
Urea and Monoammonium Phosphate†	27-27-0 34-17-0, etc.	Solid granular, a blend of 46-0-0 and 11-52-0. Fairly stable during storage and handling.	Suitable for nitrogen-and phosphorus-deficient soils. Nitrogen component can cause germination damage to seed at above recommended rates.
MicroEssentials S15	13-33-0-15	Layers of each nutrient are coated on a granule so each granule has same analysis. Includes a combination of sulphate and elemental S.	Offer some improved safety when placed with seed compared to ammonium sulphate blends.
Monoammonium Phosphate and Ammonium Sulphate	16-20-0-14 17-20-0-15	Solid, granular, sources are mixed into a common granule.	Suitable for sulphur-deficient soils. Phosphorus availability same as monoammonium phosphate. Suitable size for blending.

† Warning: Contact between urea (46-0-0) or urea blends and ammonium nitrate (34-0-0) or ammonium nitrate blends will cause the fertilizer to absorb moisture, turning into a "slush". Thoroughly clean all equipment and storage bins before switching from one product to another. Some micronutrient fertilizer may have similar compatibility problems with dry and liquid fertilizers, so consult manufacturer's instructions.

FERTILIZER RECOMMENDATION GUIDELINES

Soil testing is the only way to determine the available nutrient status of a field and receive specific fertilizer recommendations. General recommendations for those without a soil test are outlined in the Appendix of this guide. These recommendations can only provide "ball park" fertilizer requirements and are estimated for average conditions that may not occur in individual fields. As a result, these recommendations may lead to under-fertilization where optimum yield potentials and maximum economic returns will not be achieved. Conversely, these recommendations may lead to over-fertilization resulting in unnecessary costs, excessive vegetative growth, delayed maturity, lodging, reduced quality factors (*e.g.* protein, oil, etc.) and soil and water contamination problems.

Sound fertilizer recommendations for Manitoba are based on soil fertility analysis and fertilizer response. Research is conducted in the province, or under similar soil, climatic and cropping conditions as occur throughout the other parts of the Prairie region. Fertilizer recommendations based on soil testing are also included in the Appendix of this guide.

Soil testing

Yield and economic return from fertilizer can be optimized and potential soil and water pollution minimized, when nutrient application is geared to the needs of a particular crop grown on a specific field. An effective on-farm soil testing program is one in which every field is properly sampled and tested every year. This gives the producer an inventory of the nutrient levels in each field, plus specific recommendations as to the kinds and rates of fertilizer nutrients to apply for each crop. Recommendations may be based on specific times and methods of application and may provide information to modify application rates for different times and methods of application.

Reliable soil test results and recommendations depend upon:

- proper soil sampling and sample processing procedures
- proper soil analysis techniques
- sound fertilizer recommendation guidelines

Soil sampling and sample processing

Soil sampling is the key to a sound soil testing program and the one step over which producers have complete control. Generally, it is important to follow the procedures recommended by the soil testing lab that is analyzing the sample.
The following general procedures are usually recommended to ensure representative samples are provided for laboratory analysis.

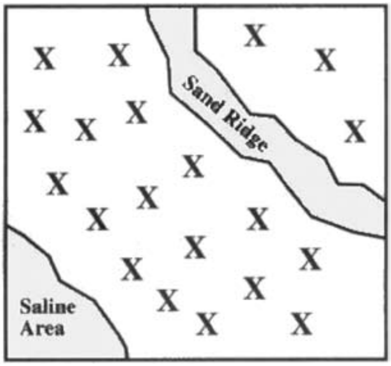
- Samples should be taken prior to seeding in spring, or in the preceding fall after soil temperatures drop. Soils that have cooled to 5°C have minimal microbial activity and hence little change in soil nitrate levels.

- Samples should be taken to the full 24″ depth to get a proper and complete measure of the amounts of nutrients (particularly nitrogen and sulphur) available. All crops usually extract nutrients and water to at least the 24″ depth over the course of a growing season.
- Samples should be kept cool and shipped immediately to the soil lab for analysis. Alternatively, samples should be laid out to dry completely within 24 hours at a temperature less than 35°C or samples should be frozen immediately until they can be dried or analyzed. High temperature drying, or use of a microwave oven, will invalidate test results and fertilizer recommendations.
- Samples should be kept clean. Substances such as fertilizer dust, salted sunflower seeds, cigarette ashes and manure can contaminate samples and result in erroneous test results and fertilizer recommendations.
- If measuring zinc levels in the soil galvanized pails should not be used.
- Samplers may wish to use lubricants to prevent soils from sticking to sampling equipment. WD-40 is preferred over vegetable oil-based lubricants.
- The use of latex gloves will prevent contamination from hands.

SAMPLING PATTERNS

Traditional Composite Random Sampling

- 15-20 cores are randomly taken throughout a field, thoroughly mixed, subsampled and sent to the lab as a single sample.
- Representative sampling areas should be sampled when using traditional composite random sampling (Figure 4). For hilly fields with knolls, slopes or depressions, take samples from mid-slope positions to get average results. Level fields appear relatively easy to sample.
- Avoid sampling obvious areas of unusual variability, such as saline areas, eroded knolls, old manure piles, burnpiles, haystacks, corrals, fence rows or old farmsteads, on headlands, within 50 feet of field borders or shelterbelts and within 150 feet of built-up roads.

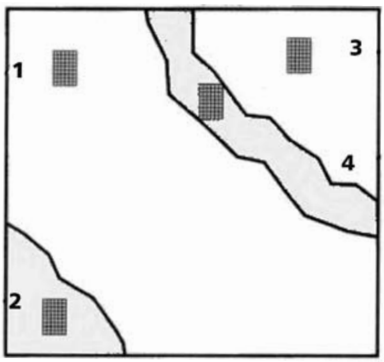


X= Single soil probe sites

Figure 4. Traditional Composite Random Sampling.

Benchmark Soil Sampling

- A small ¼ acre area is selected as typifying the field or majority soil type within the field. In this benchmark area, 15-20 samples are randomly collected and mixed together.
- This technique (Figure 5) assumes that the benchmark area is less variable than the entire field because it is smaller. This same area will be sampled year after year which should minimize sampling errors.
- Selection of the benchmark area is critical. Representative sites may be selected through close crop observation (particularly during early growth stages when fertility differences are most evident), past grower experience, yield maps, soil surveys and/or remote-sensing images.



1 & 3- Sloping Areas 4- High Sand Ridge
2- Low Saline Area
Figure 5. Benchmark Soil Sampling

Grid Soil Sampling

- This technique (Figure 6) uses a systematic method to reveal fertility patterns and assumes there is no logical reason for fertility patterns to vary within a field.
- The field is divided into small areas or blocks. A sample location within the block, often at the point in the centre or grid point, is sampled 3-10 times. Modifications to the grid point sample may be done to avoid repeat sampling of regular spaced patterns within fields, such as fertilizer overlaps, tillage or tile drainage.
- Grid sampling may be costly depending on the grid size selected. Experience in the United States indicates that a sampling density of one sample per acre is required to provide accurate information for variable rate fertilization. Sampling of larger areas may still provide useful information on the magnitude of field variability.

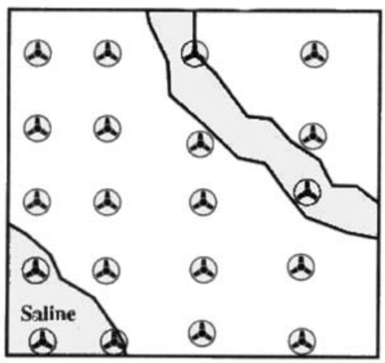


Figure 6. Grid Soil Sampling.

Landscape Directed or Zone Soil Sampling

- This technique (Figure 7) is used when major areas within fields have distinctly different soil properties, such as texture or landscape features. These areas should be sampled and possibly fertilized separately.

- Fields need to be delineated into different polygons or soil management zones. These patterns may be detected by soil survey, detailed elevation mapping, aerial black and white photographs, yield maps or remote sensed images.

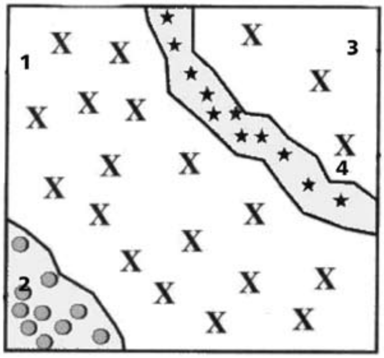


Figure 7. Landscape Directed or Zone Soil Sampling.
1 & 3- Sloping Areas 4- High Sand Ridge
2- Low Saline Area

O = probe sites from low, saline areas

X = probe sites from sloping areas

* = probe sites from high sand ridge

A popular option with soil samplers is to georeference (*i.e.* GPS) selected sample sites so that soil samples can be taken from the same point during future samplings.

PROPER SOIL ANALYSIS TECHNIQUES

Soil analysis techniques that provide meaningful test results should be used. For nitrogen (N) and sulphur (S), analysis results are typically reported in lb/ac. In the case of phosphorus (P), potassium (K) and micronutrients, analysis results are reported in parts per million (ppm). For Manitoba, the following are the recommended and approved procedures for the four major nutrients:

Nitrogen (N) - Water soluble nitrate-nitrogen measured to the 24" depth. When samples are taken to less than the 24" depth, a conversion value is commonly used to approximate the amount that is not measured[42]. This approximation may be affected by weather conditions and soil zone. It is recommended that samples be taken to the full 24" depth.

Phosphorus (P) – "Olsen" (sodium bicarbonate) technique measures extractable P in the top 6" depth and is well-suited to alkaline soils. Some laboratories (Bodycote Norwest Labs and ALS Laboratory Group (former Enviro-Test Labs)) use the acetic fluoride or modified Kelowna test. Evaluations in other Prairie Provinces indicate these methods perform satisfactorily in assessing P responsiveness of the soil. However, since the amount of P extracted is different than the Olsen (sodium bicarbonate) method, the Manitoba provincial recommendations in Appendix Table 17 cannot be used directly. The following conversions can be performed to approximate the Olsen P equivalent amount[43].

Olsen P test (ppm) = Bodycote Norwest P test (ppm) x 0.9

Olsen P test (ppm) = ALS Laboratory Group P test (ppm) x 0.9

Olsen P test (ppm) = Mehlich-3 P test (ppm) x 0.5

Potassium (K) - The "Ammonium Acetate Exchange" technique measures exchangeable K in the top 6" depth. The acetic fluoride or modified Kelowna test also contains ammonium acetate and is a suitable technique.

Sulphur (S) - Water soluble sulphate-sulphur measured to the 24" depth.

Copper, Zinc, Iron and Manganese – Diethylene triamine pentaacetic acid (DTPA) extractable in the top 6" depth.

Boron - Commonly extracted by commercial labs using hot water.

Soil pH - Measurements of soil pH can vary based on analytical methods used. Using a 1:2 soil to calcium chloride solution will reduce interference from soil salts and is used in scientific and soil survey soil characterization. Most commercial labs use the 1:1 or 2:1 soil to water ratio, which tends to increase pH readings of Manitoba soils by 0.5 units.

Salinity or Electrical Conductivity (E.C.) - Salinity measurements for research and soil survey characterization are determined by the saturated paste method where enough water is added to the sample to saturate it without leaving any free water. This best reflects the salinity that occurs at the root surface. Most commercial labs use a 1:1 or 2:1 soil:water ratio method and salinity levels will be approximately half that of the saturated paste method. E.C. values determined in a 1:1 soil to water ratio are generally multiplied by a factor of 2 to approximate the saturated paste measure. This conversion is soil texture specific and can vary. EC is expressed in dS/m, mS/cm, or mmho/cm (all equal).

Use of recommendation guidelines or application of Manitoba guidelines to different analytical techniques may not provide sound fertilizer recommendations.

Other techniques exist to estimate nutrient supply (*e.g.* ion exchange resins), however these have not been calibrated for fertilizer recommendations printed in this guide.

Plant tissue analysis

Plant tissue analysis is a tool that can be used to fine-tune fertilizer management practices. Plant tissue analysis measures the nutrient levels in growing crops. Test values are compared with established values for inadequate, adequate and excess levels for each element and plant species. In this way, the nutritional health of the plant sample and the crop it represents can be assessed and the supply and availability of nutrients to crops during the growing season can be evaluated.

Plant tissue analysis is useful in evaluating fertilizer management programs and practices (including a soil testing program), diagnosing nutrient-related crop production problems and identifying nutrient levels in crops that may limit top yield achievement, including potential micronutrient problems.

Like soil testing, the validity and usefulness of plant tissue analysis depends on proper plant sampling and sample handling procedures. These include:

- Sampling crops from individual fields separately.
- Sampling the proper plant part at the proper growth stage. This is specific to each individual crop and lab. Sampling guidelines should be obtained from a reliable laboratory providing the service.

- Sampling an adequate number of representative plants from a large number of "average" locations in a field. Abnormal plants from non-representative field locations should not be included unless the "comparative sampling" approach is used. Here, samples are taken separately from both normal and abnormal areas to determine if plant nutrition is the cause of the apparent difference.
- Dry samples as soon as possible after removal at normal room temperatures that do not exceed 35°C.
- Avoiding contamination of sample with fertilizer dust, cigarette ashes and other substances.

Like soil testing, analytical results must be assessed using standards developed specifically for crops and cropping conditions in Manitoba. Interpreting the results of plant tissue analysis often requires the assistance of a agronomist.

Table 18 provides the sufficiency levels of nutrients for many Manitoba crops at specific growth stages[44]. Nutrient levels below these sufficiency levels are considered deficient.

Other methods of assessing nutrient sufficiency of crops have been developed, but are less commonly used than traditional plant analysis. Such methods include:

- High N reference plots in the field and the SPAD chlorophyll meter for in-field assessment of N sufficiency for oats[45], winter wheat[46], corn and spring wheat.
- Final grain protein content for N sufficiency in hard red spring wheat and winter wheat (page 5)
- Fall stalk nitrate test for N sufficiency in corn
- Forage feed analysis, taken for balancing feed rations, may identify nutrient deficiencies of forage crops[47]

Many potato fields are routinely sampled to assess nutrient sufficiency through the season. The 4th fully developed leaf from the tip of a main stem is sampled and leaflets are removed exposing the petiole. Some 25-40 petioles are collected per field, usually from marked areas. Repeat sampling is done at these same locations at intervals through the season, as critical levels for N, P and K decline with crop development[48]. Sampling should be done in mornings using the established sampling pattern for most consistent results. In-season soil sampling for N may help in interpreting petiole results and making decisions for supplemental N applications. Contact your soil and plant analysis laboratory for further sampling and handling instructions.

Table 18. Crop nutrient sufficiency levels.

Crop	Plant part/ Growth stage	%N	%P	%K	%Ca	%Mg	%S	Fe ppm	Mn ppm	Cu ppm	Zn ppm	B ppm
Alfalfa	Top 6"/ Flowering	2.5-5.0	0.25-0.7	2.0-3.5	0.5-3.0	0.3—1.0	0.25-0.5	30-250	25-100	8-30	20-70	30-80
Buckwheat	Entire top/ Flowering	1.75-3.0	0.25-0.5	1.5-3.0	0.3-2.0	0.2-1.5	0.15-0.4	20-250	10-100	5-25	15-70	5-25
Cereals - barley - wheat - oats	Entire top/ Prior to filling	2.0-3.0	0.26-0.5	1.5-3.0	0.2-2.0	0.15-0.5	0.15-0.4	20-250	15-100	- 3.7-25 4.5-25 2.5-25	15-70	5-25
Canola	Entire top/ Flowering	2.5-4.0	0.25-0.5	1.5-2.5	0.5-4.0	0.2-1.5	0.25-0.5	20-200	15-100	2.7-20	15-70	30-80
Corn	Ear leaf/ Tasselling	2.5-3.5	0.25-0.5	1.7-2.25	0.2-1.0	0.2-0.6	0.15-0.4	20-250	20-150	5-20	20-70	5-25
Flax	Entire top/ Flowering	1.75-3.0	0.25-0.5	1.5-3.0	0.2-2.0	0.2-1.5	0.15-0.4	20-250	20-100	3.5-25	15-70	5-25
Grasses	Entire top/ Prior to seed fill	2.0-3.0	0.25-0.5	1.5-3.0	0.2-0.5	0.15-0.5	0.15-0.4	20-250	15-100	5-25	15-70	5-25
Peas/beans	First fully developed leaf/ Flowering	3.0-5.5	0.25-0.5	1.5-3.0	0.35-2.0	0.2-1.5	0.2-0.4	20-250	20-100	5-20	15-70	5-25
Soybeans	Upper trifoli-ate leaf/Prior to Flowering	4.25-5.5	0.25-0.5	1.7-2.5	0.35-2.0	0.2-1.5	0.2-0.4	50-350	20-100	10-30	20-50	20-50

MANURE

Manure may provide many of the nutrients required by crops - in addition to providing organic matter which helps to improve soil tilth, structure, aeration and water holding capacity.

Discussion on the agronomic use and environmental stewardship of manure is beyond the scope of the guide.

For information on manure management refer to the "*Tri-Provincial Manure Application and Use Guidelines – Manitoba Version*"[49] *or the appropriate "Farm Practices Guidelines for Hog/Beef/Dairy/Poultry Producers in Manitoba"*[50].

NITROGEN FIXATION

Rhizobium bacteria have a symbiotic relationship with legumes to convert atmospheric nitrogen (N_2) to a plant-available form. This process is called nitrogen fixation.

Sufficient numbers of effective rhizobium bacteria must be present to ensure that plants are well nodulated and able to meet the N needs of the crop. Since many soils do not contain sufficient numbers of *Rhizobium* bacteria, inoculation is recommended to assure early formation of functioning nodules.

Inoculation

The most common forms of inoculant formulations are: granular, powdered peat, liquid and frozen concentrates and pre-inoculated seed. All but granular inoculants are applied by coating the seed with a prepared culture of the required strain of *Rhizobium* bacteria. Granular inoculants are designed for application in the furrow with the seed. Compared with peat-based and liquid inoculant, the granular form is more convenient to use and seems to be more effective in dry soils. However, granular inoculants are more expensive and may require special modifications to seeding equipment to ensure placement in the seed zone.

Pre-inoculation of seed has proven effective for nodulation of alfalfa and other forage legumes and for current season use on soybeans.

Each legume or group of legumes requires a unique species of *Rhizobium* to form nodules and fix N. Commercial inoculants are prepared for specific groups of legumes as follows:

- alfalfa group – for alfalfa and sweet clover
- birdsfoot trefoil – for birdsfoot trefoil
- clover group – for red, white and alsike clover
- fababean group – for fababeans including broad and horse beans
- field bean group – for field, garden, navy, pinto and other coloured beans
- pea and lentil group – for field, garden, flat peas and lentils
- soybean group – for soybeans only

Labels will contain information on proper storage, handling and application of inoculant. Improper storage, which allows drying or heating, will reduce bacteria viability.

Most legumes are very efficient and derive almost all their N needs through N fixation, so no additional N fertilizer is required. However,

Fertilizer Recomendation Guidelines

N fixation may be reduced by acidic soil conditions, toxic seed treatments, desiccation in dry seedbeds, high soil nitrate levels or fertilizer applications.

Dry Beans

Dry beans are rather inefficient at fixing N and obtain less than half of their requirements through fixation.

Recent field studies indicate that treatment with *Rhizobium* inoculant is ineffective on current dry bean cultivars grown in Manitoba. Bean response to applied N has been large and recommendations based on soil N and expected yield are found in Appendix Table 12. The field bean production system influences the response to applied N. When beans are grown in wide rows and inter-row cultivation is used to control weeds and for hilling, some mineralization of organic N occurs due to soil disturbance. When beans are grown in narrow rows, applied N modifies the plant architecture to make it more suitable for direct combining. Plants are taller and pods are held higher off the ground which increases the harvestable yield.

High N rates on dry beans have a minor impact on maturity and white mould. White mould is more prevalent in high yield crops regardless of N application, so growers should scout fields and apply control measures when warranted. Applied N increases both bean yield and seed protein with little accumulation in soil N levels. Beans are a shallow rooted crop so N applications should be made in the spring rather than fall to avoid leaching of nitrate-N. Fall soil sampling is essential so that residual nitrate levels are accounted for when fertilizing successive crops.

Soybeans

Recent improvements in inoculant formulations and technology have greatly improved the effectiveness in developing well nodulated soybeans. Inoculation is critical on virgin fields where an inoculated crop has not been grown in the past. Many manufacturers recommend increased rates of inoculant on virgin fields to ensure effective inoculation.

Several conditions may challenge the success of soybean inoculation on virgin fields:

- Initial inoculation remains a challenge on fine textured, wet soils and growers should consider inoculation with a granular inoculant in addition to an on-seed product.
- Excessive levels of residual soil N or applied N as manure or fertilizer may inhibit inoculation. Soybeans will be forced to rely solely on this residual N for growth and yield. When possible growers should avoid such fields for soybeans.
- Some seed treatments may be toxic to seed-applied *Rhizobium*, so refer to inoculant manufacturer labels to determine compatibility and method of application when using seed treatments (*e.g.* insecticides and fungicides).

If nodules are not present and soybeans are yellowing at flowering, growers should consider a broadcast application of nitrogen. Apply 50 lb N/ac as broadcast ammonium nitrate or dribble banded UAN solution to minimize leaf burn.

For more information on inoculation, refer to the MAFRI Factsheet "*Legume Inoculation*" (120-33).

Plant growth promoting rhizobacteria (PGPR) are beneficial bacteria growing within the rhizosphere (*i.e.* next to the plant roots)[51]. PGPRs may promote plant growth through enhanced nutrient availability. Currently the only PGPR registered for commercial use is Bioboost (Registration #2005042A, *Fertilizers Act*). Bioboost, (*Delftia acidovorans*) is applied as a seed inoculant for canola.

SOIL pH AND SALINITY

Soil pH

Most Manitoba soils have a neutral (pH 7.0) to alkaline pH (pH>7.0). Soil pH influences the availability of nutrients, particularly phosphorus and micronutrients and biological activity.

Soil pH conditions result from the original soil parent material, the type of vegetation, the climate (particularly the amount of rainfall) and the age of the soils. Most agricultural soils in Manitoba are geologically young (<12,000 years), are derived from calcareous rock and developed under moderate rainfall and grassland or deciduous forest. These conditions have contributed to generally neutral to alkaline soils. The exceptions are sandy soils which have been leached or have developed under coniferous forest and peat soils.

Under low pH:

- *Rhizobium* bacteria which provide N fixation are inhibited
- herbicides in the imidazolinone family, such as Pursuit, break down slowly in acidic soil

Under high pH:

- availability of phosphorus and most micronutrients is reduced, making placement more important
- urea losses to volatilization are greater
- risk of injury from seed-placed urea is increased
- herbicides in the sulfonyl urea family, such as Ally and Glean and triazines (atrazine) break down slowly

Many of these fertility concerns on high pH soils are managed through timing and placement of fertilizer applications.

Management may also affect soil pH. Liming effectively raises the pH of acidic soils. Acidification of soils may occur through repeated nitrogen and sulphur application; however, on alkaline Manitoba soils this effect is negligible. Attempts to acidify alkaline soils are usually unsuccessful since the high calcium carbonate content effectively neutralizes acidity from added sulphur or nitrogen fertilizers[52].

Efforts should be made to manage factors that increase soil pH. High pH soils may result from erosion, tillage or land leveling which removes or dilutes surface soil with more calcareous subsoil and from salt movement or salinity in the soil.

Salinity

Soil salinity is a soil condition where water soluble salts in the crop rooting zone impede crop growth. The severity of the effects and strategies to address the problem depend upon soil testing to identify the amount and type of salts present.

High salt content increases the osmotic potential of the soil solution and prevents crop uptake of water. Crops are generally most sensitive to salinity during germination and emergence. Some plants are more sensitive to salinity than others, depending on growth habit, root system, etc.

To assess the type of salinity problem, both affected and non-affected areas of the field should be sampled. Analyses should be done for electrical conductivity (E.C.), pH, cation base saturation and content of calcium, magnesium, sodium and organic matter. Electrical conductivity of a soil-water extract is an index of the concentration of dissolved salts in the soil. As salt content increases, so does the E.C. (Table 19).

Another type of soil problem occurs when sodium levels are high in relation to calcium and magnesium in the soil. These soils are very sticky and slippery when wet and very hard, cloddy and prone to crusting when dry. The sodium adsorption ratio (SAR) should be determined by the soil test lab. The SAR is the ratio of sodium to the beneficial soil structural cations, calcium and magnesium. When the SAR value exceeds 13, the soil is "sodic". If the SAR exceeds 13 and the E.C. is greater than 4, it is considered a "saline-sodic" soil.

Consult the "*Soil Management Guide*"[53] and other publications for management of saline and saline-sodic soils.

Table 19. The effect of salinity on crop growth.

E.C. (dS/m, mS/cm or mmho/ cm)†	Degree of salinity	Hazard for crop growth	Plant Response	Relative tolerance of crops‡
0-2	Non-saline	Very low	Negligible	
2-4	Slightly saline	Low	Restricted yield of sensitive crops	Beans, peas, corn, soybean, sunflowers, clovers and timothy
4-8	Moderately saline	Medium	Restricted yield of many crops	canola, flax, oats, wheat, rye, barley, bromegrass, alfalfa, sweet clover and trefoil
8-16	Severely saline	High	Only a few tolerant crops yield satisfactorily	Slender and tall wheatgrass, Russian and Altai wildrye
>16	Very severely saline	Very high	Only a few salt tolerant forage grasses grow satisfactorily	

† as determined by the saturated paste method.

‡ range of salinity values at which crops can be expected to yield at least 50% of normal yield.

Nutrient Management Plans

A Nutrient Management Plan (NMP) helps growers to make better and more profitable decisions in crop management. Many consider that NMP's deal exclusively with manure use, but manure is applied to less than 10% of Manitoba acres each year. Nutrient Management Planning for most Manitoba growers will focus on the use of fertilizer inputs, with occasional credits for previous legume crops and manure.

The plan has 10 components, many of which are described in detail in this guide.

1. Locate facilities and fields on maps. Aerial photos such as MAFRI's Agri-Maps are most useful (http://geoapp2.gov.mb.ca/website/mafri/index3.html)
2. Identify environmentally sensitive areas on maps. Note appropriate buffer distances.
3. Specify crop rotation used by grower
4. Determine expected yields
5. Obtain results of soil, plant, and manure analysis
6. Account for nutrients from additional sources available on the farm (i.e. N from previous legumes, green manures, etc)
7. Determine nutrient requirements for each field from above information (using Appendix tables)
8. Make recommendations of nutrient rate, timing, form and method of application
9. Review and modify plan as needed (based on economics, growing season conditions, in-season nutrient assessment, etc)
10. Maintain records and complete a nutrient budget (including nutrient inputs, outputs and soil test changes)

APPENDIX

Manitoba Fertilizer Recommendation Guidelines Based on Soil Tests

This section contains tables of fertilizer recommendations for most Manitoba field crops based on soil tests. These recommendations are based on field research conducted in Manitoba and have been approved for use in Manitoba by the Manitoba Soil Fertility Advisory Committee. Following are some brief points in using the attached recommendation tables:

1. Recommendations are based on soil analysis performed according to the soil analysis section entitled "Proper Soil Analysis Techniques".
2. Soil analysis results may be reported by soil test laboratories as lb/ac or ppm. Values in ppm can be converted to lb/ac by multiplying by a factor of 2 for each 6" increment of depth for the sample (*e.g.* multiply by 2 for 6" samples and by 6 for 18" samples). Ratings for soil test levels are given as very low (VL), low (L), medium (M), high (H), very high (VH and VH+).
3. Soil nitrate-nitrogen values used in these recommendations are based on fall soil sampling. Manitoba research has shown that 8 lb/ac nitrate-N may mineralize between late fall sampling and spring seeding. If samples are taken in the spring, deduct 8 lb/ac from the analytical values before using the tables.
4. Nitrogen rates are based on a spring broadcast application for all but row crops, where rates are based on a spring band application. Relative efficiency of nitrogen varies by method and time of application, so rates should be adjusted according to Table 8 in this guide.

Adjust nitrogen recommendations from tables according to method and time of application according to this formula.

Rate of N to Apply =
(Rate from chart) X
<u>(Relative Value of Spring Broadcast)</u>
(Relative Value of Method Used)

5. Nitrogen recommendations for some cereals, canola, flax, corn and sunflowers are based on TARGET YIELDS. The TARGET YIELD is the yield that a crop might be expected to produce based upon the amount of spring soil moisture and expected growing season precipitation based on the grower's experience. The TARGET YIELD FERTILIZER RECOMMENDATIONS indicate the fertilizer rate required to meet that yield expectation. Target yield recommendations are not intended as yield predictions; nor do they imply guaranteed yield attainment. Achieving such target yields depend upon good management and cooperation of uncontrollable factors such as weather.

More information on setting target yields can be found in the section entitled, "Agronomically, Economically and Environmentally Sensible Target Yields" in the Appendix.

6. Nitrogen recommendations for cereals are further refined based upon soil moisture supply. Moisture supply is dependent upon seasonal precipitation and soil properties such as texture and drainage which affect moisture retention. Based on these criteria, soils within the province have been assigned a moisture category of MOIST or DRY. Soils of the MOIST category have a high water holding capacity or are in the cooler areas which may experience periodic dry conditions. Examples are the clay soils of the Red River Valley and the Grey Wooded soils.

Soils of the DRY category are intermediate in water holding capacity and experience dry weather conditions.

The IDEAL moisture category would occur under irrigation or when yield is not limited by lack of rainfall.

A full listing of Manitoba soils and their moisture category are available from your MAFRI office.

7. No nitrogen is recommended for production of perennial legumes and most annual pulse crops (the exception is dry beans). All legumes should be properly inoculated at seeding to ensure nitrogen fixation.

8. In dry years, deep-rooted crop such as sunflowers will extract nitrogen below the 24" sampling depth. Consider sampling at the 2-4 foot depth for this crop.

9. High nitrogen rates are recommended for cereals and flax with high target yields and low soil N. Severe lodging may occur, so growers should temper rates based on their experiences.

10. Several of the phosphorus and potassium recommendations are based upon specific placement techniques. Crops vary in their tolerance of seed placed fertilizer and this influences recommendations (Tables 7 and 12).

Example 1. A fall soil sample analysis is received with the following results:

Nutrient	Nitrate-N (0-24")	Phosphorus	Potassium	Sulphate-S (0-24")
Result	30 lb/ac	15 ppm	240 ppm	20 lb/ac

- The crop to be grown is feed barley and the projected yield is 85 bu/ac. The land is located on clay soils and is classified as a "moist" moisture category.
- Nitrogen fertilizer will be spring banded and phosphorus and potassium will be seed placed.
- From Appendix Table 4, 75 lb N/ac are required "if spring broadcast". Use Table 8 to determine rate of spring banded N = 75 x 100/120 = 63 lb N/ac
- From Appendix Table 17 and 15 ppm soil P, one determines that 15 lb P_2O_5/ac is required.
- From Appendix Table 18 and 240 ppm soil K, one determines that no K_2O is required.
- From Appendix Table 19 and 20 lb/ac soil sulphate-S, one determines that 15 lb S/ac is required.

Appendix

Fertilizer Guidelines for Soil Tests

The following recommendation tables listed in the Appendix should be used as a guide to fertilization rates. These guidelines are not intended to supercede provincial laws or to serve as application limits.

The guidelines in the following tables have been based on field research in Manitoba. Some guidelines have not been revised since 1990 due to lack of supporting field data. Development of new or validation of existing nitrogen guidelines have been done since 2000 for winter wheat, oats, flax, corn, dry beans, potatoes and forage grasses. Revisions are under development for spring wheat, barley and canola.

Appendix Table 1. Nitrogen recommendations for hard red spring wheat (based on spring broadcast application)[54].

Nitrogen Recommendation (lb/ac)										
SOIL MOISTURE CATEGORY		DRY			MOIST			IDEAL		
TARGET YIELD (bu/ac)		30	35	40	35	40	45	40	45	50
Fall Soil NO_3-N										
lb/ac in 0-24"	Rating									
20	VL	30	55	100	45	70	110	65	90	120
30	L	10	30	80	25	45	85	45	70	100
40	M	0	10	60	5	30	65	25	50	80
50	M	0	0	40	0	10	50	5	30	60
60	H	0	0	20	0	0	25	0	10	40
70	H	0	0	0	0	0	0	0	0	20
80	VH	0	0	0	0	0	0	0	0	0
90	VH	0	0	0	0	0	0	0	0	0
100	VH+	0	0	0	0	0	0	0	0	0

Appendix Table 2. Nitrogen recommendations for CPS and feed wheat (based on spring broadcast application)[55]*.*

Nitrogen Recommendation (lb/ac)										
SOIL MOISTURE CATEGORY		DRY			MOIST			IDEAL		
TARGET YIELD (bu/ac)		45	50	55	50	55	60	50	55	60
Fall Soil NO_3-N										
lb/ac in 0-24"	Rating									
20	VL	45	70	130	55	70	110	90	110	140
30	L	25	50	110	35	55	85	70	90	120
40	M	5	30	90	15	35	65	50	70	100
50	M	0	10	70	0	15	50	30	50	80
60	H	0	0	50	0	0	25	10	30	60
70	H	0	0	30	0	0	0	0	10	40
80	VH	0	0	10	0	0	0	0	0	20
90	VH	0	0	0	0	0	0	0	0	0
100	VH+	0	0	0	0	0	0	0	0	0

Appendix Table 3. Nitrogen recommendations for hard red winter wheat (based on spring broadcast application)[56]*.*

Spring Soil NO_3-N		Nitrogen Recommendation (lb/ac)
lb/ac in 0-24"	Rating	
20	VL	150
30	L	135
40	M	120
50	M	110
60	H	95
70	H	80
80	VH	65
90	VH	50
100	VH+	35

Appendix

Appendix

Appendix Table 4. Nitrogen recommendations for feed barley (based on spring broadcast application)[57].

Nitrogen Recommendation (lb/ac)										
SOIL MOISTURE CATEGORY		DRY			MOIST			IDEAL		
TARGET YIELD (bu/ac)		60	65	70	80	85	90	85	95	105
Fall Soil NO_3-N										
lb/ac in 0-24"	Rating									
20	VL	45	70	100	75	95	120	95	130	180
30	L	25	50	80	55	75	100	75	110	160
40	M	5	30	60	35	55	80	55	90	140
50	M	0	10	40	15	35	60	35	70	120
60	H	0	0	20	0	15	40	15	50	100
70	H	0	0	0	0	0	20	0	30	80
80	VH	0	0	0	0	0	0	0	10	60
90	VH	0	0	0	0	0	0	0	0	40
100	VH+	0	0	0	0	0	0	0	0	20

Appendix Table 5. Nitrogen recommendations for malting barley (based on spring broadcast application)[58].

		NITROGEN RECOMMENDATION (lb/ac)								
SOIL MOISTURE CATEGORY		DRY			MOIST			IDEAL		
TARGET YIELD (bu/ac)		55	60	65	65	70	75	75	80	85
Fall Soil NO_3-N										
lb/ac in 0-24"	Rating									
20	VL	50	80	130	80	105	155	125	150	180
30	L	30	60	105	60	80	135	105	130	160
40	M	10	40	85	40	60	115	85	110	140
50	M	0	20	65	20	45	95	65	90	120
60	H	0	0	45	0	25	75	45	70	100
70	H	0	0	25	0	5	55	25	50	80
80	VH	0	0	0	0	0	35	5	30	60
90	VH	0	0	0	0	0	15	0	10	40
100	VH+	0	0	0	0	0	0	0	0	20

Appendix Table 6. Nitrogen recommendations for oats (based on spring broadcast application)[59].

Fall Soil NO_3-N		Nitrogen Recommendation (lb/ac)
lb/ac in 0-24"	Rating	
20	VL	80
30	L	70
40	M	60
50	M	50
60	H	40
70	H	30
80	VH	20
90	VH	10
100	VH+	0

Note: N Fertilizer required = 100 lb N/ac – Soil NO_3–N (lb/ac)

Appendix Table 7. Nitrogen recommendations for open pollinated and hybrid canola[†] (based on spring broadcast application)[60].

NITROGEN RECOMMENDATION (lb/ac)					
TARGET YIELD (bu/ac)		30	35	40	45
Fall Soil NO_3-N					
lb/ac in 0-24"	Rating				
20	VL	75	105	135	165
30	L	55	85	115	145
40	M	40	70	95	125
50	M	25	55	80	110
60	H	15	40	70	90
70	H	5	35	60	85
80	VH	0	30	55	85
90	VH	0	25	55	85
100	VH+	0	25	55	85

[†] The above recommendation was based on Manitoba research with open pollinated (OP) canola. Recent studies[61] indicate that hybrid canola is more nitrogen efficient than open pollinated canola, and will produce 10-14% greater yield for the same fertilizer N rate. Genetic yield potential of hybrid canola is approximately 20-25% greater than OP canola but requires N supply to be increased by some 30 lb N/ac. For hybrid canola, modify the above table by increasing OP Target Yield by 20-25% and add 30 lb N/ac to obtain nitrogen recommendation.

Appendix Table 8. Nitrogen recommendations for flax (based on spring broadcast application)[62].

		NITROGEN RECOMMENDATION (lb/ac)		
TARGET YIELD (bu/ac)		25	30	35
Fall Soil NO_3-N				
lb/ac in 0-24"	Rating			
20	VL	60	110	160
30	L	30	75	130
40	M	0	50	100
50	M	0	25	75
60	H	0	5	55
70	H	0	0	40
80	VH	0	0	35
90	VH	0	0	30
100	VH+	0	0	30

Appendix Table 9. Nitrogen recommendations for corn (based on a spring band application)[63, 64].

		NITROGEN RECOMMENDATION (lb/ac)			
TARGET YIELD (bu/ac) SILAGE YIELD (t/ac)		85 12.6	100 14.9	115 17.1	130 19.4
Fall Soil NO_3-N					
lb/ac in 0-24"	Rating				
20	VL	80	125	170	220
30	L	55	100	145	195
40	M	30	75	125	170
50	M	5	55	100	145
60	H	0	30	75	120
70	H	0	5	50	95
80	VH	0	0	25	70
90	VH	0	0	0	50
100	VH+	0	0	0	25

Appendix Table 10. Nitrogen recommendations for sunflowers (based on spring band application)[65].

		NITROGEN RECOMMENDATION (lb/ac)			
TARGET YIELD (lb/ac)		1,750	2,000	2,250	2,500
Fall Soil NO_3-N					
lb/ac in 0-24"	Rating				
20	VL	40	85	125	170
30	L	20	60	105	145
40	M	0	35	80	120
50	M	0	10	55	100
60	H	0	0	30	75
70	H	0	0	5	50
80	VH	0	0	0	25
90	VH	0	0	0	0
100	VH+	0	0	0	0

Appendix Table 11. Nitrogen recommendations for buckwheat (based on spring broadcast application)[66].

Fall Soil NO_3-N		NITROGEN RECOMMENDATION (lb/ac)
lb/ac in 0-24"	Rating	
20	VL	60
30	L	40
40	M	20
50	M	20
60	H	0
70	H	0
80	VH	0
90	VH	0
100	VH+	0

Appendix Table 12. Nitrogen recommendations for dry field beans (based on a spring broadcast application)[67, 68] .

		NITROGEN RECOMMENDATION (lb/ac)					
Target Yield lb/ac		1,200		1,800		2,400	
Production system		Wide row†	Narrow row‡	Wide row†	Narrow row‡	Wide row†	Narrow row‡
Fall Soil NO_3-N							
lb/ac in 0-24"	Rating						
20	VL	0	40	35	70	50	100
30	L	0	30	30	60	45	90
40	M	0	20	25	50	40	80
50	M	0	10	20	40	35	70
60	H	0	0	15	30	30	60
70	H	0	0	10	20	25	50
80	VH	0	0	5	10	20	40
90	VH	0	0	0	0	15	30
100	VH+	0	0	0	0	10	20

† Wide row production systems using inter-row cultivation for weed control and hilling.

‡ Narrow row production using direct cutting or swathing for harvest.

Appendix Table 13. Nitrogen recommendations for potatoes (based on spring broadcast application)[69].

		NITROGEN RECOMMENDATIONS (lb/ac)			
Production system		Dryland		Irrigated†	
Target Yield (cwt/ac)		200	250	High (250-350)	Very High (400+)
Fall Soil $N0_3$-N					
lb/ac in 0-24"	Rating				
0	VL	140‡	170‡	200‡	260‡
20	L	80	110	140	180
40	M	60	90	120	160
60	H	40	70	90	130
80	VH	20	50	70	110
100	VH+	0	30	50	90
120	VH+	0	10	30	70
140	VH+	0	0	10	50
160	VH+	0	0	0	30
180	VH+	0	0	0	10
200	VH+	0	0	0	0

† Mineralizaton of soil organic N is substantial under irrigated production on most soils. However, Manitoba research on low organic matter, very sandy soils is limited; nitrogen rates required may be slightly higher than indicated.

‡ Soils testing very low in nitrogen may be infertile and require large applications of nitrogen. Nitrogen should be applied in split applications rather than entirely at planting.

Appendix

Appendix Table 14. Nitrogen recommendation for forage grasses[70] and export timothy hay[71] (based on spring applications).

Fall Soil NO_3-N		NITROGEN RECOMMENDATION (lb/ac)	
lb/ac in 0-24"	Rating	Forage grasses†	Timothy hay
10	VL	110	90
20	VL	100	80
30	L	85	70
40	M	70	60
50	M	50	50
60	H	30	40
70	H	15	30
80	VH	0	20
90	VH	0	10
100	VH+	0	0

† not based on economics or moisture probabilities as are Appendix Tables 15 and 16.

Appendix Table 15. Nitrogen recommendations for smooth bromegrass hay (based on spring applications)[72,73] .

Soil Moisture Category†	Arid			Dry			Moist		
Value of Hay ($/t)	$60	$80	$100	$60	$80	$100	$60	$80	$100
Required N supply lb (N/ac)	0	15	45	10	75	105	0	105	165
Expected yield (t/ac)	0.6	0.7	0.9	0.7	1.3	1.5	1.9	2.9	3.3
Soil NO_3 (lb N/ac)	NITROGEN RECOMMENDATION (lb/ac)								
20	0	0	25	0	55	85	0	85	145
40	0	0	5	0	35	65	0	65	125
60	0	0	0	0	15	45	0	45	105
80	0	0	0	0	0	35	0	35	85
100	0	0	0	0	0	15	0	15	65

† Soil Moisture Category is described by general area (and specific conditions of the study).

Moist = clay loams soils receiving good rainfall

Dry = sandy loam soils receiving good rainfall

Arid = sandy loam soils short on rainfall

Note: At $40/t, it is rarely economical to fertilize grass hay.

Assumptions in calculations are based upon nitrogen fertilizer @ $0.41/lb N and hay handling (cutting, baling, and hauling) costs at $25 per tonne.

Appendix Table 16. Nitrogen recommendations for intermediate wheatgrass hay (based on spring applications)[74, 75].

Soil Moisture Category†	Arid			Dry			Moist		
Value of Hay ($/t)	**$60**	**$80**	**$100**	**$60**	**$80**	**$100**	**$60**	**$80**	**$100**
Required N supply lb (N/ac)	**0**	**0**	**0**	**0**	**0**	**50**	**0**	**65**	**130**
Expected yield (t/ac)	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**	**1.1**	**2.2**	**2.7**	**3.2**
Soil NO_3 (lb N/ac)	**NITROGEN RECOMMENDATION (lb/ac)**								
20	0	0	0	0	0	30	0	45	110
40	0	0	0	0	0	10	0	25	90
60	0	0	0	0	0	0	0	5	70
80	0	0	0	0	0	0	0	0	50
100	0	0	0	0	0	0	0	0	30

† Soil Moisture Category is described by general area (and specific conditions of the study).

Moist = clay loams soils receiving good rainfall

Dry = sandy loam soils receiving good rainfall

Arid = sandy loam soils short on rainfall

Note: At $40/t, it is rarely economical to fertilize grass hay.

Assumptions in calculations are based upon nitrogen fertilizer @ $0.41/lb N and hay handling (cutting, baling, and hauling) costs at $25 per tonne.

Appendix Table 17. Phosphorus recommendations for field crops based on soil test levels and placement[76].

FERTILIZER PHOSPHATE (P_2O_5) RECOMMENDED (lb/ac)																
Soil Phosphorus (sodium bicarbonate or Olsen P test)			Cereal	Corn Sunflower	Canola Mustard Flax		Buckwheat Fababeans		Potatoes		Peas Lentils Field beans† Soybeans†		Legume forages		Perennial grass forages	
ppm	lb/ac	Rating	S[1]	Sb[2]	B[3]	S[1]	B[3]	S[1]	B[3]	PPI[4]	B[3]	S[1]	seeding PPI[5]	Est. stand BT[6]	seeding PPI[5]	Est. stand BT[6]
0	0	VL	40	40	40	20	40	20	55	110	40	20	75	55	45	30
	5	VL	40	40	40	20	40	20	55	110	40	20	75	55	45	30
5	10	L	40	40	40	20	40	20	50	100	40	15	75	55	45	30
	15	L	35	35	35	20	35	20	45	90	35	15	65	50	35	20
10	20	M	30	30	30	20	30	20	45	90	30	10	60	40	30	20
	25	M	20	20	20	20	20	20	40	80	20	10	50	35	20	15
15	30	H	15	15	15	0	15	20	35	70	15	0	45	30	15	10
	35	H	10	10	10	0	10	20	30	60	10	0	30	20	0	0
20	40	VH	10	10	10	0	10	20	30	60	10	0	30	20	0	0
20+	40+	VH+	10	10	10	0	10	20	30	60	10	0	25	20	0	0

S[1] – seed-placed rates

Sb[2] – side banded rates for row crops

B[3] – banded away from the seed

PPI[4] – if P is broadcast, rates must be 2x that of banding to be as effective.

PPI[5] – for forages phosphorus is applied most effectively by banding 1″ to the side and below the seed. If phosphate cannot be banded, then broadcast and preplant incorporate.

BT[6] – broadcast for established stands of forages

Est. stand = established stands of forages

† for field beans and soybeans, safe rates of seed-placed P are limited to 10 lb P_2O_5/ac with narrow row widths (<15″) and no seed-placed P when grown in wider row widths.

Appendix Table 18. Potassium recommendations for field crops based on soil test level and placement[77].

Soil Potassium (ammonium acetate K test)			FERTILIZER POTASH (K_2O) RECOMMENDED (lb/ac)												
			Cereals		Corn		Sunflowers		Potatoes		Canola, Mustard, Flax, Peas, Field beans, Faba beans, Lentils, Buckwheat, Soybeans	Legume forages		Perennial grass forages	
ppm	lb/ac	Rating	S[1]	PPI[3]	Sb[2]	PPI[3]	Sb[2]	PPI[3]	Dryland Sb[2]	Irrigated Sb[2]	PPI[3]	Seeding PPI[3]	Est. stand BT[4]	seeding PPI[3]	Est. stand BT[4]
0	0	VL	30	60	100	200	30	60	100	150	60	150	100	90	65
25	50	VL	30	60	90	180	30	60	90	140	60	150	100	90	65
50	100	L	15	30	80	160	15	30	80	120	30	100	70	45	30
75	150	L	15	30	75	150	15	30	75	110	30	50	35	45	30
100	200	M	0	0	65	130	0	0	65	95	0	35	25	45	30
125	250	M	0	0	55	110	0	0	55	80	0	0	0	0	0
150	300	H	0	0	50	100	0	0	45	70	0	0	0	0	0
175	350	H	0	0	40	80	0	0	40	60	0	0	0	0	0
200	400	VH	0	0	30	60	0	0	30	45	0	0	0	0	0
200+	400+	VH+	0	0	0	0	0	0	0	0	0	0	0	0	0

S[1] – seed placed rates
Sb[2] – side banded rates for row crops
PPI[3] – broadcast and preplant incorporated.
BT[4] – broadcast for established stands of forages
Est. stand = established stands of forages

Appendix Table 19. Sulphur recommendations for field crops based on soil test level[78].

Soil Sulphate-Sulphur in 0-24″		FERTILIZER SULPHUR (S) RECOMMENDED lb/ac		
lb/ac	Rating	Cereals Flax Buckwheat Forage grasses	Canola, Corn Sunflower, Field peas Field beans, Faba beans Soybeans, Potatoes	Forage legumes
0	VL	15	20	30
5	VL	15	20	30
10	VL	15	20	30
15	L	15	20	30
20	L	15	20	30
25	M	0	20	30
30	M	0	20	30
35	H	0	0	0
40	VH	0	0	0
40+	VH+	0	0	0

Appendix Table 20. Soil test criteria for micronutrient fertilizer use.

Micronutrient	Critical Level	Marginal Level
Copper (Cu)†	0.2 ppm 5.0 ppm on peat soils[79]	0.2 – 0.4 ppm on mineral soils 5-12 ppm on peat soils
Iron (Fe)†	4.5 ppm	
Manganese (Mn)†	1.0 ppm	
Zinc (Zn)†	1.0 ppm for corn[80] 0.5 ppm for field beans 0.25 ppm for cereals	
Boron (B)	The soil test has not proven to be an effective diagnostic tool.	

†using DTPA extractant for copper, iron, manganese and zinc.

Appendix Table 21. Summary of common methods of applying generalized categories of micronutrient products on the prairies.

Nutrient	Fertilizer form	Time of soil application	Broadcast & Incorporate	Seed-placed	Foliar
Chloride (Cl) Potash – 50% Cl	Chloride	Spring or fall	50-80 lb Cl/ac	10-20 lb Cl/ac	uncommon
Copper (Cu)	Sulphate[81,82,83]	Spring or fall	3.5–5 lb Cu/ac	Not recommended	Not recommended†
	Oxysulphate[84,85] <50% solubility	Fall	5 lb Cu/ac	Not recommended	Not recommended
	Chelated[86,87,88,89]	Spring	0.5 lb Cu/ac	0.5 lb Cu/ac	0.2-0.25 lb Cu/ac
Zinc (Zn)	Sulphate[90]	Spring or fall	3.5–5 lb Zn/ac	Not recommended	Not recommended
	Oxysulphate[91] <50% solubility	Fall	5-10 lb Zn/ac	Not recommended	Not recommended
	Chelated[92,93]	Spring	1 lb Zn/ac	Needs verification	0.3-0.4 lb Zn/ac
Manganese (Mn)	Sulphate[94,95,96]	Spring	50-80 lb Mn/ac‡	4-20 lb Mn/ac	Not recommended
	Chelated[97,98,99]	Spring	Not recommended	Not recommended	0.5–1 lb Mn/ac
Boron (B)	Sodium Borate[100]	Spring	0.5-1.5 lb B/ac	Not recommended	0.3–0.5 lb/ac

† Although foliar applications of copper sulphate are effective, the product is extremely corrosive.

‡ Broadcast and incorporated rates of manganese are generally uneconomical.

Developing Fertilizer Recommendations without a Soil Test

Growers may choose not to soil test every field every year and yet still need to develop a fertilizer recommendation. They can consider the following approach in making a recommendation[101]. General fertilizer recommendations without a soil test are provided in Appendix Table 23.

The approach is based on drawing a balance between inputs and outputs during the previous growing season. Any positive excess in the balance can be considered as a soil test value for next year. This method works only for nitrogen, since soil phosphorus and potassium soil tests are meant to measure both 'available' and 'potentially available' levels and, in any event, change slowly; therefore, the same soil test can be used for 2-3 years.

Consider all inputs and outputs:

INPUTS	OUTPUTS
Soil	
Fertilizer	Crop Removal
N Fixation	Leaching Loss
Plant & Animal Residues	Denitrification
Precipitation	Volatilization
Available pool	
Mineralization	Immobilization

Focus on those that are most important and cannot be controlled (for example, volatilization is gaseous loss of ammonia/urea and can be controlled by banding the N fertilizer). This example does not involve legumes/pulses. The previous year's soil test goes under inputs. So, now we have:

INPUTS	OUTPUTS
Fertilizer	Crop Removal
Mineralization	Leaching Loss
Soil test	Denitrification
	Immobilization

Starting with the inputs:

Step 1: You need to start from last year's soil test. This soil test must be for a 0-24" depth; if not, you need to estimate a 0-24" depth soil test, so multiply results from 0-6" by 2 or 0-12" by 1.5 (remember this is only an estimate!)

Step 2: We now need an estimate of N mineralized (released) from soil organic matter during the growing season. Mineralization amounts are dependent upon quantity and quality of soil organic matter, crop residues and microbial activity driven by soil heat and moisture. For organic matter levels less than 8%, an average estimate can be made by multiplying the % organic matter from the soil test by 14.

Step 3: The plant roots do not reach 100% of the mineralized N and whatever the plants roots don't reach the microbes do; some of it could be potentially lost out of

Appendix

the system. In any event, on average, 20% of mineralized N is normally left in the soil as "available" N.

Step 4: The final input is the "actual" N that was applied as fertilizer to the previous crop.

Step 5: On average, a crop consumes 50% of the fertilizer and microbes immobilize or consume about 20-25% of this applied N. Approximately 25% of fertilizer N is available for the following crop.

Now, let's examine the outputs:

Step 6: Unless a crop is to be seeded on fallow, soil microbes will utilize some of the "available" N in the soil to break down the straw from the previous crop, a process that is known as immobilization. An average estimate of 30 lb N/ac is reasonable.

Average leaching and denitrification losses are very low (normally less than 7%) under normal conditions. If "abnormal" conditions prevailed during the previous year, it is strongly recommended that an "actual" soil test be taken.

Step 7: You finally need to account for the amount of nitrogen removed in the crop. You can use crop removal tables (Table 1) to arrive at an estimate of N uptake and removal.

Step 8: Estimated soil test

Now, let's put all of these inputs and outputs together (same as you would write cheques and deposits in your chequing account):

Appendix

Example in Estimating a Soil Test (0-24"):

Soil test N from preceding year: 54 lb N/ac
Organic matter: 4%
Applied fertilizer N (actual): 100 lb N/ac
Canola yield: 40 bu/ac

Step #	Item	Input (deposit) (+)	Output (cheque) (-)	Balance
1	Soil test (0-24")			54
2	Mineralized N (4% OM) - total	4 X 14 = 56		110
3	Mineralized N (4% OM) - not used		56 X 20% = 11	99
4	Fertilizer N - total	100		199
5	Fertilizer N – not used		100 @ 25% = 25	174
6	Immobilized N		30	144
7	Crop removal		40 bu X 2 lb N/bu = 80	64
8	Estimated soil test (0-24") (lb N/ac)			64

Developing a Fertilizer Recommendation Rate

The same principle can be used in reverse to estimate a fertilizer N recommendation as follows:

Step 1: Determine crop need – based on expected yield and removal rate

Step 2: Use the estimate of soil nitrate levels

Step 3: About half of this available nitrate-N is retuned to the organic pool

Step 4: Amount mineralized from organic matter (as before in Step 2 and 3)

Step 5: N immobilized by crop residue (as before in step 6)

Step 6: Calculate N need (difference from above)

Step 7: Calculate N fertilizer need based on efficiency (usually about 50%)

Example in Developing a Fertilizer Rate:

Crop and target yield:
50 bu/ac wheat

Step #	Item	Input (deposit) (+)	Output (cheque) (-)	Balance
1	Crop removal		50 bu X 1.7 lb N/bu = 85	-85
2 and 3	Soil test (0-24”)	64 X 50% = 32		-53
4	Mineralized N (4% OM) - used	56 X 80% = 45		-8
5	Immobilized N		30	-38
6	Deficit			38
7	Fertilizer N to cover deficit	38 X 50% = 76		0

Adjustments may need to be made to these estimates based upon environmental conditions that may cause greater than expected nitrogen losses. These conditions would be leaching of nitrate-N on sandy soils and denitrification when soils are saturated. Adjustments may also be required where release of N from soil organic matter may be higher or lower than average.

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Agronomically, Economically and Environmentally Sensible Target Yields

Most nitrogen and some other nutrient recommendations are based on expected yield goal or target yield. Setting this target yield will have a large effect on the rate of fertilizer or manure recommended, so it is important that a realistic and appropriate level be set.

This yield goal can be estimated in a number of ways. Following are a number of suggestions:

A) Developing a base yield.

1. Develop a base yield based on your historical average for that field and your farm. The base yield can be determined from your own records, or crop insurance records for your area. Consider a recent 5 year average yield, or if yields vary widely, drop the lowest and highest yields and use a 3 year average.
2. Consider the field's soil capability and specific production limiting factors such as soil salinity and drainage.
3. Once a reasonable base yield is set, add about 5-10% to account for new technology such as new varieties, seeding or fertilizing systems or crop protection products.

B) If rainfall and stored soil moisture limit yields, one may choose to use a climate and rainfall probability model to set yield potential. Table 22 contains cereal yield potential based on available moisture from anticipated growing-season rainfall and stored soil moisture (MAFRI Factsheet "Moisture and Target Yields"). Stored soil moisture can be measured or estimated prior to seeding based upon the depth of moist soil and soil texture.

Table 22. Cereal yield potential based on available moisture[102].

Total Potential Available Moisture	HRS Wheat	CPS Wheat	Barley
	Yield (bu/ac)		
10″	24	30	53
11″	29	37	59
12″	35	44	66
13″	40	59	72
14″	45	58	79
15″	51	64	85
16″	57	72	91
17″	62	78	98
18″	68	86	104

You might wish to select a range of moisture conditions for consideration and base your final decision closer to seeding. Also, keep in mind that soil moisture in spring and grain yield at the end of the growing season are often poorly related, unless moisture reserve is large, relative to growing season rainfall. Furthermore, in some fields or regions where excess water is a frequent problem, large moisture reserves may not be helpful for raising yield potential.

C) Consider the top crop yields that are commonly harvested in your area. These may be from research or test plots or fields under optimum growing conditions. These are the top yield potential for your area and will not be achievable every year. When using these values, ensure that your own practices (e.g. timeliness of seeding, weed control, etc.) are consistent with these high yields. In most cases this approach would need downward adjustment in this base yield to account for production limiting factors in fields.

Your target yield is reasonable when they are actually achieved. Your target is too low if it is exceeded 2 years in 5 and too high if it is never achieved.

General fertilizer recommendations without a soil test

The following are general fertilizer guidelines to be used in the absence of a soil test (Table 23).

The suggested rates are based on a long-term average soil test values across the province and are not as accurate as a soil test recommendation for a specific field and year.

Table 23. General fertilizer recommendations without a soil test.

Crops	Nitrogen (N) (lb/ac)	Phosphate (P_2O_5) (lb/ac)	Potash† (K_2O) (lb/ac)	Sulphate‡ (S) (lb/ac)	Comments
Cereals					**Spring-seeded cereals –** For most efficient use, place phosphate, potash and nitrogen in the seed row when possible. Refer to Tables 7 & 12 for safe rates. **Fall-seeded cereals –** Between 20 and 30 lb/ac of nitrogen can be applied with the seed to encourage early growth if soils are very low in nitrogen. The required phosphorus and potassium should be placed in the seed row in the fall for optimum efficiency and promotion of winter survival. Total seed placed fertilizer should not exceed (175 lb/ac). High rates of nitrogen in the fall may decrease winter survival of the stand. Preplant banding may also lead to seed bed damage, reduce seedling establishment and reduce the amount of snow trapping which may reduce winter survival. Additional nitrogen may be more safely applied as a broadcast application in the spring.
Wheat					
- Hard Red Spring	55 – 90	30-40	15-30	15	
- Prairie spring	60-100	30-40	15-30	15	
- Durum	55-90	30-40	15-30	15	
- Winter	90-120	30-40	15-30	15	
Barley					**Barley –** Depending on soil moisture conditions feed barley cultivars will yield up to 24% more than malt barley cultivars at equivalent nitrogen supply.
-feed (1)	55-90	30-40	15-30	15	
- malt (2)	55-90	30-40	15-30	15	
Rye	40-65	30-40	15-30	15	
Oats	55-90	30-40	15-30	15	
Triticale	40-65	30-40	15-30	15	
Oilseeds					**Canola/rapeseed and mustard –** Refer to Tables 7 and 12 for safe seed placed rates. **Flax –** Refer toTables 12 for safe seed placed rates.
Canola/ rapeseed	70-90	30-40	30-60	20	
Mustard	70-90	30-40	30-60	20	
Flax	40-65	30-40	30-60	15	

† On sandy-textured or organic soils apply this rate of K_2O

‡ When sulphur is required, apply this rate of sulphate sulphur

Crops	Nitrogen (N) (lb/ac)	Phosphate (P_2O_5) (lb/ac)	Potash† (K_2O) (lb/ac)	Sulphate‡ (S) (lb/ac)	Comments
Oilseeds Sunflowers	55 – 90	30 – 40	15 – 30	20	**Sunflowers –** Germinating sunflower seeds are sensitive to fertilizer placed with the seed. **Row equipment –** when sunflowers are seeded with row equipment, all phosphate and potash should be sidebanded 2″ beside and below the seed at time of seeding. Some or all of the nitrogen may also be sidebanded. The total amount of fertilizer material side-banded should not exceed 300 lb/ac. **Discer Seeder –** When sunflowers are solid-seeded with a discer seeder in 12 – 24″ row spacing, up to 25 lb/ac P_2O_5 can be applied provided all fertilizer runs are left operating. If all phosphate must be placed with seed, the amount of phosphate should not exceed 15 lb/ac P_2O_5 for 12″ row spacing, 10 lb/ac P_2O_5 for 18″ row spacing and 5 lb/ac P_2O_5 for 24″ row spacing. Nitrogen requirements not side-banded should be placed away from the seed as a band or broadcast application.

† On sandy-textured or organic soils apply this rate of K_2O

‡ When sulphur is required, apply this rate of sulphate sulphur

Crops	Nitrogen (N) (lb/ac)	Phosphate (P_2O_5) (lb/ac)	Potash[†] (K_2O) (lb/ac)	Sulphate[‡] (S) (lb/ac)	Comments
Special Crops					
Buckwheat	40 – 65	30 – 40	30 – 60	15	**Buckwheat –** Any nitrogen in excess of 6 lb/ac, phosphate in excess of 20 lb/ac P_2O_5 and all potash and sulphur should be placed away from the seed to avoid injury.
Corn	65 – 135	30 – 40	30 – 100	20	**Corn –** When possible, phosphate, potash and nitrogen should be banded 2″ beside and below the seed at time of seeding. The total amount of fertilizer material side-banded should not exceed 300 lb/ac. Nitrogen requirements not side-banded at time of seeding should be side-dressed before the corn is 6″ high. Excessive nutrient levels may occur when high rates of fertilizer are used on continuous corn. Soil testing to a depth of 24″ is strongly recommended to monitor nutrient levels and avoid over-fertilization.
Potatoes	60 – 90	45 – 55	45 – 80	20	**Potatoes –** All fertilizer should be added as a side-band application 2″ beside and below the seed at time of seeding for the most efficient use of the fertilizer. No more than 80 lb/ac nitrogen in urea form should be applied as a sideband application at time of seeding.
Canary Seed	General fertilizer recommendations for rye or triticale may be used.				

[†] On sandy-textured or organic soils apply this rate of K_2O

[‡] When sulphur is required, apply this rate of sulphate sulphur

Crops	Nitrogen (N) (lb/ac)	Phosphate (P_2O_5) (lb/ac)	Potash[†] (K_2O)' (lb/ac)	Sulphate[‡] (S) (lb/ac)	Comments
Pulse Crops					**Pulse Crops –** Nitrogen is not recommended for most crops. Add proper inoculum to seed so that nodules will fix nitrogen requirements.
Faba beans	Inoculate seed	30 – 40	30 – 60	20	Field beans may require 20 – 40 lb N/ac or up to 100 lb/ac in some cases.
Lentils	Inoculate seed	30 – 40	30 – 60	20	All phosphate in excess of 10 lb/ac P_2O_5 and all potash and sulphur should be placed away from the seed to avoid seed injury.
Soybeans	Inoculate seed	30 – 40	30 – 60	20	Where field beans or soybeans are seeded in wide rows, all fertilizer should be placed away from the seed. Applying seed placed fertilizer to beans and soybeans in wide rows may cause stand reductions.
Field beans	40 – 90	30 – 40	30 – 60	20	
Forage Crops					Phosphorus fertilizer can be applied most effectively by banding the materials 1" to the side and below the seed. If P_20_5 cannot be banded, incorporate it and all other fertilizer materials into the soil before seeding.
(A) Grasses					
New stands	40 – 60	30 – 40	45 – 90	15	
Established stands	(Note 1)	20 - 30	30 – 60	15	(Note 1) An economic return to the application of nitrogen fertilizer on established grass stands is questionable when the selling price of hay is low and the yield potential is low due to dry soil moisture conditions. Refer to Appendix Tables 14-16.
					Response of grasses to applied nitrogen depends on the type of nitrogen fertilizer, time of application, amount applied, species of grass, age of stand, number of cuts and climatic conditions. Annual broadcast applications of phosphorus, potassium and sulphur fertilizer on established grass crops may be in late fall or early spring. Where runoff from snowmelt is common, avoid surface broadcast applications of phosphorus in the fall; consider applying phosphorus in early spring or following the first cutting or subsurface injection into the stand. Do not apply fertilizer to frozen soils subject to water runoff.

† On sandy-textured or organic soils apply this rate of K_2O

‡ When sulphur is required, apply this rate of sulphate sulphur

Crops	Nitrogen (N) (lb/ac)	Phosphate (P_2O_5) (lb/ac)	Potash[†] (K_2O) (lb/ac)	Sulphate[‡] (S) (lb/ac)	Comments
(B) Legumes					Phosphorus fertilizer can be applied most effectively by banding the materials 1" to the side and below the seed. If P_2O_5 cannot be banded, incorporate it and all other fertilizer materials into the soil before seeding.
New stands	Inoculate seed	55 – 75	60 – 150	30	
Established stands	Nitrogen is not recommended	40 – 55	40 – 100	30	Annual applications of fertilizer on established legume crops may be done in the fall or early spring. Where runoff from snowmelt is common, avoid surface broadcast applications of phosphorus in the fall; consider applying phosphorus in early spring or following the first cutting or subsurface injection into the stand. Do not apply fertilizer to frozen soils subject to water runoff.
(C) Grass-legume mixtures					If the mixed stand contains more than 25% legume, fertilize as for a pure legume stand. If there is less than 25% legume in the stand, use the recommendations for pure grass stands.

[†] On sandy-textured or organic soils apply this rate of K_2O

[‡] When sulphur is required, apply this rate of sulphate sulphur

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