EB-65

North Dakota

Soil and Fertilizer Handbook

D.W. Franzen
Soil Science Specialist

NDSU EXTENSION SERVICE

North Dakota State University, Fargo, ND 58105

JANUARY 2003

Table of Contents

Soil is the medium that supports plants physically, chemically and biologically. Soil is a mixture of minerals and organic material at the surface of the earth that has been altered by the effects of climate, vegetation, landscape position and time.

Most soils are about 50 percent mineral and organic materials and about 50 percent pore space. Ideally for plant growth, about one half of the soil pore space is filled with water and one half is filled with air. Pore space is important because it allows for both passage of air and retention of water for use by plants. Plants need both air and water in the root zone for respiration and for water and nutrient uptake. The pores need to be large enough to enable roots to grow between soil particles. Even with the great pressure exerted by growing and expanding roots, they are limited by the physical nature of some soils.

A measure of the total soil porosity is the soil bulk density. Bulk density is the weight of soil in place, including its pore space, per unit of volume. Often this is expressed as grams/cubic centimeter. A soil with a bulk density of 1.1 g/cm^3 would be a soil with a good deal of pore space and one that would be described as high in "tilth." It would be easy to cultivate, and plant roots would have no trouble growing through a soil with this bulk density. A soil with a bulk density of 1.4 g/cm^3 would be a soil with less pore space and probably a soil with many smaller pores. It would be more difficult to grow plants in this soil.

The goal of agriculture is completely opposite that of a civil engineer building a road. In road building, for example, water and pore space is an enemy, so a great deal of effort is made with heavy equipment to pack soil particles and eliminate as much pore space as possible. This reduces the introduction of water into the road bed that might contribute to shrinking and swelling and frost heave after the road surface is laid down. In agriculture, tillage systems have been developed to encourage as much pore space as possible to allow fast infiltration of water and healthy air exchange for plants.

The mineral portion of the soil is made up of different sized particles (Table 1). In some soils, stones are a major proportion of the soil volume, but usually the term "soil texture" refers to the proportions of sand, silt and clay sized particles in a soil. Sand, silt and clay in soil texture terms refers to particle size and not necessarily to the mineral makeup of the particles, although there is a strong tendency for certain minerals to fall into certain particle size groups. Sand is the largest particle, clay is the smallest and silt is in between. Sand is the gritty part of the soil, and soils with significant amounts of sand, such as the areas around Karlsruhe, the Sheyenne delta, and many hilltops from Langdon to Wishek, definitely feel gritty. Soils with abundant clay, such as those around Fargo and Bottineau, are very sticky feeling and difficult to mold in your hands. Silty soils, like some just west and east of the Missouri River and in the Minot area, feel silky when wet.

Table 1. Particle size ranges of selected soil textures.

Textural category	Size, mm diameter
Gravel	> 2 mm
Sand	0.5-2 mm
Very coarse	1 - 2 mm
Coarse	0.5 - 1 mm
Medium	0.25 - 0.5 mm
Fine	0.1 - 0.25 mm
Very fine	0.05 - 0.1 mm
Silt	0.002 - 0.05 mm
Clay	< 0.002 mm

All soils are a combination of the particle sizes seen and classified as in Figure 1. Soil texture classes like silt loams, sandy loam, loams and clay loam have distinct limits of sand, silt and clay that define them. Skilled soil scientists can estimate the levels of sand, silt and clay to within a couple percentage points just by feel. Sand-sized particles tend to be quartz, with a small component of other primary and secondary minerals. Silt-sized particles tend to be high in feldspars, smaller pieces of quartz and other non-clay minerals. Clay-sized particles tend to be clay minerals, with a small fraction of minerals that make up sand and silt-sized particles.

The development of soils is a dynamic and continually changing process. Soils are influenced by the five soil forming processes of biological activity, topography (landscape structure), parent material, climate and time. With variations in climate and certainly with time, soils change in their physical and chemical properties.

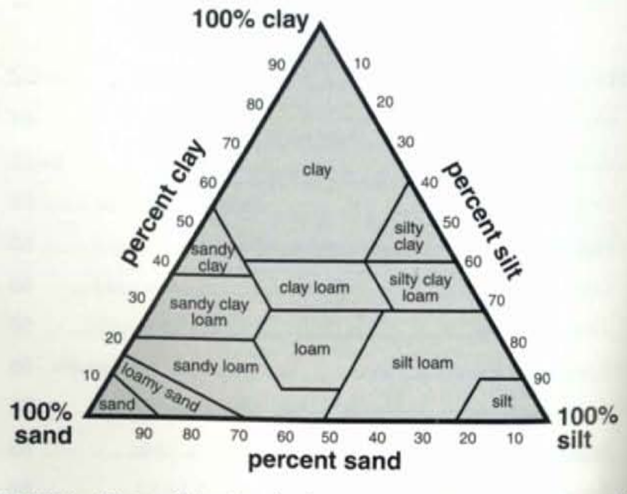


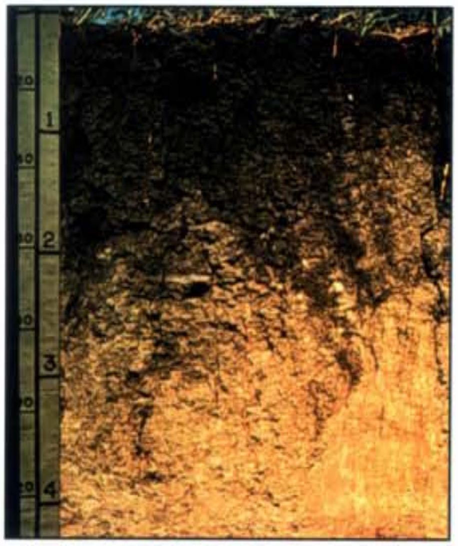
Figure 1. The soil textural triangle is used to classify soil based on sand, silt and clay content.

The basic parent materials in North Dakota are the result of recent glacial ages, the degradation of bedrock in place, or the more recent deposition of rivers, streams and wind. In the eastern part of the state, in the area known as the Red River Valley, the soils are derived from lacustrine (lake bed) sediments which are the remnants of glacial Lake Agassiz. These sediments are very deep, sometimes over 100 feet thick, over glacial till, outwash, granite and shale bedrock. There is a tendency for the sediments to contain high levels of smectite clay close to the river and become gradually coarser to the western edge of the Valley. At the western edge is an area of inter-beach sediments, where the lake level was stable for a time during its recession and built low, sandy beaches through sorting of wave action near the lakeshore. From the western edge of the Valley to the northwest border of the state and the Missouri River is the area called the Glacial Till Plain. The eastern portion of this plain is covered with thin to thick layers of glacial till. The texture of the soils in this area varies depending on the regional activity of water and the manner in which the glaciers moved, melted and retreated but in general tend to be loams. Sandier areas are found on outwash plains and many hilltops from which the clays were sorted by water during the glacial melting. Clay soils are more common in depressions and in small lakebeds where water movement was slow. Within each of these regions are smaller regions influenced by the recent flooding of small rivers and streams and the deposition of wind blown sediments, and sometimes by human activity, such as the reclamation of mined land.

Soil is usually altered in layers, called "horizons." We call the upper surface, usually enriched in organic matter from decayed plant and animal materials, the A horizon. This zone is usually higher in organic matter than the rest of the soil profile but also is subject to eluviation, or loss, of minerals and/or clay through the downward movement of water. Below the A horizon, when there is noticeable development in the soil, there is a zone enriched in clay, salts, carbonates or changed in some manner chemically, called the B horizon. The B horizon is a zone of illuviation, or accumulation of materials. Between the A and B horizon there may be a layer of soil with some evidence of platy structure, caused by lateral water movement above a limiting layer. If this horizon is present, it is called an E horizon and is a zone of excessive eluviation. Below the B horizon is a zone where little alteration of soil has occurred since the parent material was deposited. This zone is called the C horizon. The entire soil is called the soil profile. The entire zone of material above bedrock, which lies beneath all soil, is called the regolith.

The following three examples represent soils from a different part of the state with some similarities and some major differences based on the climate and parent material from which they were developed.

Fargo clay



A soil of the Red River Valley. fine, smectitic, frigid, Typic Epiaquerts

(Description from Cass County Soil Survey, N.D. Prochnow et al, US Gov. Printing Office, 1985)

Fargo consists of deep, poorly drained, slowly permeable soils on glacial lake plains. The soils are formed in fine textured lacustrine sediments. Slope ranges from 0-3 percent.

Ap - 0-7 inches; black (10YR 2/1) silty clay, very dark gray (10YR 3/1) dry; moderate subangular blocky structure parting to weak fine subangular blocky; very hard, friable, sticky and plastic; few fine and many very fine roots; common very fine pores; neutral pH; abrupt, smooth boundary.

A 7-10 inches; black silty clay, dark gray when dry, weak medium prismatic structure parting to weak fine angular blocky; very hard, friable, slightly sticky and plastic; few fine and many very fine roots; few fine pores; neutral pH; gradual smooth boundary.

Bw1 - 10-16 inches; very dark gray silty clay, dark gray when dry; moderate medium prismatic structure parting to weak subangular blocky; very hard, firm, sticky and plastic; few fine and many very fine roots; few small pores; faces of peds have shiny, waxy sheen when moist; tongues of A horizon material throughout; slight effervescence in the lower part; neutral pH; gradual wavy boundary.

Bw2 - 16-22 inches; dark gray silty clay, gray when dry; weak medium prismatic structure parting to weak fine angular blocky; very hard, friable, sticky and plastic; common very fine roots; few fine pores; faces of peds have shiny waxy sheen when moist; tongues of A horizon material throughout; strong effervescence; mildly alkaline; gradual wavy boundary.

Bckg - 22-30 inches; dark grayish brown silty clay, grayish brown when dry; weak fine prismatic structure parting to weak medium subangular blocky; very hard, firm, sticky and plastic; few very fine roots; tongues of A horizon material; lime disseminated throughout; strong effervescence; mildly alkaline; gradual wavy boundary.

Cg1 - 30-45 inches; olive gray silty clay, olive gray when dry; weak prismatic structure parting to weak to medium subangular blocky; very hard, firm, sticky and plastic; few very fine roots; strong effervescence; mildly alkaline; gradual wavy boundary.

Cg2 - 45-60 inches; olive gray silty clay, olive gray when dry; common medium prominent dark brown mottles; massive; very hard, firm, sticky and plastic; few medium masses of segregated lime; strong effervescence; moderately alkaline.

Barnes loam

Fine-loamy, mixed, superactive, frigid Calcic Hapludolls- A soil of the glacial till plain.

(Description from Soil Survey of Stutsman County, P.L. Abel et al., US Gov. Printing Office, 1985)

Very deep, well drained, moderately slowly permeable soils on till plains and moraines. These soils formed in glacial till, with slopes from 0-25 percent.

Ap - 0-7 inches; black (10YR 2/1) loam, dark gray (10YR 4/1) when dry; weak medium subangular blocky structure parting to moderate medium granular; slightly hard and friable; slightly sticky and slightly plastic; common or many very fine and fine roots; about 5 percent gravel; neutral pH; abrupt boundary.

Bw - 7-12 inches; dark brown loam, brown when dry; moderate medium prismatic structure parting to moderate medium subangular blocky; slightly hard and friable; slightly sticky and slightly plastic; common or many very fine and fine roots; about 5 percent gravel; neutral pH; clear, wavy boundary.

Bk - 12-29 inches; grayish brown loam, light gray when dry; moderate medium subangular blocky structure; slightly hard and friable; slightly sticky and slightly plastic; common very fine and fine roots; about 5 percent gravel; many fine and medium irregularly shaped soft masses of lime; violent effervescence; moderately alkaline; gradual wavy boundary.

C - 29-60 inches; dark grayish brown loam, light brownish gray when dry; few fine prominent red mottles; massive; slightly hard and friable; slightly sticky and slightly plastic; about 5 percent gravel; strong effervescence; moderately alkaline.

Vebar

Coarse-loamy, mixed, superactive, frigid Typic Haplustolls- A soil derived from sandstone in southwest North Dakota

(Description from Hettinger County Soil Survey, M.G. Ulmer and P.M. Whited, US Gov. Printing Office, 1990)

Consists of moderately deep, well drained, moderately rapidly permeable soils on uplands on material weathered from soft bedrock. Slope is 1-20 percent.

Ap - 0-6 inches; brown (10YR 4/3) fine sandy loam, dark brown (10YR 3/3) moist; moderate fine granular structure; slightly hard, very friable, slightly sticky and slightly plastic; many very fine and few fine roots; neutral; abrupt smooth boundary.

Bw - 6-20 inches; pale brown fine sandy loam, brown when moist; weak coarse prismatic structure parting to weak medium subangular blocky; slightly hard, very friable, non-sticky and non-plastic; many very fine roots; mildly alkaline; clear, smooth boundary.

Bk - 20-32 inches; light brownish gray fine sandy loam, dark grayish brown when moist; weak very coarse prismatic structure parting to weak medium subangular blocky; slightly hard, fine roots; common medium soft masses of lime; strongly effervescent; moderately alkaline; clear, irregular boundary.

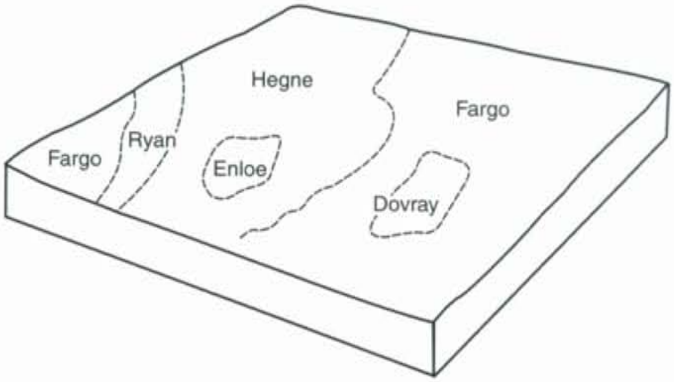
Cr - 32-60 inches; light gray, soft sandstone, light brownish gray moist; few very fine roots in weathered zones; common fine soft masses of lime in fractures; slightly effervescent; moderately alkaline.

All three of these soils have a mollic epipedon, which is a dark colored surface horizon, and have high base saturation (high in the basic cations, Ca^{+2} or Mg^{+2}, K^{+}, and Na^{+}). The Fargo, however, is a Vertisol while the other two soils are Mollisols. A Vertisol is a soil which tends to invert itself over time because of continuous cracking and swelling due to the amount and type of clay it was developed in. All three soils were developed under prairie vegetation. The thickness of the Mollic horizon decreases as historical rainfall patterns decrease and summer temperature increases. Fargo mollic horizon is thicker than Barnes, which is thicker than Vebar. All three have relatively neutral pH due to landscape position, but all three have carbonates within the root zone, due to the entire region being in an environment in which evapotranspiration in the summer months is greater than rainfall.

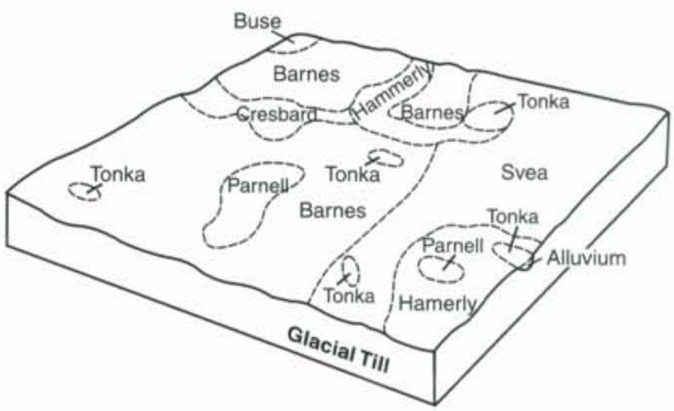
Given similar parent material, past vegetation, climate, and time, soils on a landscape differ because of landscape position. Certain soils can be expected to be associated with other soils in a catena, or progression down the landscape from hilltop to depression (Figure 2). Soils thus associated are called associations. Depending on the detail of the soil survey and the size of each soil series, soils described in the soil survey may be mapped as associations. Even when they are not listed as an association, it is likely in a soil survey map that inclusions of associated soils too small to map with enough detail are included in the survey map boundaries.

All counties in North Dakota have published soil surveys available. These soil surveys were made to a scale of 1:20,000. These surveys are called Order 2 soil surveys and were developed to help people understand the basic properties of the land. Although it is common for soil series to be grouped as inclusions in series mapping units (mono taxa) or in association mapping units, the overall agricultural productivity and suitability of these soils for the general purposes intended is mostly consistent with the mapping. These maps, however, were not intended to be used for site-specific purposes of fine scale, and unless a more detailed soil survey is commissioned, they should be used with caution for within-field soil nutrient management.

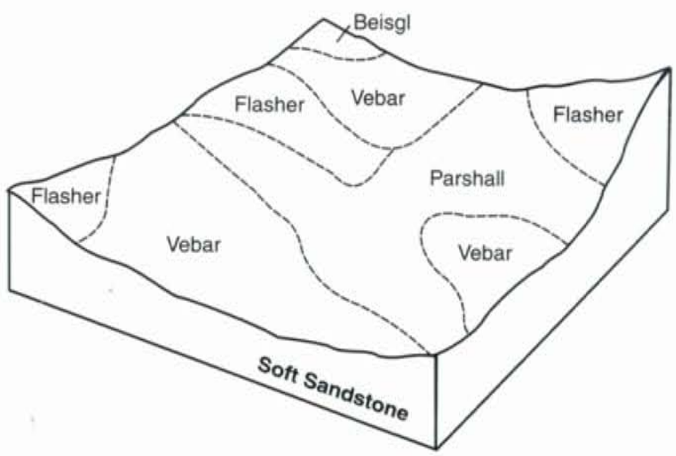
Figure 2. Soil associations.



Fargo-Hegne silty clay loams association.



Barnes-Svea loams association



Vebar-Parshall-Flasher loamy sands association

Soil Physical Properties

Soils are essential for plant life. Soils provide the means to store and release water through a growing season, serve as a reservoir for plant nutrients like nitrogen and phosphorus, and provide a means of support so plants can grow upright and capture sunlight and air. Well-structured soil is also important, because it provides the right amount of strength to resist wind and rain from carrying away the productive part of the soil, and also provides pore space for water to enter the soil and for air exchange so that roots can breathe, or respire.

Soil wetness can be measured on either a weight or volume basis. The weight basis is more common in production agriculture and is often referred to as the gravimetric water content. To obtain a gravimetric water content, the wet soil sample is weighed, then placed in a drying oven at 220° F for 24 hours. The sample is then weighed again to obtain the dry weight and the two weights are applied in the following formula:

$$\text{Percent gravimetric water content} = \frac{\text{(wet soil weight) - (dry soil weight)}}{\text{(dry soil weight)}} \times 100\%$$

Water moves within soils. Water moves because of the sum of forces which act on water and the forces of the attraction between water and the soil. Since measurement of water is conducted at a point in time during the water's journey to wherever it might eventually go, the force connected with this is called the total water potential.

The total water potential is the sum of at least three forces of which the following are most important in soils:

gravitational potential + matric potential + osmotic potential,

Gravitational potential is the force of gravity on water. The value of the gravitational potential depends on the point of reference of the measurement. If the measurement is made at the soil surface, as it often is, then the resulting value anywhere under the surface is negative (since the higher an object is, the more potential force can be exerted by gravity).

Matric potential is the energy of the water attraction to the soil and its pore space. Capillary movement of water is described by this force. Generally, the smaller the pore space, the larger role this force plays in water movement and retention. During hot drying days in the clay soils of the Red River Valley, when the water table is only 3 to 4 feet below the surface, large amounts of water are transported to the surface by this force.

Osmotic potential is the movement of water from low solute concentration to high solute concentration.

In soil, the gravitational and matric potential play the largest role. When plants are present, they exert another force on water through mainly osmotic potential. Plants exert a negative force on water, which attracts it to the roots as it is taken up into the plant. Plants accomplish this through the regulation of solutes and salts within the plant cell and intracellular spaces in the roots. The higher the concentration of salts within the plant cells, the greater the pull of water into the plant. The wilting point of plants varies greatly, but the general value given is the water remaining in the soil at 15 atmospheres of negative pressure (suction). This means that plants exert a continual force of about 15 atmospheres of suction to attract water and pull water into the roots, and water held more tightly than that cannot be extracted by the plant. The soil water force moving against the plant force is related to the matric potential plus the osmotic potential of the soil. As the water content of soil decreases, the matric potential of the soil increases, eventually exceeding the plants ability to overcome it and absorb water from the soil, which results in plant wilting.

Field capacity is a term used to describe the water left in the soil following saturation and a short period of drainage from large pores. It is usually scientifically measured as the water remaining after the soil is saturated and a ⅓ atmosphere suction is applied to the soil.

Texture plays a major role in plant availability of water due to the amount of water various particle sizes can hold and the force with which they hold water. This ability to hold water at different levels of suction is illustrated in Figure 3 . At low suction (the force of gravity on free water), clay soil holds more water than a sandy soil. However, as the large pores quickly drain in the sandy soil, the clay soil holds on to most of the water. The total water content held more firmly by the soil particles after gravity drainage but still available to plants is therefore much higher in clay soils than in sandy soils. The phrase "Dickinson is always about 48 hours away from a drought" often heard in that area is true not so much due to climate as to the frequent occurrence of sandy loam soils in the area. After precipitation, the gravity water moves rapidly through the soil, leaving only a small amount of plant-available water behind.

Figure 3. Relationship between soil water content and total matric potential (suction) of a sandy soil compared to a clay soil.

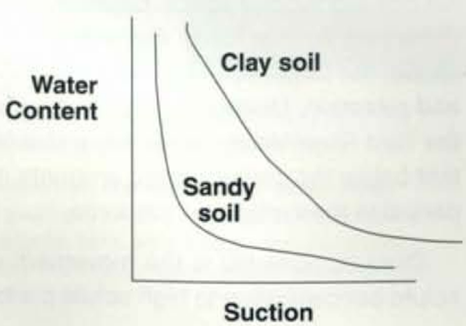


Table 2 lists the amount of water normally held at various soil textures between suctions of ⅓ atmosphere and 15 atmospheres. Canadian data support the contention that clay soils may hold more available water for wheat than silt loam soils due to the ability of wheat to extract water from the soil at lower suction than other crops.

Table 2. Plant available water at various soil textural classes per foot of soil.

Textural class	Inches water/foot soil
Loamy sand	0.5-0.75
Sandy loam	0.75-1.25
Loam, fine sandy loam	1.25-1.6
Clay loam	1.6-2.0
Silt loam	1.8-2.5
Clay	2.0 - 2.3

Crops traditionally grown in North Dakota, such as spring wheat, barley and dry beans, require less water than crops such as corn and soybeans (Table 3). Alfalfa and sunflower have higher water requirements but have been successfully cultivated in the region because of their ability to root deeper into the soil and take advantage of additional moisture. The amount of water taken up by crops in a given year will vary based on relative humidity and temperature.

Table 3. Approximate yield and general water use to achieve yield for different crops.

Crop	Yield	Inches of water needed	Yield/inch water	Rooting depth
Alfalfa	5 tons	24	0.21 tons	6 ft.+
Barley	60 bu	12	5 bu	2-4 ft.
Corn	120 bu	21	6 bu	2-4 ft.
Pinto beans	2200 lb	12	180 lb	2 ft.
Soybeans	40 bu	18	2.2 bu	2-4 ft.
Spring wheat	40 bu	15	2.7 bu	2-4 ft.
Sunflower	2000 lb	18	110 lb	4-6 ft.

Soil water management is an important component of tillage practices. Tillage systems can be used that will increase the retention of snow in winter and serve as a mulch, reducing loss of evaporative water. Tillage systems that bury most or all residues are called conventional till. Tillage systems that leave enough residue on the surface to prevent erosion are called conservation tillage. There are numerous systems of conservation tillage and numerous goals by the farmers who use them. Some farmers are trying to cut down on trips across the field and save fuel and equipment costs. Other farmers are trying to improve seedbed preparation by making sure there is moisture at planting. Others truly are interested in reducing erosion, building soil productivity and improving soil health.

Soil Conservation

Roughly half of the productivity of North Dakota soils is due to the dark topsoil at the surface. Because early pioneer farmers in the region lacked knowledge and the soil conservation technology that is available today, many of the hilltops and slopes in the state were depleted of their original topsoil from 1900 until the 1960s. Soils which still have topsoil mostly have shallower topsoil depth than they were when they were first farmed. Our soils are a fragile shell which should be treated with care if they are to remain as productive as they are today. Application of fertilizer does not replace the yield-stimulating affects of healthy, deep topsoil.

Tillage practices also influence soil erosion. Each tillage trip decreases the amount of residue (Table 4). The one exception is a field cultivator pass following sugarbeet harvest, which results in residues buried at harvest by the beet lifter being exposed again at the surface. However, tillage with a disc, plow or chisel plow results in burying residue. One-trip tillage and seeding operations may be called minimum till. This practice usually leaves some residue on the surface to protect the soil from wind and water erosion to some degree. Other tillage systems that result in relatively bare soils can be improved through the use of crop strips and cover crops. Crop strips seeded at the same time as a low residue crop such as dry edible beans are left to stand after harvest, reducing the effects of wind. Some crops, such as flax strips, are seeded after harvest and allowed to stand all winter to reduce wind erosion.

No-till systems are very common, especially in western North Dakota, where they serve the purpose of conserving soil, conserving water through the mulch cover they create, gradually building organic matter content and soil health, and allowing continuous cropping in land thought suitable for crop-fallow systems (Figure 5). In no-till systems, the seeder enters the ground with minimal soil disturbance, and a large proportion of the residue remains at the surface. No-till systems allow the development of soil structure through undisturbed activity from crops and microorganisms, which results in improved infiltration of water into the soil, reducing water erosion and increasing the efficiency of precipitation and water use. No-till farmers must be careful and patient and allow soils to adequately dry before seeding so that traffic pans are not formed. Destructive tillage will result in a drastic decrease in stable aggregates and set back the improvements made on the field during the years of no-till. It can take up to five years for farmers to realize the full benefits of no-till, so it takes a considerable investment to switch to this form of tillage system.

Tillage of any kind reduces the amount of residue on the soil surface (expect in sugarbeets, where sugarbeet residue is buried at harvest and can be brought back up to the surface using a field cultivator pass). Table 4 lists the percent residue remaining on the surface with different tillage passes. It is important to note that even no-till seeding reduces residue cover somewhat, depending on the tool used to penetrate the soil surface and place seed and/or fertilizer at the proper depth. However, the amount of residue remaining after no-till seeding is still considerable.

Soil loss is related to residue cover. Figure 4 shows the general relationship between these residue cover and soil loss.

Water and wind erosion are soil degrading processes in North Dakota, with wind generally resulting in more soil loss within the state than water, although heavy rainfall from thunderstorms and rapid snow melt can be severely erosive on steep or long slopes. Several strategies have been adopted to reduce the effects of wind on soil loss. Although a relatively treeless plain before European settlement,

Table 4. Percentage of residues left following selected tillage operations.

Tillage Operation	Residue Remaining
	(%)
Chem-fallow	100
Undercutters/sweeps (>24")	90
No-till seeder, eagle points	90
Field cultivator (14-22" low crown shovels)	85
Field cultivator (8-12" shovels)	80
Rodweeder with shovels	80
No-till seeder with narrow shovels	80
Cultivator/seeder with chisels and spikes	75
One-way disk (18-22" disks)	60
Tandem disk/one-way disc (24-26" disks)	50
Moldboard plow	0-10
Overwintering (no tillage)	70-80

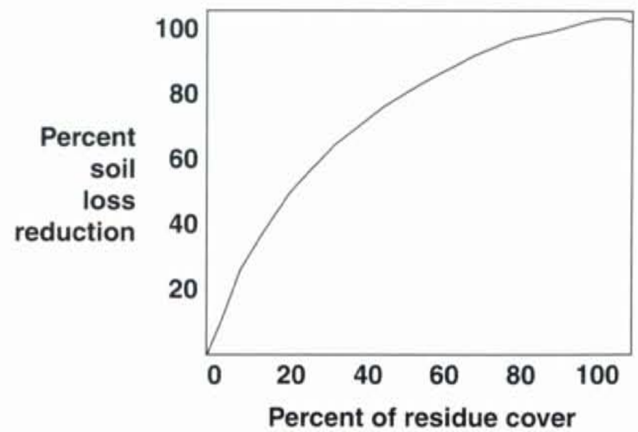


Figure 4. Estimated soil loss potential from wind or water as related to residue cover.

Figure 5. No-till seeding into small grain stubble.

many fields now contain lines of trees along field borders, or within the field at intervals. Best results are attained when tree lines are placed perpendicular to the prevailing winds. These barriers protect an area equal to roughly 10 times the barrier height on the leeward side, and four times barrier height on the windward side (Figures 6 and 7).

Other forms of tillage are used to incorporate different positive aspects of one system into another. Strip tillage is a no-till system that uses a residue remover over the seeding row at planting to expose a narrow strip of soil. The soil, which is darker than the residue, absorbs sunlight, resulting in a warmer environment and in some years speeds seed germination, which sometimes is a problem in the cooler, moister no-till soils. Residue cover is maintained over most of the field, achieving the goals of erosion control and soil health improvement.

Another type of minimum-till farming that is proving to be practical in eastern North Dakota is strip planting. Strips of winter rye are seeded in the fall following grain harvest and tillage. The area between the strips is wide enough to allow planting of row crops the following spring. In the spring, the strips are killed with herbicides with no soil residual activity and the crop is seeded between the rows of cover crop. These bare strips are warmer than a true no-till soil surface, resulting in faster seedling germination, but the protection provided by the cover crop greatly reduces the potential of wind and water erosion.

In certain areas where trees are impractical and conservation must be conducted quickly, strips of unharvested corn or flax can be grown. These strips are seeded with the crop, but are left to stand at the end of the season when the main crop is harvested These crop strips are grown relatively close together. A six-foot tall corn row would effectively shelter about 84 feet. A two-foot tall flax row would only shelter about 28 feet. Use of cropping strips greatly reduces soil loss by wind (Figure 7).

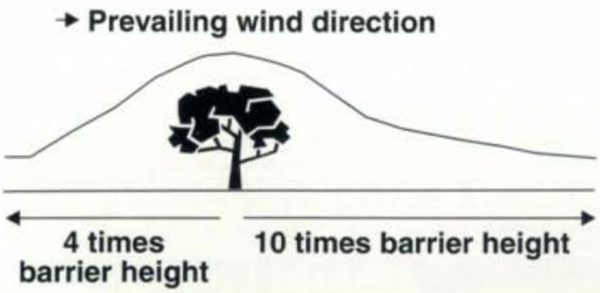


Figure 6. Influence of wind barrier on protection from erosion from windward and leeward sides.

Figure 7. Flax strips protect a harvested and tilled dry edible bean field.

Basic Soil and Plant Relationships

Plant Nutrients

Growing crops require 16 essential elements to sustain growth and reproduction. Three of these elements, carbon, hydrogen and oxygen, are obtained directly from air and water. The other 13 elements can be described as mineral nutrients, since most are obtained directly from the soil. These 13 essential mineral nutrients are shown in Table 5, along with their respective chemical symbols and molecular weights.

The 13 essential elements are sometimes classed into three groups called primary or macronutrients, secondary nutrients and micronutrients (sometimes called trace elements). The use of these terms is not meant to present any element as more essential than another, for without an adequate supply of all essential elements, crop growth suffers. However, the names are an indication of the relative quantity of nutrient contained in a plant, as well as the frequency of fertilizer application and quantity of nutrient required to supply crop needs. The primary nutrients are nitrogen, phosphorus and potassium. The secondary nutrients include calcium, magnesium, chloride and sulfur. The micronutrients are iron, copper, boron, molybdenum, zinc and manganese. The minerals and organic material which make up the soil contain relatively large amounts of essential elements. A total chemical analysis of the soil would suggest that no supplemental nutrient elements are required for crop growth. However, only a small amount of these needed elements is available for crop growth at any given time. This relationship is simply illustrated in Figure 8, where a large pool of relatively unavailable minerals is shown but only a small amount of available nutrients are available at any point in time.

Table 5. The essential elements for most North Dakota crops.

Element	Symbol	Atomic Weight	Form of Plant Uptake
Nitrogen	N	14	NH_4^+, NO_3^-
Phosphorus	P	31	HPO_4^{2-}, $H_2PO_4^{2-}$
Potassium	K	39	K^+
Sulfur	S	32	SO_4^{2-}
Calcium	Ca	40	Ca^{2+}
Magnesium	Mg	24	Mg^{2+}
Zinc	Zn	65	Zn^{2+}
Manganese	Mn	55	Mn^{2+}
Copper	Cu	64	Cu^{2+}
Iron	Fe	56	Fe^{3+}
Boron	B	11	$H_3BO_3^-$
Molybdenum	Mo	96	$HMoO_4^-$
Chloride	Cl	35.5	Cl^-

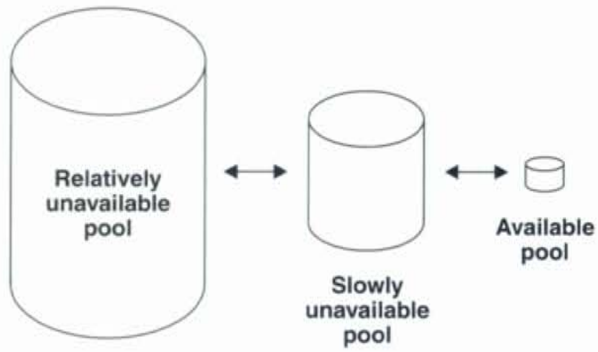


Figure 8. A simple view of soil nutrient availability pools.

Organic Matter

The word "organic matter" is meant to define any plant or animal derived material containing carbon (excluding carbonates $-CO_3^{-2}$) in the soil. Organic matter can therefore be fresh residues, slightly decomposed residues, unrecognizable residues and well-decomposed materials. During residue decomposition, N is conserved while C is reduced through microbial respiration as carbon dioxide (CO_2). High N containing residues, such as broadleaf plant leaves, decompose quickly, while low N containing residues, such as wheat or flax straw, decompose slowly.

Organic matter stability is beneficial, since organic matter has more useful properties than simply being a handy nitrogen reservoir. Organic matter serves to hold soil aggregates together. This allows better water penetration and reduces early season crusting, which may limit stand establishment, and enables deeper penetration of soil by plant roots. Organic matter also positions some plant nutrients in a more available form than some soil minerals.

C/N Ratio and Residue Decomposition

One way to estimate the speed of residue breakdown and the affect on soil N availability is through an understanding of the carbon/nitrogen (C/N) ratio of residues. The C content of residues varies somewhat but averages about 45% of dry plant tissue. Therefore, if an analysis is conducted of plant tissue, it is easy to take the N content and estimate the C/N ratio of the residue.

For example, a sample of sugarbeet leaves is analyzed and an N content of 3% is found.
45%C / 3% N = C/N ratio of 15

In another example, a sample of wheat straw is analyzed and an N content of 0.5% is found.
45% C / 0.5% N = C/N ratio of 90.

How does the C/N ratio affect N status in the soil? It can be assumed that about two-thirds of the C in residue will be lost due to respiration of soil organisms during decomposition, leaving one-third behind to form additional soil organic matter. Soil organic matter has an average C/N ratio of about 10. Therefore, there must be enough N either from the residue itself, or from the surrounding soil, to achieve a 10/1 ratio of C/N at the practical endpoint of decomposition.

Taking one ton of dry residue from the previous example of sugarbeet leaves, the following can be derived:

Sugarbeet top residue	2000 lb.
C in sugarbeet top residue	45% X 2000 lb = 900 lb C
N in sugarbeet top residue	3% X 2000 lb = 60 lb N
C left after decomposition	1/3 X 900 lb C = 300 lb C
N required for 10/1 C/N ratio following decomposition	300 lb C /(10 C/1 N) = 30 lb N
N status of the soil following decomposition	60 lb N initial - 30 lb N organic matter = 30 lb N free in the soil.

The same exercise can be calculated using the wheat straw example, but with different results:

Wheat straw residue	2000 lb
C in wheat straw residue	45% X 2000 lb = 900 lb C
N in wheat straw residue	0.5% X 2000 lb = 10 lb C
C left after decomposition	1/3 X 900 C = 300 lb C
N required for 10/1 C/N ratio following decomposition	300 lb C/(10 C/1 N) = 30 lb N
N status of the soil following decomposition	10 lb N initial - 30 lb N needed for organic matter = a need for 20 lb N from soil

Although a similar amount of residue was added to the soil in these examples, N level in the soil following decomposition was different. In sugarbeet leaf decomposition, N was released into the soil, while in the wheat residue example, soil N was depleted during decomposition. Generally, release of free N or immobilization of N is governed by the C/N ratio of the residue as follows:

C/N ratio	N status due to residue decomposition
<20/1	Release of N into the soil
20/1-30/1	N status is neutral, neither declines nor increases
>30/1	N is tied up in organic matter and free soil N levels decrease

When the North Dakota prairies were first plowed, a large quantity of nitrogen became available to crops because of the accelerated decomposition of native organic material. In the early part of the 20th century, the amount of nitrogen released by further oxidation of organic matter slowed. The practice of summer fallow was adopted to help control weeds and store water to improve crop yields, but it also helped to accumulate an additional year of nitrogen release from organic matter breakdown. However, today, after one hundred years of cropping, little net organic material is broken down during fallow and a progressively smaller amount of nitrogen is made available to crops through mineralization of older organic material. Subsequently, nitrogen derived from mineralization comes mostly from the decomposition of recently incorporated crop residues.

Tillage makes a difference in the speed of residue decomposition and the amount retained as soil organic matter. Plowing introduces oxygen into the soil and mixes residues in contact with more soil, speeding up breakdown of both residue and organic matter. Minimum tillage, such as one-pass seeding following a fall chisel plow operation, does not introduce as much oxygen and residues and organic matter tend to break down less quickly. The no-till system has been shown to be most effective in increasing soil organic matter. It is most like the grass-forb and bison disturbance system of the past and increases of organic matter have been found not only in the residue layer at the very surface of the soil, but even at greater depths within the soil.

Nutrient Availability

Plant nutrients are made available from soil reserves, crop residue mineralization and introduction of fertilizer amendments. Availability of fertilizer amendments depends on the placement, timing, dispersion or solubility and the chemical form of the amendment.

One type of nutrient availability is called positional availability. The specific placement of fertilizer nutrients within the soil may make the nutrient available or unavailable. Figure 9 illustrates two situations where nutrients are unavailable because of positional placement problems.

Not all crops require nutrients in the same place. Some crops, such as small grains, corn, canola, sugarbeets and potatoes, respond to concentrated bands of fertilizer near the seed at planting. Other crops, such as soybeans, flax, sunflowers, field peas, lentils, and dry beans, usually perform better with broadcast applications of fertilizer.

7

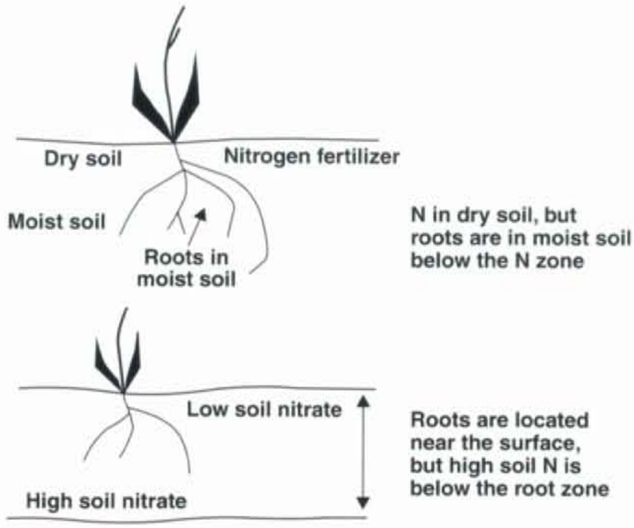


Figure 9. Two ways in which soil supplied nutrients can be positionally unavailable.

Clay Structure and Importance

The amount of nutrient available to plants, the resistance to change of available nutrient levels in soil due to nutrient addition or removal, and the ability to hold some nutrients tightly enough to minimize leaching losses while keeping the nutrients available for plant uptake is mostly the result of a soil process called cation exchange. Clay and organic matter are primarily negatively charged. Most clay minerals in North Dakota are composed of a sheet of aluminum oxides sandwiched between two sheets of silicon oxides, called smectite. Because of the orientation of oxygen or hydroxyl ions around the aluminum and silicon atoms within the sheet, the shape of the individual silicon molecules forms a tetrahedron, while the aluminum compounds form an octahedron (Figure 10).

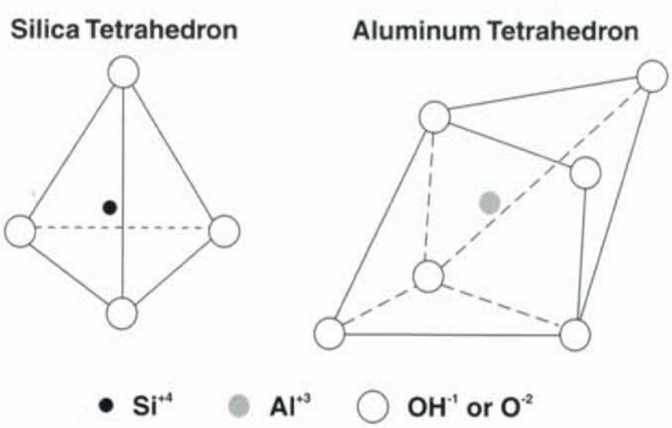


Figure 10. A silicon tetrahedron and an aluminum octahedron. These are the basic components of clay mineral layers.

Smectite is important because of its shrinking and swelling characteristics. Water can penetrate between clay sheets and the volume of the clay expands when wet, particularly when freezing. When the clay dries, water is pulled from between clay layers and the volume shrinks. This important property gives many of the soils in the Red River Valley and in the glacial till plain east of the Missouri River resistance to the long-term effects of compaction and enables soils to regenerate their productivity even after a wet fall and fields full of ruts from trucks and other heavy farm equipment. West of the Missouri River, soils are made from much older residual material and some kaolinitic clays can be found along with smectites. These soils are not as forgiving and are also adversely affected in some areas by the effect of native sodium.

Cation Exchange

During the original mica mineral formation from which clay minerals are derived, atoms of like size as the predominant aluminum or silicon atoms but with lower charge substituted within the sheets of clay minerals, in a process called "isomorphous substitution." Aluminum is sometimes substituted by magnesium or iron in the octahedral layer, while silicon is substituted by aluminum in the tetrahedral layer. Substitution changes the charge of the clay layer since the substituting ions have a less positive charge than the original ions. The degree of substitution during the formation and weathering of these clays determined the amount of negative charge the clays have (Figure 11). Smectite clays that shrink and swell have higher CEC than those clays that do not because of higher surface area. Kaolinitic clays, which have one sheet of aluminum octahedral

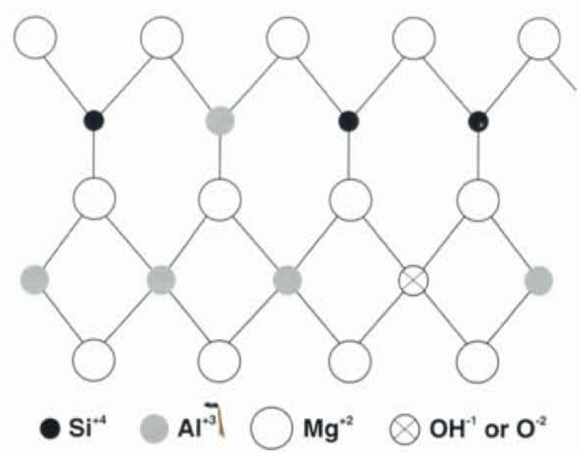


Figure 11. (Mg^{2+}) for aluminum (Al^{3+}) in the octahedral layer and Al^{3+} for silicon (Si^{4+}) in the tetrahedral layer. Substitutions such as these are very common during clay weathering and result in a net negative charge for the clay surface.

and one sheet of silicon tetrahedral and have low shrink and swell characteristics, have low CEC, mostly pH dependent charge from the clay surfaces.

Organic matter is negatively charged because of hydroxyl (OH-) groups, carboxyl (COOH-) groups and other negatively charged arrangements on the organic matter surfaces. The charge is pH dependent, which means that changes in pH up or down can increase or decrease charge, but most is negative at pH levels common in North Dakota. In North Dakota, this charge is small compared to the contribution of clay toward the CEC.

The process of cation exchange works because positively charged ions (cations) such as calcium (Ca^{2+}), magnesium (Mg^{2+}) or potassium (K^{+}) are attracted to the negatively charged clay and organic matter particles. When cations are added to the soil, the cations do not simply attach to the clay or organic matter because the charge is already satisfied by other cations near the clay surfaces. Added cations must substitute for cations already held on the clays and organic matter. This substitution is called cation exchange (Figure 12).

Certain cations are more attracted to the clays than others. The degree of attraction depends on the total charge of the ion and the effective ionic radius. In general, given two ions with like radius, the one with the greater charge is more tightly held and more likely to replace the other. However, there is a sphere of water molecules which surround each cation, called the water of hydration. The radius important to cation exchange is the distance between the center of each cation and the outside of its sphere of hydration. Because magnesium is a smaller atom than calcium, it would suggest that magnesium would be more tightly held. However, magnesium is surrounded by a greater sphere of water in soil solution and so is actually less attracted to clays and organic matter than calcium. The relative strengths of attraction for clay and organic matter are as follows:

$Al^{+3} > H^{+} > Ca^{2+} > Mg^{2+} > NH_4^{+} = K^{+} > Na^{+}$

Soil testing laboratories can estimate cation exchange capacity using several testing procedures. Cation exchange capacity values for a soil depend on the test used. It is not possible to exchange all cations from organic matter and clay surfaces because some are held too tightly, so the test procedures have limitations. Cations are not held in contact with clay and organic matter in a neat layer. Close to the surfaces are the most tightly held cations. Surrounding this layer is a cloud of less tightly held cations that tend to spend more time near the surfaces than in true solution. Cations in this outer cloud are more easily substituted for by passing cations in solution (Figure 13).

Figure 12. An illustration of cation exchange.

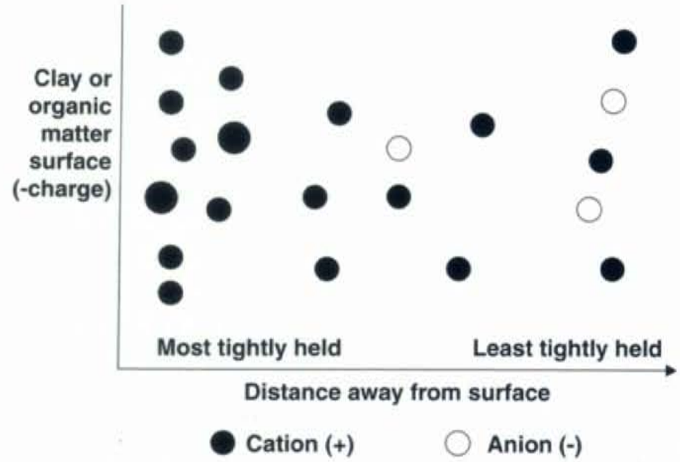


Figure 13. A representation of an idealized cation cloud adjacent to a clay or organic matter surface.

In addition, North Dakota soils contain free salts. Normal agricultural labs analyze extracted salts along with exchanged cations. Therefore, CEC results in the lab are often higher than they would have been had the soils been sufficiently leached prior to the procedure.

Plant Nutrient Uptake

Soil nutrients come in contact with plant roots in three different ways; mass flow, diffusion, and contact exchange (Figure 14). Contact exchange is the least likely to occur because plant roots must touch the soil particle and actually contact the nutrient directly without any movement of water. Given the enormous surface area in a soil compared to that of a root, contact exchange is only a small part of the nutrient uptake process.

Some nutrients, mainly calcium (Ca^{2+}), sulfate (SO_4^{2-}), nitrate (NO_3^{-}), boron ($H_3BO_3^{-}$) and chloride (Cl^{-}), move primarily by mass flow. In mass flow, water movement to plant roots, pulled by transpiration from the plants, carries along plant nutrients in solution. To be available through mass flow, there must be either a large concentration of the element in the water (Ca^{2+}), or the nutrient must be easily dissolved and moved by water (NO_3^{-}, Cl^{-}, $H_3BO_3^{-}$, and SO_4^{2-}).

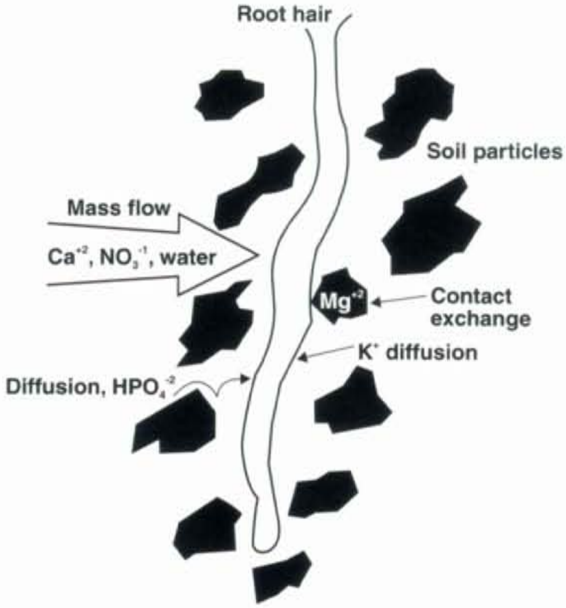


Figure 14. Examples of mass flow, diffusion and contact exchange. Soil nutrients travel to plant roots by one or more of these mechanisms.

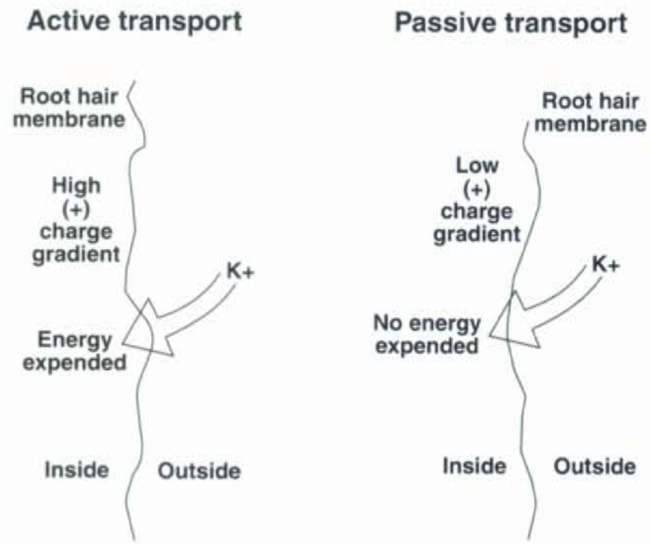


Figure 15. A comparison of active and passive transport in plant roots.

Nutrients in limited supply in the soil or those with low solubility are moved to plant roots by diffusion. As an example, when someone lights a cigarette in a room with little air movement, soon everyone in the room can smell the smoke. The smoke moves throughout the room by diffusion. Although diffusion in air is much faster and reaches much farther than in water, the same principles apply. In diffusion, the nutrient molecules move by randomly bouncing into each other and into water molecules through natural vibrations. The distances traveled by molecules moving in solution through diffusion is very small. Phosphate, potassium, ammonium, magnesium, zinc, iron, copper, manganese and molybdenum all move to plant roots primarily by diffusion.

Once in contact with plant roots, soil nutrients are taken into plants by either active or passive transport through root cell membranes (Figure 15). Most nutrient uptake takes place within root hairs, or through symbiotic fungi called mycorrhizae which act as root hair supplements for plants. In either case, nutrients that are in large relative supply and correct charge are taken in through passive transport with water flow into plants. Nutrients in lower supply or of different charge than within the plant root are taken up through active transport. In passive transport, there is no energy required by plants. Active transport requires energy and oxygen, which is why soil air is important to plants and one reason why water-logged soils are not very productive for most crops.

Mychorrhizae

More needs to be learned regarding mycorrhizae in cropping systems. Grassy crops in North Dakota support mycorrhizal relationships. Only some of our broadleaf crops support mycorrhizae. Canola and sugarbeet are the two crops with weak mycorrhizal relationships. Perhaps because of a lack of mycorrhizae during the sugarbeet growing season, corn following sugarbeet or fallow often displays a condition known as fallow syndrome. Fallow syndrome exhibits P-like deficiency in corn. Plants are stunted and may show purpling in the leaf tissue. During fallow, or following a crop not favorable for mycorrhizae, mycorrhizae numbers decline. Additional steps need to be taken to provide adequate P to the subsequent crop to make up for the lack of uptake mechanisms in the corn plants. High rates of P are required as a side-banded starter fertilizer to alleviate the P stress from lack of mycorrhizae.

Figure 16. Cross section of mycorrhizae coating a small root.

Soil Transformation Processes Affecting Nutrient Availability

Mineralization

When residues decompose, some nutrients may be released in an inorganic form. This release is called mineralization. Potassium (K^+) is easily washed out of plant tissue with rainfall since a high percentage is not physically attached to binding organic molecules. Nitrogen (N), P, S and some other nutrients may be released during decomposition of residues if plant levels are higher than the resulting products of decomposition contain. The rate of mineralization is dependent on temperature and soil moisture. Mineralization is very slow when soils are near freezing and increases with increasing temperature. Moist soils, but not flooded conditions, encourage faster mineralization compared to dry soils.

Nitrification

Two types of aerobic bacteria participate in transforming ammonium-N to nitrate-N. Several different kinds of bacteria in the family Nitrobacteriaceae first transform NH_4^+ to NO_2^- (nitrite). This includes Nitrosomonas spp. (which is most well-known and easiest to study) and Nitrosolobus spp. (which in some researchers' opinion may be more important than Nitrosomonas). Nitrite is toxic to plants at low levels, but does not occur at high levels in soils because of the activity of Nitrobacter spp. and soil chemical processes, which transforms NO_2^- to NO_3^-. This reaction is very fast compared to the activity of Nitrosomonas sp.

Nitrification rates vary significantly by soils, soil moisture and temperature. For example, at 50° F, after one week, approximately 10% of applied N would be expected to transform to nitrate each week. At 65° F, conversion might be nearly complete in three weeks. Nitrification takes place even in frozen soil, but the rate is very slow. Nitrification rates begin to be significant when soil temperatures are above 50° F and are maximized around 80° F. The total effect of nitrification can be significant even at temperatures below 50° F if there is sufficient time between N application and when soils are completely frozen. Slow nitrification may add up to large potential levels of NO_3^-, and therefore applications of fall ammonia sources are usually delayed until late fall to reduce risk of spring N losses. Soils must be moist but not flooded for optimal nitrification.

Denitrification

Under flooded conditions, soil oxygen levels are low and anaerobic bacteria may transform NO_3^- into nitrogen gases, such as N_2O (nitrous oxide), NO_2 (nitrogen dioxide), and N_2 (nitrogen gas). Although there is evidence that some denitrification takes place in frozen soils, its activity is greatest when soil temperatures are above 60° F. In warm summer soils, temporary flooding of ponds has resulted in the loss of half of the available NO_3^- in 48 hours. In North Dakota, most denitrification is seen in the eastern part of the state. Areas in the west may see periodic ponding, but residual N levels remain high. Whether this is due to a low population of denitrifying bacteria because of semi-arid environments or other reasons is not known.

Sulfur transformations

Plants take up S as sulfate SO_4^{-2}, but sulfur within plants is mostly sulfide (-S), such as the sulfur in the amino acids cystine and methionine. Some microorganisms in the soil, such as fungi and bacteria, are specialized to utilize sulfide-S and transform it back to SO_4^{-2}. *Thiobacillus* spp. are some of the most common and efficient microorganisms that perform this transformation. They prefer acid soils (about pH 4) for optimal activity, although some activity is evident at a wide range of pH. The transformation of S to SO_4^{-2} can be relatively fast, with some studies showing significant SO_4^{-2} generated within a few weeks to a few months. Certain fungi and other microorganisms also participate in this transformation, but their activity is slower than that of *Thiobacillus* sp. Transformation of elemental sulfur fertilizer must also go through the same transformation process before being utilized by plants. There is evidence from North Dakota and Manitoba research that transformation of elemental sulfur fertilizer is very slow compared to studies in warmer climates to the south and east in the United States.

Soil Microorganisms

Soil is a living system composed of abiotic (non-living) and biotic (living) components. Abiotic soil components include mineral matter (clay, silt and sand), water, air and organic matter. Plant roots and soil fauna and microorganisms make up the biotic portion of soils. It is the interactions among the biotic and abiotic factors that are associated with growth and development of crop plants and general health of the soil.

A knowledge of soil microorganisms is essential to management of agricultural production systems. Without soil microoganisms, life as we know it would not exist. For instance, we would be overwhelmed by undecomposed organic residues from plants and animals. Virtually everything we do is influenced by these organisms and their activity in soil. Interactions among soil organisms may be very complex and are crucial to the functions of soils.

Types of Soil Microorganisms

Microorganisms are grouped in classes of similar characteristics and sizes. Many are not visible to the naked eye. Generally, the smaller the organism, the greater their number in the soil.

Table 6. Typical numbers of organisms in a handful of soil.

Organism	Numbers
Bacteria	300 million - 50 billion
Actinomycetes	100 million - 2 billion
Fungi	500,000 - 100 million
Protozoa	100,000 - 50 million
Nematodes	1,000 - 10,000
Arthropods	100 - 1,000
Earthworms	0-2

One of the first observations regarding this dynamic population is their size. Many can be observed with only the most powerful microscopes. To appreciate their size, consider a football resting on the 50 yard line in the Fargodome. Now reduce the Dome to the size of the letter "O" on this page. The football now represents the size of some of the minute microorganisms found in soil.

Functions of Microorganisms in Soil

Microorganisms ingest foods, convert them to other forms for energy and excrete transformed materials back into the soil. Carbon compounds are converted to carbon dioxide. If food is in abundance, they can reproduce rapidly. If food and environment are not favorable, they may lie dormant for some time before increasing in numbers again. In the process of fulfilling basic functions necessary for their existence and perpetuity, organic compounds including manure, plant residues and pesticides are decomposed, preventing them from entering surface and ground water and becoming pollutants. They sequester nitrogen and other plant nutrients that might otherwise enter groundwater and some fix nitrogen from the air, making it available to plants. Many organisms enhance soil aggregation and porosity through excreted materials, thus increasing water infiltration and reducing runoff. Soil organisms also prey on crop pests and are food for above-ground animals, such as birds and spiders.

The Soil Microorganism Environment

Soil microoganisms live where the environment and food supply is best for them. They need space to reproduce, a food supply, air or lack of air, nutrients and moisture. They can be found anywhere that organic matter can be found. Most microorganisms can be found in the top 6 inches of soil, but microorganisms have also been found as deep as 10 miles in oil wells. Most soil microorganisms are found near roots, in residues, in soil organic matter, and on the surface of soil aggregates.

Organisms near roots – Concentrations of microorganisms can be found around roots, where nutrients and organic debris from growing plants are located. Bacteria feed on sloughed off dead plant cells and root exudates, including proteins and sugars. Protozoa and nematodes graze on bacteria that surround the roots. A great deal of nutrient cycling occurs very near the root surface. This biologically active area surrounding the root is called the rhizosphere.

On residue – Fungi derive most of their nutrients from the decomposition of dead materials. Fungal hyphae, which are fine filaments analogous to roots, can transport nitrogen from surrounding soil to hard-to-decompose high carbon residues. Bacteria cannot transport nitrogen over distances, so high carbon residues are not normally decomposed by bacteria without the help of fungi. Bacterial decomposition occurs most commonly on fresh green residue where nitrogen is in greater supply. Bacteria and fungi are more able to decompose residues already shredded by larger organisms such as earthworms, insects, and arthropods.

On soil organic matter – Fungi are common inhabitants of soil organic matter. Organic matter is much more difficult to break down, because the most easily decomposed compounds are mostly already transformed, leaving more lignin and other stable compounds as end-products. Only fungi produce the enzymes needed to break down the organic compounds most resistant to decomposition.

Aggregate surfaces – The activity of aerobic bacteria and fungi are greater on surfaces of soil aggregates than in the interior. Some microbial activities which are more anaerobic, such as denitrification, are more prevalent inside aggregates. The activity of soil microorganisms on the surface of aggregates helps to stabilize the aggregates and leave them less susceptible to the affects of compaction and slaking due to rainfall.

Between aggregates – The larger spaces and pores between aggregates enable larger creatures such as arthropods, nematodes, and earthworms to move about. Organisms susceptible to desiccation are found in smaller, water-filled pores.

Microorganism Activity

The activity of microorganisms is measured in population number. There is not a single stable population of microorganisms during a year. In winter, populations are low and dormant. Winter freezing kills many microorganisms. As temperatures warm, populations increase and peak in mid summer. Later in the year, when food supplies dwindle and environmental conditions become more rigorous, populations decline. Following the first frost, numbers plummet to winter lows and the cycle is repeated the following year. Some species are more prevalent during times of dry weather, while others prefer wet or even flooded conditions.

Microorganism Groups

Bacteria

Bacteria are one-celled organisms, about 1 micrometer (1/25,000 inch) in diameter, and usually longer in length than width. The bacteria in an acre of soil weigh as much as two cows. Bacteria perform very important functions in soil. They are important in nutrient cycling, plant disease suppression, soil aggregation and residue decomposition. Substances from bacteria help to bind soil into stable aggregates which resist compaction and surface crusting. Stable aggregates also increase water infiltration and reduce runoff.

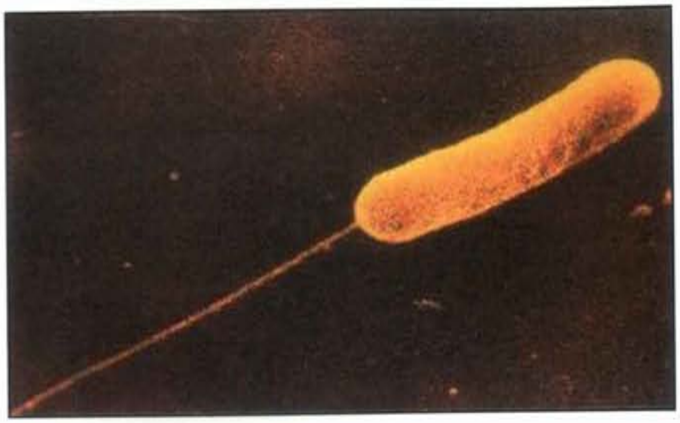


Figure 17. Rod-shaped bacteria with flagella
(courtesy of Dr. Tom Loynachan, Iowa State University).

Fungi

Fungi are plant-like organisms, but unlike most plants they derive their energy from other organisms, which are usually dead plant and animal tissues, and are not capable of photosynthesis. Fungi have root-like structures called "hyphae" that grow as long threads or strands. The hyphae push their way into residue, rocks and soil particles, taking up nutrients and excreting substances along their length. A single hyphae may be as long as several feet. Fungi are important in decomposing residue and physically bind soil particles together into aggregates.

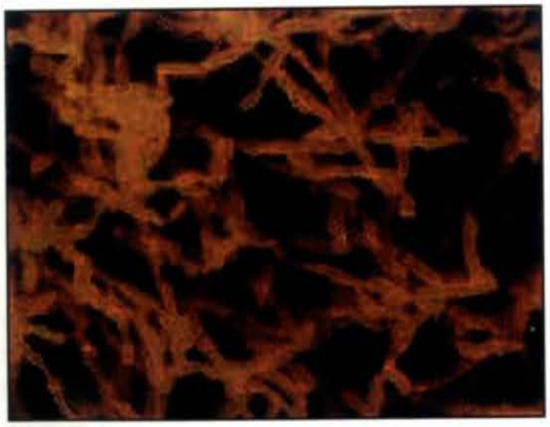


Figure 18. Fungi with hyphae strands
(courtesy of Dr. Tom Loynachan, Iowa State University).

Protozoa

Protozoa are single-celled animals. They feed mostly on bacteria but also ingest other protozoa and other microorganisms smaller than themselves. They help to release nitrogen from residues and from ingested bacteria and fungi.

Nematodes

Many people who focus on pest management in agriculture have come to know nematodes as a bad thing, since some cause crop damage, especially to the roots. However, most nematodes are beneficial in breaking down residues, feeding on soil predators and disease-causing organisms, and being an essential part of the soil microorganism food chain. Nematodes are tiny worms. Some can be seen with the naked eye, while many others are too small to see without a microscope.

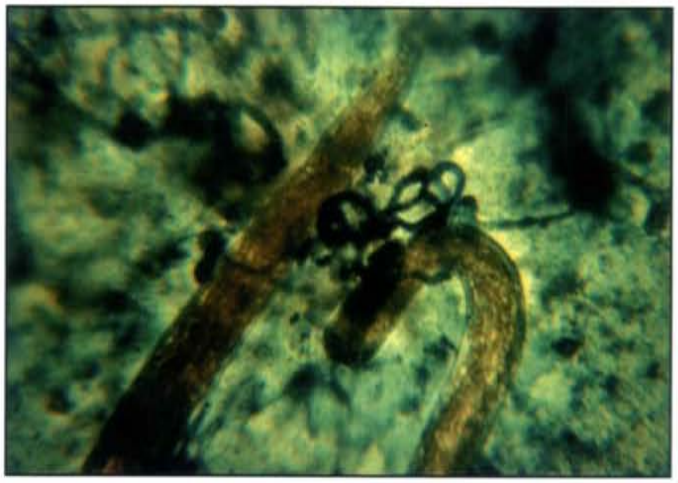


Figure 19. Nematodes and fungal hyphae
(courtesy of Dr. Tom Loynachan, Iowa State University).

Arthropods

Arthropods include insects and arachnids, such as mites. They feed on many different kinds of materials, including plant residues and smaller microorganisms. As they feed, they move through the soil, aerating it and enhancing the decomposition of residues. Their fecal pellets provide a rich manure of nutrients readily available to plants.

Figure 20. A centipede
(courtesy of Dr. Tom Loynachan, Iowa State University).

Earthworms

Earthworms are familiar to most people. They are large enough to be seen easily. In North Dakota, most earthworms are the type that move laterally in the soil and live relatively close to the surface. Nightcrawlers are not as common, and tend to burrow more vertically and deeper in the soil. Earthworms form channels to facilitate water movement to deeper depths. Laterally burrowing earthworms play an important role in reducing runoff, but at the same time not forming a channel directly to groundwater in most cases. Earthworms transform plant residue into materials more easily decomposed by other microorganisms. Their excretions help to bind soil particles together. They serve as natures plow and their middens (excretions) are a valuable source of nutrients for plants and other organisms.

Figure 21. Earthworms in a shovelful of North Dakota soil
(courtesy of Dr. E. Deibert, North Dakota State University).

Nutrient Functions Within Plants

Thirteen mineral nutrients are required by plants. These mineral nutrients are required for plants to grow and reproduce and cannot be substituted for by any other nutrient, with rare exceptions. Lack of proper nutrition causes nutrient deficiency symptoms in crops. A summary of the relative frequency of known deficiencies within North Dakota is shown in Table 7.

Nitrogen

Plants absorb nitrogen as either ammonium (NH_4^+) or as nitrate (NO_3^-). NO_3^- is easily absorbed and is not toxic to the plant. NH_4^+ is also easily absorbed, but because it is toxic to plants, is transformed immediately into one of several amino-compounds ($-NH_2$) so that it can be transferred safely throughout the plant. Nitrate is usually the predominant form found in agricultural soils. Nitrogen (N) is an essential component of amino acids, which are the building blocks of proteins. Proteins can be structural, or they can be specialized workhorses called enzymes. Enzymes help reduce the energy barriers which keep many chemical processes from happening randomly in a plant. There are enzymes that help break down certain compounds and some which synthesize other compounds. There are specific enzymes necessary for nearly every energy-requiring process and activity within a plant.

Nitrogen is also a part of the DNA molecule, filling an important role in cell division and reproduction. The chlorophyll molecule also contains nitrogen. Chlorophyll is the light energy receptor for the process of photosynthesis, which converts light energy into chemical energy in the plant and is essential for life as we know it. Nitrogen deficiencies appear in crops as a yellowing of older plant tissue and general stunting of plants (Figure 22). Nitrogen deficient small grains produce few tillers.

Nitrogen deficiencies are found where soil nitrogen levels are low, where rates of organic matter and plant residue breakdown are slow, where water is moving out of the rooting zone, carrying nitrates with it (leaching), or where water has stood in soils for a period of time during warm weather.

Nitrogen is mobile in the plant and moves from areas of relative abundance to areas of need. When N is in abundance, it is held inside cell vacuoles (storage locations) until needed. Early in the season when plants are small, N content (% N) is high. The N content of plant tissue declines with age, and N is transferred from higher N content storage areas to areas like seed that have a greater need. N deficiency is seen in lower leaves and older tissues first. If the deficiency is not corrected, newer

Table 7. Summary of known nutrient deficiencies in North Dakota.

Nutrient	Frequency of Deficiency	Common crops most likely to respond
Nitrogen	High	Small grains, row crops including dry beans and soybeans, grassland and pasture crops.
Phosphorus	High	All crops.
Potassium	Low	Crops in leached, coarser soils.
Sulfur	Medium	Canola, alfalfa, small grains, potato, corn. Most often found on low organic matter, coarser soils.
Calcium	Very low	Tomato, sugarbeet; deficiency is related to physiological problem during periods of poor xylem flow.
Magnesium	Very low	Sugarbeets.
Zinc	Medium	Corn, potato, dry beans, flax.
Manganese	Very low	Soybean, oat, sugarbeet, wheat.
Copper	Very low	Wheat, oat, durum.
Iron	Medium	pH/carbonate, enhanced deficiency in the presence of high soluble salts, soybean, flax, wheat, sunflower, dry bean.
Boron	Rare	Sunflower, alfalfa, cauliflower, sugarbeet, canola.
Chloride	Medium	Small grains, corn.
Molybdenum	Unreported	

Figure 22.
Nitrogen deficiency in spring wheat and sunflower.

leaves may be affected, but not as much as older tissues. Plants become stunted, leaves become pale green or yellow (especially older leaves) and grain yield and protein levels will be lower. Oil content of the seed will typically be somewhat higher when N is limiting. Sugarbeets should be nearly N deficient at harvest so that energy goes into the root storage and not in producing new green leaves.

When soil nitrate levels are high, plants can accumulate nitrate in tissues at levels above what is required for normal growth. A shortage of nitrogen will cause the plant to mobilize extra nitrate stored in older tissue and send it to younger, developing tissue. Plant nitrate concentration can therefore be a diagnostic tool of the nitrogen health of the plant. Deficiencies can be verified using plant tissue nitrate testing or total nitrogen analysis. Care must be taken to understand the effects of growing conditions on plant tissue nitrate levels, however. Drought-damaged forages can contain levels of nitrates that are toxic to ruminant animals, for example. Generally, poor growing conditions unrelated to nitrogen fertility can cause higher than normal plant nitrate content.

Phosphorus

Plants absorb phosphate as either HPO_4^{2-} or $H_2PO_4^-$ ions. Soil pH is an important factor in determining which ion is most dominant in the soil solution (Figure 23). An important function of phosphorus in plants is energy transfer through the formation and reduction of phosphate bonds in a specific chemical energy-carrying compound called ATP. Photosynthesis results in the production of additional phosphate bonds needed to form ATP, while energy-requiring processes used in growth and metabolism break this bond to utilize its stored energy. Phosphate is also a part of cell membranes, which form the barrier regulating the flow of compounds into and out of a cell. Phosphorus is also a part of the DNA molecule and is therefore very important in cell division and reproduction. Phosphorus is mobile in the plant, similar to nitrogen. It moves from areas of abundance to areas of need, usually younger tissues, new leaves and reproductive areas. Phosphorus in the soil is relatively immobile. Unless the soil is eroded and moves with wind or water, soil P remains where it was placed. One exception to this rule concerns extremely high soil testing levels of P, frequently resulting from excessive manure applications. Under wet conditions, downward P movement has been seen, probably in the form of organic P compounds.

Phosphorus deficiency most often slows early plant growth with no other obvious symptoms. Sometimes deficient corn, barley and some mustard plants can show purple or reddish tints in the leaf and vegetative tissues. Deficiency in wheat generally exhibits a thinner than normal leaf and stunted plants. Tillering in wheat and barley is severely reduced. Deficiency in potatoes often resembles late blight symptoms. Phosphorus deficiencies can be verified with soil tests and plant tissue analysis. Phosphorus deficiencies occur throughout North Dakota.

Plants may exhibit P deficiencies, but the primary cause may not be low soil P levels. Any condition restricting early root growth, such as cold soils, wet soils, dry soils, compaction, poor soil condition such as the presence of clods, herbicide stress, insect damage to the roots, or seedling disease, may also result in a lack of P to the plant. Conditions resulting from low soil mycorrhizae activity, such as following fallow, or a crop not compatible with the proper mycorrhizae, like corn following sugarbeet, may also result in low P uptake into the plant.

Phosphorus deficiencies are found generally in areas with low native soil P levels, in high pH and high carbonate soils and in unfertilized crops following fallow. Although fertilizer recommendation charts combine all soils into the same category of ease of buildup with fertilizer applications, it is evident from reviewing field histories that soil P levels can be built and maintained more easily when the soils have pH lower than 7 and have no carbonate levels than soils with pH around 8 with high carbonate levels. Although there are no firm guidelines for P buildup in these higher pH, higher carbonate soils, it is clear that building soil test P levels in these soils is possible, but higher P rates are required.

Potassium

Plants absorb potassium as the potassium ion, K^+. Potassium is a major cell electrolyte, used to balance electrical charge within the plant produced from the uptake of nitrate, sulfate and chloride ions, as well as from the internal production of organic acids. Potassium is an enzyme activator and helps regulate stomates, which allow air to pass into and out of the plant, thus controlling water vapor loss.

In sugarbeet, sodium can substitute for potassium in many functions. Although not classified as an essential element for all plants, sodium is important for sugarbeets in the absence of potassium. Some potassium is required when sodium levels are high, but sodium is not required when potassium levels are adequate.

In many plants, such as corn, wheat and soybean, potassium deficiency results in stunted plants and yellowing of the outer leaf margins of older leaves (Figure 24). Severe deficiency can advance the yellowing into necrosis, or a "scorched" appearance. Potassium deficiencies of sugarbeet begin with irregular brown patches between the veins on older leaves. Advanced stages will show general bronzing of the areas between the leaf veins. Leaf tissue will eventually brown and die, but petioles will remain green for some time. Sugarbeet leaves will also give off a faint putrescent odor when potassium deficient.

Potassium deficiency can be verified by soil and plant analysis: however, in sugarbeet, sodium levels also need to be determined. Potassium deficiency is generally found in highly leached sandy soils in North Dakota. Available potassium levels are generally high in most North Dakota soils due to their relatively young age in the glaciated portions of the state and the high potassium parent materials of the sediments west of the Missouri River combined with the relatively dry climate in the west.

Sulfur

Plants absorb sulfur as the sulfate (SO_4^{2-}) ion. Sulfur is a part of several amino acids and is therefore a component of most proteins. Sulfur initiates protein synthesis and is a part of flavor compounds in mustard, garlic and onions. It is also a part of some vitamins and many enzymes.

Plant tissues can accumulate sulfate when it is available in excess of plant requirements, however, plants cannot translocate extra sulfate to younger tissue if soil levels decrease. The ratio of nitrogen to sulfur in plant tissue is generally about 10:1, although the ratio can vary somewhat. Canola, for example, has been identified as one crop in which a 7:1 ratio of N to S is recommended by some Canadian publications, compared to other crops which tend to need about a 15:1 ratio of N to S. Total sulfur

Figure 24. Potassium deficiency in corn.

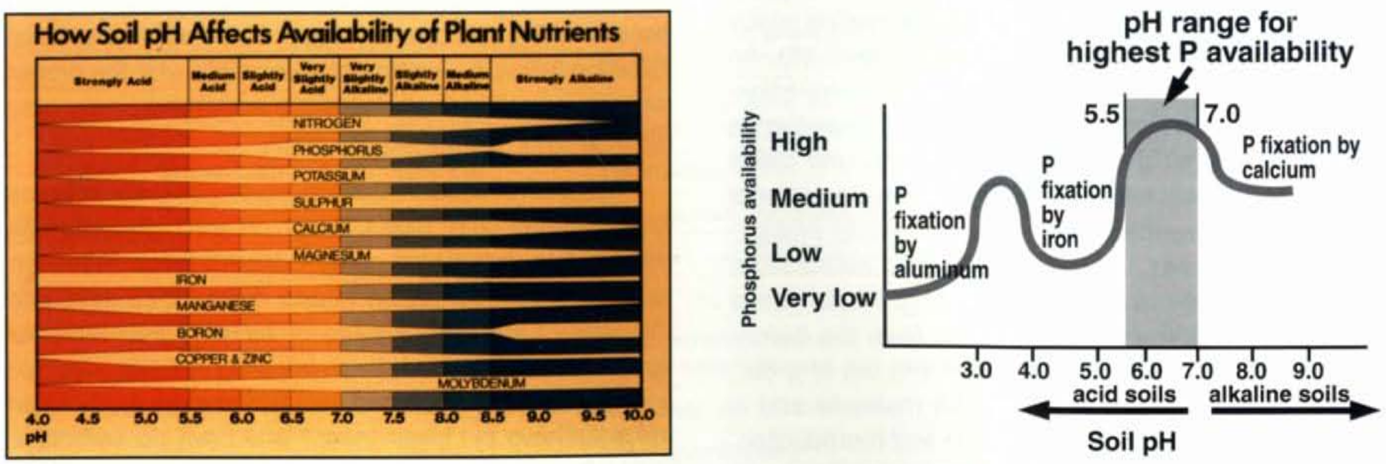


Figure 23. Relative effect of pH on plant availability of soil nutrients.

in the plant includes both sulfate and organic sulfur compounds. Plant analysis of sulfur content generally includes the combination of both forms.

Sulfur deficiency is characterized by a yellowing of younger leaves, although this symptom can be complicated by soil availability of sulfur at different times of the year (Figure 25). In North Dakota, plants may be deficient early, with yellow leaves, then roots may reach higher sulfate levels associated with the water table deeper in the soil and younger leaves may recover, producing total plant symptoms similar to nitrogen deficiency for a period of time.

The present soil test for S is very poor. It underestimates S availability in some western soils because of its failure to anticipate S mineralization from organic matter and residue. It overestimates S availability in soils containing gypsum crystals in eastern soils. During preparation for soil analysis, soil is ground to pass a fine mesh screen, pulverizing these crystals into a powder and resulting in greater sulfate extraction and estimate of availability than would be present in the soil in place. Soil variability of S is also highest among any plant nutrient in fields. It is often better to anticipate S deficiencies by locating eroded, low organic matter or sandy soils than it is to try to isolate low S areas with the soil test. S deficiency can be enhanced by high levels of N, such as overapplication of fertilizer.

Canola is one crop with an exceptional S requirement. It is the only crop in North Dakota to which S application is recommended regardless of S soil test. Canola seed contains up to five times the sulfur concentration of wheat and barley and twice the total soil removal of sulfur as small grains at similar relative yields. Canadian and North Dakota canola growers have reported that sulfur deficiencies were rare until they began raising canola. Other crops in the rotation seldom exhibit sulfur deficiency symptoms. Canola sulfur deficiency symptoms include leaf cupping, interveinal yellowing of upper leaves, purpling along leaf margins and bracts and poor seed development. Proper nitrogen nutrition enhances the deficiency symptoms (Figure 26). Deficiency also delays maturity and produces mature pods on green stems, with poor seed development within the pod. Curiously, these exceptional S requirements are not shared by other mustard family crops, such as mustard or crambe.

Sulfur deficiencies can be verified with plant tissue analysis. The sulfur soil test is not very diagnostic and sulfur soil levels within fields are extremely variable. High testing composite soil samples need to be viewed with suspicion, especially on high sulfur requiring crops such

Figure 25. Sulfur deficiency in spring wheat.

Figure 26. Sulfur deficiency in canola.

as canola, since sulfur deficiencies are more common on sandy soils and hilltops. A field consisting of several soil types may be better characterized for sulfur by testing sandier soil types, eroded areas or higher elevation landscapes separately from other parts of the field.

Calcium

Calcium is in abundant supply in most North Dakota soils however, physiological deficiencies have been observed in tomato and sugarbeet when soil supplies are interrupted by dry soil conditions. Calcium uptake is also inhibited in saline soils containing a great excess of magnesium or sodium. Calcium is very important in the regulation of several enzymes, regulates cell wall development and is an important component of cell wall construction, as well a constituent of the cell wall itself. Calcium moves through the plant in the transpiration stream, which is the avenue from roots to leaf stomates, and is one-directional. Calcium is not readily translocated between plant tissues, and plants do not accumulate high calcium concentrations when it is in excess. Proper development of fruits and storage roots depend on a constant soil supply of calcium.

Deficiency in tomato is characterized as blossom end rot. Calcium deficiency in sugarbeet can result in younger leaves curling over the top of the growing point, producing a hooded appearance. Calcium deficiency is hard to detect with plant analysis or soil testing, because it is usually caused by low soil water uptake by the plant. Irrigation timing is important in tomato, and under low transpiration conditions such as high humidity, sprays of calcium chloride solution may be necessary to protect a maturing tomato crop.

Calcium deficiency has been documented in the Red River Valley on sugarbeet, but the deficiency was physiological, caused by prolonged humid weather or dry soils which both interfere with the transpiration stream carrying Ca to younger tissues.

Recently, soluble Ca sources have been useful in reducing the effect of white mold (Sclerotinia) in dry beans when applied as a foliar spray at flowering. Calcium is important in maintaining cell integrity due to its role in helping build cell walls and serving as a component of cell walls. Dry beans are most susceptible to Sclerotinia when the humidity is high. Flower petals also have low levels of transpiration compared to leaves. High humidity also results in less Ca being carried through the transpiration stream to the new blossoms. Perhaps Ca supplements help maintain cell integrity and resist Sclerotinia infection during periods of low transpiration and reduced Ca movement within the plant. Calcium sprays, combined with fungicides, have been effective at reducing white mold.

Magnesium

Plants absorb magnesium as the Mg^{2+} ion. Magnesium is the central element within the chlorophyll molecule. It is also an essential element in the production of proteins and activates several enzymes. It is a cofactor of several enzymes, meaning that it is essential for the activity of an enzyme process but not an actual part of the enzyme itself.

Magnesium deficiency is shown first by the yellowing of older leaves. Initially, yellowing is usually interveinal. As the deficiency progresses, leaf margins may become necrotic and resemble potassium deficiency. Magnesium deficiencies can be verified with soil and plant analysis. Deficiencies are rare in North Dakota due to the high level of base saturation of most soils and the high level of Mg present in those soils.

Boron

Boron is absorbed by plants as the $H_3BO_3^-$ ion. Boron is essential in carbohydrate metabolism and in auxin regulation. Auxins are plant growth regulators, similar to the activity of 2,4-D, which help to mobilize nutrients to the actively growing parts of the plant and whose manufacture by the plant directs growth and development. The amount of available boron in soil is highly correlated to soil organic matter. Boron deficiency can be shown in heart rot of sugarbeets, head drop in sunflower, and "yellows" in alfalfa. Deficiency can result in growing point death in flax, mustard and bean. Deficiency of boron has been observed in North Dakota in sugarbeet and sunflower under dry soil conditions.

Boron deficiencies can be verified by soil and plant analysis however, soil boron levels necessary for adequate nutrition need to be higher in dry surface soils than in soils which have adequate moisture. Responses to B fertilization on low soil B sites in sunflowers have been recorded, but results were inconsistent. Unlike most nutrients, application of B when it is not needed can reduce crop yield if levels are already high or the application rate is excessive. Deficiencies are uncommon in North Dakota.

Iron

Iron is absorbed by plant roots mostly as Fe^{3+} (ferric iron) and then rapidly reduced to Fe^{2+} (ferrous iron) once inside the plant. Iron availability is decreased at pH values greater than 7.0. High pH can cause precipitation of insoluble iron compounds. Wet soil conditions and high soil bicarbonate (HCO_3^-) levels associated with high soil carbonate levels are also important factors in decreasing iron availability to plants.

Iron exists in the aerated portion of soils as insoluble Fe^{+3}. Iron is much more soluble in anaerobic environments, such as groundwater, as Fe^{+2}. Iron is a component of many enzymes and is required for photosynthesis. Iron deficiencies appear first as yellowing of younger leaves. The yellowing is mostly interveinal but can also affect the entire leaf (Figure 14). Different crops have varying tolerance to low iron availability. Varieties within each crop also vary in tolerance to low iron availability. Broadleaf plants increase iron availability by releasing hydrogen ions and phenolic acids from the roots, decreasing pH levels surrounding the immediate root zone. An acid zone in the rhizosphere (area surrounding the root) is necessary for plants to release a reducing substance that transforms Fe^{+3} to Fe^{+2}, resulting in iron becoming one trillion times as soluble as is usually available in soils. Grassy plants tend to release organic chelating compounds called phytosiderophores, which increase the availability of iron in the nearby soil by combining with Fe^{+3} and keeping the iron in solution until the plant can take it up. Efficient crops and varieties have greater ability to biochemically modify the root environment than less tolerant crops and varieties.

Soybeans are susceptible to low soil iron availability. Iron deficiency is expressed as yellowing in between veins on younger leaves. This yellowing is called "chlorosis" (Figure 27). Severe iron chlorosis is not seen until the first trifoliolate leaf emerges, since prior to this stage iron from the seed is translocated to new growth. At emergence of the first true leaves, iron becomes an immobile nutrient and the plant must rely on soil availability to supply iron needs (Figure 27).

Figure 27. Iron deficiency symptoms of soybean.

Other crops with a susceptibility to iron chlorosis are flax and dry beans. Wheat and sunflower may sometimes show chlorosis, but sightings have mainly been confined to very high salt areas around pot holes and ditch banks.

Iron chlorosis in this region is often more severe than chlorosis reported in the central US soybean belt. High soil carbonates, increased solubility of bicarbonate caused by soil wetness, and the presence of elevated levels of soluble salts influence the presence and severity of iron chlorosis in soybeans in North Dakota and northwestern Minnesota. Cold temperatures also aggravate the problem in some spring seasons. Excessive nitrate can also contribute to iron chlorosis. Nitrate does not interfere with iron uptake, but it interferes with iron metabolism and utilization within the plant cells.

Application of iron fertilizers to alleviate chlorosis has only been moderately successful. Iron-EDDHA chelate appears to be most helpful in correcting chlorosis. Plants have greened up compared to control with application of both seed-placed and foliar iron, but only some of the results showed a yield difference at harvest. Additional stress from post-emergence herbicides should be avoided to minimize lower yields due to chlorosis.

Other strategies to reduce chlorosis include methods to develop a drier soil for plants to grow in. No-till, which improves soil drainage, has been shown to reduce chlorosis. Growing soybeans in wider rows instead of solid-seeding reduces chlorosis. Increasing seeding rate also reduces chlorosis.

There are genetic differences among soybean, dry bean and flax varieties for susceptibility to iron chlorosis. To combat chlorosis, plant the most iron chlorosis tolerant varieties available in a maturity range.

Deficiencies of iron can sometimes be verified with plant analysis, but results are usually inconclusive. Plant tissue appears to need a minimum level of iron in order to survive, so although the plants may be discolored and stunted due to deficiency, the plant analysis may show adequate amounts in the plant. It is also difficult to take a good plant sample because of contamination with dust. Plant tissue should be washed with deionized water to remove soil, then handled carefully to prevent contamination of plant tissues with iron compounds during processing. A quick diagnosis may be made by spraying a small amount of iron chelate or iron sulfate on a small area of affected plants and observing whether they green up. Iron soil analyses are not always reliable because iron deficiencies are related to factors such as soil drainage, salinity and carbonate content, not the actual amount of Fe in the soil. Although present in the soil, iron is often low in availability to plants in North Dakota because the average pH in most fields is over 7, levels of carbonates are high and plants may be stressed from high soluble salts .

Manganese

Manganese is absorbed by plants as Mn^{2+}. Soil manganese availability can be decreased with cold temperature, high soil moisture and high soil pH. Manganese is a part of many plant enzymes, including some active in photosynthesis. It is also required in the regulation of some plant growth hormones.

Manganese deficiency is first shown on younger leaves, and yellow spotting or lesions often accompany interveinal yellowing in some crops. Beans and peas may have brown areas within the seeds at maturity. Grasses have yellow spotting and streaking at the leaf base. In oats, the condition is called "grey speck." Deficiencies can be verified with plant analysis. Soil analysis is not always conclusive. Environmental factors can sometimes be more important than soil levels. Varieties differ widely in tolerance to low manganese availability. Manganese toxicity, induced by high soil water content and low Fe availability is probably more common in North Dakota than Mn deficiency.

Zinc

Zinc is absorbed by plants as the Zn^{2+} ion. Zinc uptake by plants is decreased with low soil temperatures. There is also variability among varieties in their response to low soil zinc levels. In zinc sensitive crops such as corn or bean, zinc deficiency has been induced by high phosphate levels, particularly from banded phosphate applications. In sensitive crops, application of zinc with a row-banded starter P application will help alleviate any induced Zn deficiency. High soil phosphate levels are not necessarily related to zinc deficiency, however. In many fields, high P levels are present because of livestock and human activity in the past. Areas high in P because of manuring are also high in soil zinc and are unlikely locations for the expression of zinc deficiency symptoms.

Zinc is involved in photosynthesis, as well as being a part of many enzymes. Zinc deficiency produces leaf abnormalities, yellow interveinal chlorosis and lack of vining in bean (Figure 28). Zinc deficiency in corn is seen as yellow to white striping between the midrib and leaf edges. Seed and flower abortion can be observed in bean, pea and flax. Zinc deficient flax also exhibits symptoms called chlorotic dieback, where the growing point of the flax dies and shoots form in buds lower on the stem, causing increased branching. Zinc deficiency can also cause maturity timing differences in dry edible bean, which contributes to quality problems at harvest. Dry beans are stunted and do not vine properly, and early in the season leaves may turn yellow, brown and necrotic.

Deficiencies can be verified with soil and plant analysis. Handling of soil samples, however, can influence the apparent availability of Zn and other micronutrients. Most micronutrient analysis is calibrated to a dry soil sample. Samples tested before adequate drying may exhibit different levels than if they had been analyzed after drying. Spraying a small area with suspected Zn deficiency with a dilute Zn fertilizer and observing the results can also be a diagnostic tool.

Zinc availability in soils is highly dependent on soil pH. Zinc is 100 times more available in a pH of 6 than in pH 7. When chelated Zn applications are used, the benefits last for only one growing season. When mineral forms such as zinc sulfate are applied, rates are usually high enough that if pH levels are less than 7, soil test levels of Zn will remain high for several years. However, if soil pH levels exceed 7,

Figure 28. Zinc deficiency on dry bean. Deficiency is characterized by stunted plants with yellowing in leaf tissues, which become whitened and develop necrotic areas in the leaf. Vining is greatly reduced.

soil Zn levels will quickly decrease after the application season, so that in two to three years soil Zn levels will again be low. Therefore, in high pH soils, treating sensitive crops annually is a better plan than trying to achieve soil buildup with large multi-year applications.

Copper

Copper is available to plants as the Cu^{2+} ion. Plant copper uptake can be reduced and deficiencies intensified with excessive nitrogen fertilization and high phosphorus fertilization in wheat. Crops that respond to copper in Alberta are grown on soils that are very high in organic matter (>8%), while copper responding sites in Minnesota are peat derived. Responses to copper fertilizer in spring wheat were observed on heavy clay soils high in organic matter in North Dakota in the past. Organic matter holds copper strongly and availability is reduced.

Several enzymes include copper in their structure. Copper is also a part of several compounds important in photosynthesis. Deficiency symptoms include deformed tops in the younger plant tissue of broadleaf plants. Flowering is reduced and ovules are often aborted. Deficiency in wheat results as necrosis of leaf tips prior to anthesis and head development. An expression of deficiency in wheat is also a condition known as "false blackchaff," which appears as a blackening of the glumes in ripening wheat. It may be mistaken for the disease blackchaff, but false blackchaff is not bacterially induced as is the disease. Deficiencies can be verified with soil and plant analysis, but the line between deficiency and sufficiency is very fine. Some Canadian research has also established a link between ergot and low copper availability.

Recently, copper responses in mineral soils have been observed on wheat and barley in Canada and North Dakota. Responsive sites are low organic matter, sandy soils. Responses have been most striking in Alberta, where large areas of low organic matter, sandy soils are found. Large yield increases and decreases in ergot disease have been documented. More recently, similar yield increases have been seen in North Dakota in similar soils, however, the results have not been as consistent as those from Canada. Of 26 sites studied, only three positive yield responses were seen. Most of these sites had soils where a response was expected because of the low organic matter, sandy texture and relatively low soil Cu levels, but only a small number of modest yield increases were documented. Several decreases in the incidence and severity of head scab (Fusarium) were observed, but none were great enough to substitute for a fungicide application. Copper may increase yields but it should be applied only to low organic matter, sandy soils. The use of Cu on these soils would be expected to increase yields only occasionally.

Figure 29. Copper deficiency in spring wheat.

Molybdenum

Molybdenum is absorbed as the molybdate ($HMoO_4^-$) ion. Unlike other plant nutrients, the availability of molybdenum increases with pH. Molybdenum is essential for the enzyme nitrate reductase, which reduces nitrate to ammonium ions in the plant. Without this enzyme function, nitrates would be worthless as a nitrogen source to plants. Molybdenum is also required by the enzyme nitrogenase in legume nodules, which is necessary for biological nitrogen fixation. Deficiency of molybdenum is similar to nitrogen deficiency, with interveinal chlorosis of older leaves; however, the leaf margins rapidly turn brown and become necrotic as nitrate accumulates. Deficiency also causes whiptail in sugarbeet. Deficiencies can be verified by planting seed treated with a sodium molybdate material in a test strip. There is no evidence that molybdenum deficiency is a problem in North Dakota.

Chloride

Chloride is absorbed by plants as the ionic form of chlorine (Cl^-). High soil nitrate and sulfate levels can depress chloride uptake by plants. Chloride is used by plants as a counter ion to balance charge and to help maintain plant turgor, or rigidity of cell membranes, helping to keep out unwanted compounds and disease organisms. Chloride is also essential for photosynthesis. Several small grain diseases are encouraged by low chloride levels. Chloride deficiency causes irregular yellow to necrotic spotting of small grain leaf tissues. The need for chloride is determined by a soil test. Over-application of chloride can cause toxicity in bean and potato. Chloride toxicity in North Dakota is most often caused by natural accumulations associated with soil salinity rather than fertilizer potash application, although heavy applications of KCl can contribute to the problem. North Dakota recommendations for chloride application on small grains is based on extensive work in South Dakota, North Dakota and Montana during the last 20 years. A summary of South Dakota work is shown in Table 8. Generally, yield increases are likely at soil test levels below about 40 lb/acre 2 feet. Current recommendations are based on those findings.

Table 8. The degree of crop response from spring wheat due to soil test chloride (Cl^-) levels. South Dakota summary 1982-86.

Soil Test Category	Soil Cl^- Content	Yield Response Frequency	– Average Response – Responsive Sites Only	Across All sites
	lbs/a 2 ft.	%	bu/a	
Low	0-30	69	5.0	4.0
Medium	31-60	31	6.3	2.6
High	>60	0	—	0.3

Fertilizers Commonly Used in North Dakota

Fertilizers contain plant nutrients in a form that is readily taken up by plants. Not all materials containing plant nutrient elements are good fertilizers. Some materials have characteristics such as low solubility which make them unsuitable as a fertilizer. Fertilizers are not "magic." They can positively influence plant growth and development by supplying the nutrients needed for plants that are not provided for by soil supplies. If the soil is already supplying these nutrients, application of fertilizers may not make a positive impact on yield. They may even reduce crop yield and quality if over-applied. The fertilizers discussed in this handbook have been studied and used commercially for decades. Used properly, they will be effective in replenishing the soil of essential plant nutrients and help sustain crop production indefinitely. A list of the most commonly used fertilizers in the state and the tonnage sold within the state between 1995 and 1999 is shown in Table 9. The density of certain fertilizers is shown in Table 10. Some fertilizer materials may be more convenient to apply than others, and some may be less likely to produce environmental contamination by the fertilizer or its biologically produced byproducts. Abuse and over-application can be made not only with commercial fertilizers but with manures and green manures if application practices are mismanaged.

Table 9. Tonnage of fertilizer sold in North Dakota, 1995-1999.

	Year				
Fertilizer	**1995**	**1996**	**1997**	**1998**	**1999**
	Tons				
NH_3-anhydrous	350,240	492,753	418,112	366,967	345,664
Urea	294,561	254,014	310,508	319,124	348,453
34-0-0	11,311	12,049	9,105	1,901	1,920
Total N, all grades	501,971	607,065	570,346	531,773	516,434
P_2O_5 all grades	184,159	205,174	211,661	201,273	173,624
90% sulfur	1,288	2,920	3,411	3,400	2,782
21-0-0-24S	7,109	10,419	14,393	24,971	31,291
Total S- all grades	3,404	5,232	7,733	8,028	9,249
K_2O- all grades	42,798	33,611	32,600	34,147	27,429

Table 10. Density of common fertilizers.

Liquid fertilizers	**Analysis**	**Density, lb/gal**
Anhydrous ammonia	82-0-0	5.2 (50°F)
28-0-0, UAN	28-0-0	10.66 (70°F)
10-34-0	10-34-0	11.4 (70°F)
Dry fertilizers	**Analysis**	**Density, lb/cubic foot**
Ammonium nitrate	33-0-0	62
Ammonium sulfate	21-0-0-24S	64
Urea	46-0-0	45
Potash, KCl	0-0-60	65
MAP	11-52-0	55
DAP	18-46-0	55

Note: Density will vary due to manufacturer and handling techniques. Dealers and farmers should use a density scale.

Nitrogen Fertilizers

Anhydrous ammonia

Anhydrous ammonia is the most commonly used fertilizer in North Dakota (Table 9). It is normally the least expensive nitrogen source for producers, even though it has the highest related costs associated with its use at the retail dealer level. Anhydrous ammonia is manufactured using a modification of the Haber-Bosch process developed in Germany at the beginning of the 20th Century. This development, which contributes to over one-half of the N used in crop uptake in the world, is considered by some to be one of the great scientific and engineering achievements in history. It is a process in which natural gas is the main ingredient. The following is an extremely simplified flow chart of the process:

Natural gas + N_2 (from air) + H_2O (under pressure as steam) with a catalyst = $NH_3 + CO_2$

Figure 30. Anhydrous ammonia is colorless and boils at -28°F.

It takes 33.5 million metric BTUs of natural gas to make one ton of NH_3.

The guaranteed analysis is 82-0-0, meaning 82% N. Anhydrous means "without water," and anhydrous ammonia is a relatively pure product. The chemical formula is NH_3. Ammonia is a gas at room temperature, since the boiling temperature is -28°F (Figure 30). Ammonia storage tanks at major terminals are refrigerated to keep the product below its boiling temperature. These tanks do not develop appreciable pressures, generally less than 1 pound per square inch (psi). At retail fertilizer dealers, however, the ammonia is not refrigerated, and the storage tanks are built to withstand pressures higher than 250 psi. At a temperature of 90°F, the tank pressure would be approximately 170 psi.

Ammonia use carries possible health risks which include eye damage, skin burns, and lung tissue damage if these organs are exposed to high concentrations of gas or liquid. The pressurized condition of the ammonia can result in serious exposures because of the rapid dispersion of gas when it is suddenly released from its pressurized condition. One gallon of liquid ammonia expands rapidly to 860 gallons upon release to atmospheric pressure at room temperature. Safety precautions during handling include wearing unvented goggles, rubber gloves, and a long sleeve shirt. There should also be a 5 gallon container of water on the ammonia nurse tank. Immediately flooding the afflicted area with water is the best first aid when treating for ammonia exposure. Inhalation of ammonia vapors is best treated by moving out of the ammonia cloud. Always work upwind of ammonia to decrease the risk of injury.

Ammonia applied to soil will evaporate if placed at the soil surface. However, ammonia is very attracted to water, so if some soil covers the ammonia, the ammonia will be temporarily trapped in the soil water, forming a solution similar to household ammonia cleaners. The reaction is as follows:

$$NH_3 + H_2O \rightarrow NH_3{\bullet}H_2O \rightarrow NH_4^+ + OH^-$$

The reaction of ammonia with water can take up to 24 hours to complete, although most of the ammonia is converted to ammonium ions within a few hours after application. Application of ammonia to high pH soils will result in a small portion of ammonia converting to free ammonia in the soil solution. In warm weather, this portion is greater than 5% of the total ammonia. In colder weather, less than 1% is present as free ammonia. Following the first reaction, a second reaction is needed to thoroughly trap and immobilize the ammonium (NH_4^+) ions in an available but stable form. The NH_4^+ ions need to adsorb onto clay and organic matter surfaces through a cation exchange reaction, as illustrated in the following example:

$$NH^+_{4\,(soluble)} + K^+\ clay \rightarrow K^+_{(soluble)} + NH_4^+\ clay$$

Once the cation exchange reaction takes place, NH_4^+ is very resistant to movement. Ammonium ions may be somewhat mobile in light-colored sandy loams or coarser soils. In sandy soils, the ability to hold cations is low (low CEC). Although some retention of NH_4^+ is likely, water movement through a sandy soil will move NH_4^+. Ammonia loss to the atmosphere after anhydrous ammonia application is one of the most common ways that fertilizer N is lost from the soil. Inadequate coverage, cloddy soil, wet soil and high exit pressures all contribute to the problem.

Nitrates are a major component of some fertilizers. However, most nitrates in soils are produced by soil bacteria (*Nitrosomonas* spp. and others) under aerobic, moist and warm conditions. These bacteria use NH_4^+ as a food source, much as humans use carbohydrates. The NH_4^+ is oxidized by the bacteria to nitrite (NO_2^-) and then oxidized by another bacteria (*Nitrobacter* spp. and others) to form nitrate (NO_3^-). During the winter, the activity of nitrifying bacteria is near zero. As the soil warms, their activity increases. In warm soils, ammonium (NH_4^+) can convert to nitrate nearly completely in two weeks. The transformations of nitrogen-containing compounds by soil bacteria are universal for all sources of NH_4^+- nitrogen in soils, both organic and inorganic in origin.

Nitrification inhibitors such as nitrapyrin can be added to ammonia and other nitrogen fertilizers before or during application to reduce the population of nitrifying bacteria in the immediately surrounding soil. These products are used extensively in warmer and wetter areas of the country to prolong the duration of the ammonium form of nitrogen in ammonium-based fertilizers. The nitrification inhibitors are particularly useful where rainfall is anticipated during the early spring and summer months that may move water and nitrates out of the rooting zone. In North Dakota, nitrification inhibitors are seldom used but might be of benefit when nitrogen fertilizers are applied in the fall to coarser textured soils or soils that are susceptible to ponding early in the spring.

Nitrate is a health concern to human infants when it is present at high concentrations in drinking water. High nitrate levels cause a condition known as methemoglobinemia, or "blue baby syndrome." High levels of nitrates are also contained in some green leafy vegetables, like celery or iceberg lettuce, but are not considered as great a problem for infants because they do not ingest large quantities of these foods. Cases of methemo-globinemia are rarely seen at nitrate-N concentrations less than 40 ppm in water, but a safety factor has been built into the current designation of nitrate-N concentrations of over 10 ppm as a health hazard to infants. Livestock health has also been adversely affected by concentrations of nitrates exceeding 40 ppm. It is therefore desirable to manage all nitrogen inputs to minimize movement of nitrates outside of the rooting zone.

Ammonia is applied using an applicator of similar construction to that shown in Figure 31. The most important components of an ammonia applicator are the metering device, the manifold, and the tool which directs ammonia into the soil. The meter can be a ground-driven meter, a variable orifice meter, or an electronic controller following a cold-flow chamber. Ground-drive meters are sometimes used, and farmers willing to maintain them have had good experiences with their use. Variable rate orifices are most common. They work similar to an ordinary gate valve in principle. Higher rates are achieved by increasing the diameter of flow through the meter, and lower rates achieved by restricting flow. Rates are adjusted manually. The electric controller is increasing in popularity because of its greater precision and ability to more evenly apply ammonia at different temperatures. It allows the operator to adjust flow rates on-the-go.

Figure 31. Anhydrous ammonia applicator. A tractor will pull the applicator with hitch at right. Black hoses are for hydraulic control of wings and shutoff mechanism. The applicator is attached to a nurse tank at the rear (left). Ammonia from the nurse tank enters the applicator, goes through the meter (center) and exits a manifold through small white hoses to outlets at the back of each knife.

The electric controller consists of a cold-flow chamber, followed by a flow control valve very similar to those used in electronic controls for liquid chemical applications, and finally a flow control sensor. The success of the electronic controller lies in using cold-flow principles to reduce ammonia vapors in the application stream to very low levels. Control sensors have a problem with bubbles in solution. By rapidly cooling the ammonia in a cold-flow expansion chamber, most ammonia coming out of the chamber is liquid and can be accurately measured (Figure 32).

Ammonia is injected into the soil as a mixture of both liquid and vapor. In a heavy clay soil, the zone of influence of the ammonia has a radius of about 2 inches surrounding the band, with a larger radius if the soil contains cracks or the ammonia has higher exit pressures. In a sandy soil, the zone of influence may reach a radius of 3 inches around the band. Ammonia is applied to crops before planting or as a side-dress application in row-crops. If applied before planting, a delay of one week following ammonia application will usually prevent free ammonia from reaching the seed and reducing germination. Delay is particularly

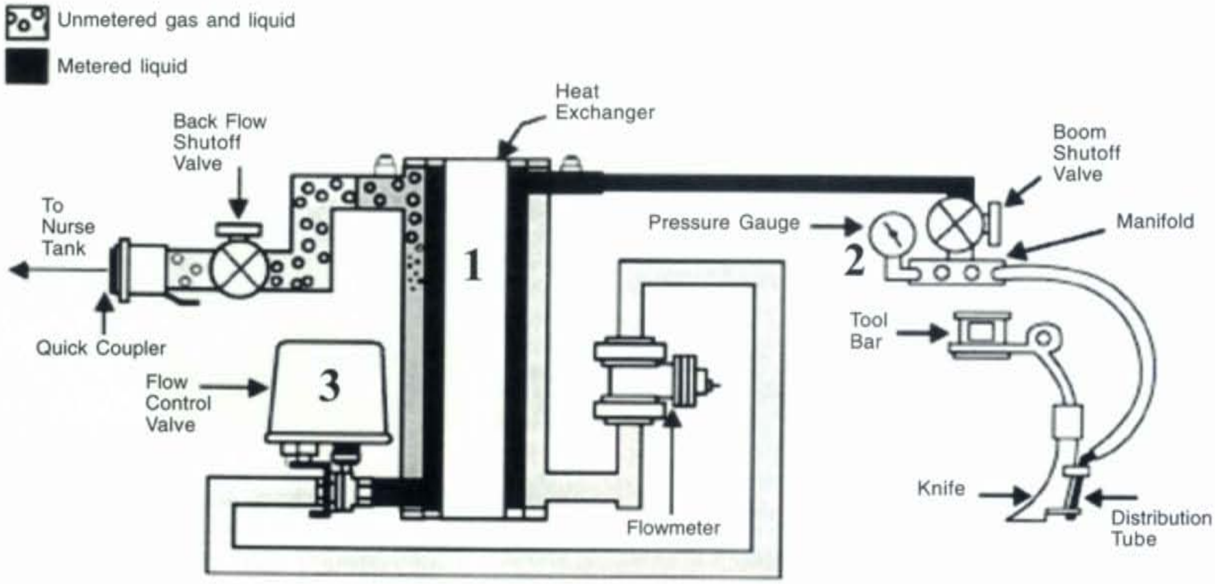


Figure 32. An electric controlled ammonia regulator. The main components are a cold-flo chamber (1), flow regulator (2) and tractor monitoring and adjusting console (3).
(Permission to use drawing provided by University of Nebraska and Dickey-John Corp.)

important for row crops. Many producers decide not to wait, but reduce the risk of serious seed emergence problems in a single row by applying ammonia at an angle to the row. Germination is sometimes reduced where the ammonia band and planter row intersect, but the damage is spread between several rows instead of ruining one continuous row. Another common practice to reduce germination loss is to increase the depth of application to 6-8 inches instead of 3-4 inches. By applying ammonia at a greater depth, more soil is likely to cover the trench between the point of ammonia discharge and the seed. Deeper ammonia application also reduces the risk of losses to the atmosphere.

A recent innovation in ammonia application is the combination of metering of ammonia through a flow system and then generating high pressure with a piston pump. The high pressure ammonia then moves through high pressure hoses to deliver ammonia in a straight stream into the soil. Early work in Canada appears positive. The use of this system may allow closer application to the seed than is possible with systems today. Further work is needed to see if this is the case and to determine where the ammonia is placed under a variety of soil and residue conditions.

Ammonia is sometimes applied to small grains at seeding, but ammonia should not be applied with the seed. Ammonia should not be applied directly under the seed, unless the application tool effectively seals off the ammonia band from the seed above. A minimum safe lateral distance from the seed is 2 inches in heavy soils and 3 inches in sands. However, cloddy soils can result in more movement, so soil conditions must be considered during application. Ammonia moves more in very dry soils than in moist soils. Ammonia also moves upward rapidly in wet soils where the application tool makes a slit in the mud rather than forming a normal temporary trench that fills in quickly as the applicator moves through the field. Ammonia should not be placed directly under the seed, since the ammonia will follow the knife track upward if it can.

Ammonia can be applied in the fall when temperatures reach 50°F or lower and the calendar date is after September 25 in the north and October 1 in the south. Soil nitrifying bacteria are less active at lower temperatures, and little nitrate is produced from ammonium N after early morning soil temperatures at the 4 inch depth reach 50°F. Therefore, in most soils except those which are saturated in the spring, or have sandy loam or coarser soils, fall ammonia application is a good management option in North Dakota.

Ammonia applications must be made beneath the soil surface. Most often, the application point is a welded or bolted tube at the rear of a special knife shank or chisel plow shank (Figure 33). Ammonia should be placed between 4 and 6 inches deep for small grains, and no deeper than 10 inches for row crops. Ammonia applied too close to the surface, less than 3 inches, can sometimes be less effective than deeper placed ammonia. The high release pressure causes a percentage of N to escape to the atmosphere immediately. Some farmers feel the necessity of shallow NH_3 in order to apply fertilizer and seed in one

Figure 33.
Ammonia applicator knife (left), shallow NH_3 placement tool (right).

pass. An efficiency factor decrease of 10% should be considered when NH_3 is applied at 3 inches or less deep. A 100 lb/a N rate applied at 3 inches deep or less should be considered only as effective as 90 lb/a N placed 4 to 5 inches deep.

Some growers try to reduce shallow application losses by using wider than normal diameter tubes on the distribution manifold of the ammonia applicator to decrease release pressure into the soil. This arrangement, which is called "poor man's cold-flow" by some, lowers the exit pressures of ammonia from the tool outlet into the soil. However, because of the added turbulence inside the larger hoses, application of N may not be as even as with standard hose diameters. Poor man's cold-flow also gives the applicator a false sense of security against slow losses which are possible if the soil application allows the ammonia an avenue of escape. In shallow soil applications, particularly in wet or cloddy soil conditions, ammonia can volatilize slowly out of the soil through the open trench and losses can be significant. Losses are possible for several days if ammonia is in contact with the air, until ammonium ions are retained by the soil exchange complex at clay and organic matter surfaces. An efficiency penalty of 10% should be considered regardless of the release pressure of the shallow ammonia application.

Shallow placed ammonia can sometimes become positionally unavailable. A dry period can prevent N uptake from the dry soil surface layers. In dry years, deeper placed N will be in contact with moist soil longer, making it more available to plant roots.

Side-dressed nitrogen is a good option for row crops, particularly in sandy or irrigated soils (Figure 34). Side-dressing allows more time for the producer to fine-tune yield goals. Ammonia can be applied to row crops until the height of the crop physically limits application. The applicator is usually set up with knives between each row, or every other row. Either knife spacing will work well, although every other row requires an alert applicator who watches for signs that a tube is plugged. In the every row arrangement, a plugged tube means that two rows receive one half the N application. One disadvantage of the every other row arrangement is the possibility of a plugged tube, which denies N to two rows, creating N deficient streaks across the field. For all sidedress applications in wetter soils, covering paddles, discs or harrows are used to cover the slit made by the ammonia knife or shank. In sidedress applications, free ammonia escaping from a badly sealed application can burn leaves.

Does "ammonia make the soil hard"? Studies have shown that long-term use of ammonia has no adverse effects on soil microbial activity. Initially, high concentrations of ammonia are toxic to microbes in an area about two inches in radius from the center of application. Within two weeks, however, microbial activity is higher in the band of high ammonia than before application. Ammonia does not have any adverse effects on soil structural properties (Table 11). A twenty year Kansas study showed no adverse effects on compaction or structure. A ten year Iowa study also showed no ill effects. Some producers who see a difference in a field may be attributing structural problems following ammonia application to the ammonia fertilizer. However, it is more likely that soil conditions and the timing of field trips is causing the differences they see. The tillage associated with ammonia application in soils that are moist in the spring can cause soil compaction problems. Delaying the application a day or two, combining trips or applying ammonia in the fall are strategies that can improve soil structure.

Figure 34. A sidedress N application to sunflower *(courtesy of Don Lilleboe).*

Table 11. Summary of two studies testing the long-term effect of anhydrous ammonia on bulk density of the soil.

Study Location and Time Duration	Treatment	Bulk Density
		g/cm³
Iowa State, 10 years	Ammonia	1.34
	No N	1.31
Kansas State, 20 years	Ammonia	1.45
	No N	1.50
		No significant differences

Figure 35. Spinner assembly on the rear of a dry fertilizer applicator. The power take-off (PTO) turns the fans, while a ground drive wheel turns the chain which moves fertilizer to the rear of the fertilizer bed. Application rate is adjusted with the gate opening.

Urea

Urea is a white, granular fertilizer which is the second most common nitrogen fertilizer in North Dakota. The analysis is about 46-0-0. Urea can be broadcast applied or banded. It is sometimes used as a top-dress application. Urea is a very popular fertilizer, but it requires more management ability to mix, store, and apply than dry phosphate or potash. Because of its low density, broadcast application using a spinner applicator of a fertilizer blend containing urea may tend to streak the urea fertilizer (Figure 35). Urea is not thrown from the applicator as far as denser fertilizer granules in the blend, causing urea to concentrate in a narrower pattern behind the applicator. Blends using urea should be double-spread when applied with a spinner spreader. Boom-type dry fertilizer applicators do not need double spreading (Figure 36).

Urea is hygroscopic, meaning it attracts water. It is therefore important to store urea on a floor that does not sweat or leak. Store inside where humidity levels are kept as low as possible. Some dry fertilizer storage facilities line urea bins with plastic sheets before filling to reduce sweating,

Figure 36. Pneumatic-boom style dry fertilizer applicator.

but this is usually not necessary if the floors, walls and ceilings are of good construction and the facility is kept clean. Keeping a storage location clean of fertilizer dust helps keep building humidity levels low.

Urea cannot be mixed with certain dry fertilizer products due to compatibility problems. The two fertilizer products which cause the greatest problems are ammonium nitrate (33-0-0) and triple super phosphate (0-46-0, or 0-44-0). Mixing urea with either of these two fertilizers can cause the material to become wet and impossible to spread correctly. If urea is impregnated with a liquid ag-chemical, it is important to check compatibility with a small amount first. Liquid ag-chemicals used at rates above 1 qt/acre sometimes can turn a normally stable urea mix into a semi-liquid. Since urea absorbs little of the impregnated liquid chemical, dry chemical granules are often a better choice for impregnating urea blends.

Urea is commonly band applied at planting, but rates should be restricted because urea is very toxic to the seed. In small grains, no more than 20 lb N/acre as urea should be applied next to the seed with a double-disc drill and 6-inch row spacings. In corn, no urea should be applied with the seed, or severe stand reduction may occur. Air-seeders, which spread the seed and fertilizer over wider areas than normal drilling, reduce the risk of urea phytotoxicity somewhat. However, urea application in a 4-inch seed spread band can still reduce stand and delay maturity when compared to seed and fertilizer separation at rates of urea higher than 20 lb N/acre on sandy soils. Urea applied at 80 lb N/acre in a 12" row spacing with the seed reduced stand by 30% in a North Dakota study. Many splitters on the market allow seed to be placed on either side of a central fertilizer band. Banding is discussed in more detail in a special section of this bulletin.

Once applied to the soil, urea ($CO(NH_2)_2$) goes through two transformations. The first is a hydrolysis to ammonia gas and carbon dioxide gas, activated by the soil enzyme urease.

$$CO(NH_2)_2 + H_2O \overset{\text{Urease}}{\leftrightarrow} CO_2 + 2NH_3$$

Moist soil conditions, warmer temperatures, and application onto crop residues all increase urease activity and the rate of urea breakdown. Urease is still active at temperatures as low as 35°F. Urease originates in living microbial tissue but is active on urea long after the organisms death. Urease is found in nearly all soils and the volatile ammonia produced by urea hydrolysis needs to be considered when managing urea.

Ammonia released from the breakdown of surface-applied urea is susceptible to volatilization losses. Released ammonia can be lost more readily if water is evaporating from the soil. Evaporation can carry the ammonia away similar to a distillation process. High pH can increase volatility losses, but solubility of free ammonia in water and resulting ammonia volatility is reduced when temperatures are cold.

Urea is best managed by covering with soil soon after application. This can be accomplished with an incorporation following broadcast application by knifing the product in with an air-seeder or by subsurface banding with a planter at seeding. Incorporation should be completed within two days on fields with surface residue and within four days on fields that are mostly free of surface residue when weather is hot or windy or if soils are moist. When temperatures are cool, the soil is dry and the wind is calm, urea may be stable as long as a week. There have been reports of ammonia loss as high as 50% in North Dakota when applied to moist soils covered with stubble, followed by a prolonged dry period. One-quarter to ½ inch of precipitation within 48-72 hours is sufficient to incorporate urea, with ¼ inch needed under low residue and ½" under high residue soil surface conditions. Urea can be applied in the fall after mid-October when early morning soil temperatures at 4 inches drop to 50°F or lower and if the urea is incorporated in some way. Fall application is best delayed for at least two weeks following the start of the fall ammonia application season. Anhydrous ammonia has immediate nitrification inhibitor characteristics that urea does not. A rule of thumb would be to delay banded urea applications one week after the start of fall ammonia application, and delay at least two weeks for broadcast applications of urea. Fall application is not advised for sandy soils or soils that may be ponded in the spring.

Urea can be used as an emergency fertilizer to increase yields on crops too tall to apply fertilizer with any other method. Urea can be aerially applied until anthesis in small grains or tasseling in corn. Best results are obtained when precipitation is received within two to three days following application, or the area is irrigated to move the fertilizer into the soil. When temperatures are cool and winds light, urea is stable for a longer time before rain. Application should be made to dry plant tissue to minimize burn, although some burn is still likely in corn where urea enters the whorl. There is less potential for burning with lower rates on corn. Volatilization losses may also be high if there is no precipitation for over a week. Urea applied by air to growing crops to improve yield should be considered a last resort, and the producer needs to understand the potential for burn and the possibility of low nitrogen use efficiency due to a late surface application.

Urease inhibitors

Because of the danger of ammonia volatilization when the urease enzyme breaks down urea at the soil surface, several compounds have been developed which inhibit urease activity to some degree. The compounds most commonly used are phenyl phosphorodiamidate (PPD) and N-(n-butyl) thiophosphoric triamide (NBPT). These compounds can lengthen the time needed between application and a rainfall but add cost to a fertility program. Farm producers most often elect to change application technique or timing instead of using a urease inhibitor for a broadcast application.

A commercial product, Agrotain® (NBPT), has been tested and proven effective in preventing urea volatilization for up to two weeks following application. The liquid product is impregnated (sprayed into the mixing drum while blending) and the NBPT coated urea is then applied.

Ammonium nitrate

Ammonium nitrate use is decreasing in North Dakota as urea becomes more popular. Ammonium nitrate is a dry, white granular fertilizer. It is a strong oxidizing agent and can be used in explosives. It should not be mixed with any organic material or finely divided metal powder. When shipped, it requires placarding as an oxidizer. Fertilizer grade ammonium nitrate is generally not hazardous as an explosive by itself. It requires some technical knowledge to make an explosive out of ammonium nitrate. There are different grades of ammonium nitrate. The grade most commonly used to make explosives requires the buyer to be registered with the Bureau of Alcohol, Tobacco and Firearms and is not available from local fertilizer retail outlets.

The guaranteed analysis of ammonium nitrate fertilizer is approximately 34-0-0. The chemical formula is NH_4NO_3. Ammonium nitrate should not be applied in the fall because there is a chance of leaching the nitrate component from the rooting zone. Ammonium nitrate is hygroscopic and needs to be stored in a location with low humidity. Ammonium nitrate should not be mixed with urea because of compatibility problems.

Ammonium nitrate can be broadcast spread, knifed in with an air-seeder or banded with a planter. The same dangers of streaking during broadcast application exist with ammonium nitrate as with urea because of density differences with other dry blend ingredients, therefore double spreading is recommended when spinner spreaders are used.

Ammonium nitrate has a greater salt index than urea, but it does not release free ammonia to the same degree as urea. As much as 30 lbs/a of total nitrogen plus actual potash can be applied with small grain seed when ammonium nitrate is used. If soils are very dry, the 30 lb/a rate with the seed should be reduced. Higher rates of N as ammonium nitrate are safe to apply when seed and fertilizer are spread out with an air seeder (Tables 16-18). Ammonium nitrate does not lose ammonia to the air when spread on the soil, so it is preferred over urea by some no-till and pasture producers.

Ammonium sulfate

Ammonium sulfate is a light brown, gray to white dry granular fertilizer that is becoming increasingly popular in North Dakota. The chemical formula is $(NH_4)_2SO_4$. The guaranteed analysis is 21-0-0-24 with 21% N and 24% sulfur (S). Ammonium sulfate is less hygroscopic than ammonium nitrate or urea. Dry storage is important, but caking is not as common as other dry nitrogen fertilizers. Most commercially available ammonium sulfate is an angular and crystalline granule. It is not commonly a smooth, round granule, although new production facilities in North Dakota market such a granule.

Ammonium sulfate can be applied as a broadcast or banded application to most crops. Similar restrictions to placement should be followed when placing ammonium sulfate close to the seed as are followed with ammonium nitrate. Ammonium sulfate is a good top-dress choice for winter wheat since the nitrogen is all in the ammonium form. Volatilization from ammonium sulfate is lower than from urea. Some volatility has been shown when ammonium sulfate is applied to calcareous soils under warm, moist soil conditions, however the rate is slow compared to ammonia volatilization from urea.

UAN (urea/ammonium nitrate solutions, 28%)

The most common nitrogen solution used in North Dakota is urea-ammonium nitrate (UAN), with the guaranteed analysis generally of 28-0-0, or 28%. It is a non-pressure nitrogen solution with approximately half of the nitrogen as urea and the other half as ammonium nitrate. It may also contain a very small percentage of free ammonia. UAN can be stored at very low temperatures without "salting out," which is a term for crystallizing when a solution contains more dissolved material (solute) than it can hold at a given temperature. The colder a solution is, the less solute the solution can hold. Also, the greater the amount of solute in solution, the lower the freezing temperature. For urea/ammonium nitrate solutions, the ideal mix is a 28% solution, because it has the lowest freezing temperature and salting out temperature of any of the mix possibilities.

UAN is a clear solution, but it is sometimes dyed yellow or green by the manufacturer. It can be broadcast applied and incorporated in the spring, or side-dressed with a knife-type applicator in row crops. There is sometimes an ammonia odor, which reflects the small amount of ammonia in the solution. Incorporation within two to three days after application is needed to minimize nitrogen volatilization.

UAN is also an effective fertilizer for pasture or no-till fields when it is dribbled instead of sprayed on the soil surface. Dribbling UAN on 12 inch centers is effective for pastures, and generates less ammonia volatilization loss than broadcast urea. This method would also serve as an alternative method of delivery on newly seeded small grains.

In row crops, an application of 28% is sometimes used to supply N late in the season, or if early N application was not possible. To do this successfully requires a high-clearance sprayer with drop nozzles between each row. Each nozzle fitting must contain an orifice designed to apply a straight stream of 28% at a reasonably low pressure to prevent excessive splashing. The fertilizer material should then be incorporated with a rain within two to three days of application to prevent volatilization losses and promote availability of the added N to the plant roots. Some leaf burning may occur, but not as much as a broadcast application. Late 28% application is not a preferred method, but it is a way to provide nitrogen for crops where wet weather earlier in the season has prevented other more preferred methods of N application. Diluting the 28% solution by 50% with water will normally decrease the burn potential of a broadcast application.

It is best to apply nitrogen fertilizers to spring wheat at or before seeding. If this is not accomplished, then top-dressing after emergence until the five leaf stage is possible. If a 28% solution is used, it should be applied to wet foliage during cool weather. Dilution with water also reduces burning. Rates of 28% higher than 30 lbs N/a may severely burn emerged small grains. If rates greater than 30 lbs N/a are required, consider applying the 28% with a straight stream orifice about 14" apart at right angles to planting direction. Some leaf burning is probable where the solution contacts green tissue.

In some situations, protein content of wheat has been increased when up to 10 gallons per acre of 28% are applied following anthesis at the watery ripe stage of growth. Application during cool, damp weather will reduce leaf burn. Leaf burn can be serious under some conditions.

Aqua ammonia and low pressure nitrogen solutions

Aqua ammonia used to be more common than it is today. Low pressure nitrogen solutions all contain an ammonia component. Low pressure nitrogen solutions may contain dissolved ammonia only, or a combination of ammonia and other soluble nitrogen products. The advantage of the ammonia solutions is often the cost of raw materials in years where ammonia is much cheaper per pound of N than urea or other N sources. A high pressure aqua ammonia solution is only able to concentrate about 20% N; however, when mixed with urea or ammonium nitrate, the percentage of N may increase to about 50%. Pricing is nearly always between anhydrous ammonia and true solutions.

Safety is still a concern in any type of pressure solution, because the ammonia vapor from a pressure solution can cause the same injuries as from anhydrous ammonia. Tanks used for storage and transport must be sealed and contain some pressure. Caution should be used when handling the products. Low pressure nitrogen solutions are soil-applied products and are injected into soil in the same manner as anhydrous ammonia. They are rarely sprayed on the surface because of ammonia volatilization losses, but are knifed into the ground as a preplant or sidedress application. Pressure solutions should not be applied as a foliar treatment.

Other less common nitrogen fertilizers

There are many other forms of nitrogen fertilizers, including solution fertilizers, "natural products" and manures. The same principles stated for the previous fertilizers also govern the behavior of other fertilizers in soils. To learn how to manage these other nitrogen sources, determine the ingredients of the fertilizer grade and use the basic management rules for each fertilizer to direct application methods and timing.

Manures

Manures should not be handled as a waste but as a precious resource. Manures contain not only plant nutrients, but organic materials able to build organic matter quickly and also biological components that are not present in commercial fertilizers. If manure is relatively weed-free, or weed control is not a problem, fresh manure has the greatest plant nutrient benefits, especially N content (Table 12).

Table 12. **General nutrient analysis of liquid and solid manures.**
(Livestock waste facilities handbook, Midwest Plan Service, 1995.)

Form	Source	Bedding/Storage	Dry Matter	N	P_2O_5	K_2O
			%	— lb/1000 gal.		—
Liquid	Swine	Anaerobic pit	4	36	27	22
	Dairy	Anaerobic pit	8	24	18	29
	Beef	Anaerobic pit	11	40	27	34
Solid	Swine	With bedding	18	8	7	7
	Dairy	With bedding	21	9	4	4
	Beef	With bedding/dirt	15	11	7	10
	Turkey	No bedding	29	20	16	13

Fresh manure should be applied to the field as evenly as possible using a manure spreader and incorporated within 12 hours. If incorporated after 12 hours, the free ammonia in the manure will be lost. Further breakdown and mineralization of organic N will result in further losses of ammonia in the following days (Table 13).

When manure is allowed to compost, N content is lowered as a substantial amount of N escapes from the activity of anaerobic bacteria and ammonia volatilization. Phophorus content increases. The resulting compost is more homogenous than fresh manure and can be sampled more efficiently. There are commercial laboratories in the region with the ability to analyze manures for nutrient content.

Green manures

Several crops can be used as a green manure. These crops are usually, but not always, legumes. Other crops, such as feed turnips, may accumulate relatively high levels of soil N if residual N levels are high enough, and with incorporation should release a high percentage of the N to the subsequent crop. In a sense, most broadleaf crops act as a green manure. N rich leaves from potatoes, sunflowers and sugarbeets are mineralized and subsequent crops benefit from their N contribution in the rotation.

True green manure crops are most likely grain and forage legumes. At a recent study at Carrington, legumes grown as a green manure ranged from 19 lb N/acre to over 100 lb N/acre gain that could be credited to subsequent crops (Table 14). Cereals such as rye serve to take up N as a "catch crop" to reduce leaching risks.

Table 13. Nitrogen availability estimates for use in a growing season following a broadcast manure application.

Source	Timing of Incorporation: <12 hours	12 hours-4 days	None
	—	% of total N applied	—
Beef	60	45	30
Dairy	60	40	20
Poultry	75	55	30
Swine	65	45	30

Table 14. Biomass and N yields from selected legumes terminated as green manures, Carrington, 1990-1991.

Legume	Biomass	Termination Date	Nitrogen gain estimate assuming the following was the result of biological fixation (bf): 40% from bf	70% from bf
	lb/a		lb/a	
Alfalfa	1796	8/3	19	33
Sweetclover	2901	8/8	33	58
Berseen clover	3284	8/5	34	59
Hairy vetch	4702	8/5	71	124
Black medic	1256	10/2	14	25
Black lentil	3744	7/28	40	69
Foxtail dalea	3652	8/27	42	74
Partridge pea	3059	9/7	33	58
Soybean	2514	8/14	26	46
Dry Bean	2895	7/29	27	48
Field Pea	3536	7/13	36	64
Faba bean	2582	7/13	36	64
Lupin	3416	7/26	43	76
Chickpea	3226	7/25	37	64

Phosphate Fertilizers

Commercial fertilizers that contain phosphate are derived from phosphate rock deposits mined in the southeastern United States or from deposits mined near the Idaho/Wyoming border. Phosphate rock was once ground to a fine powder and applied as a fertilizer in more acid soil areas of the world. Phosphate rock successfully increases yields on acid soils but is very inefficient on high pH soils such as are found in most of North Dakota. Phosphate fertilizers are produced by reaction with acids, with or without ammonia during the process.

Phosphate fertilizer manufacturing begins with the production of acids using either a dry process or a wet process. In the dry process, rock phosphate is treated in an electric furnace. Treatment in the electric furnace produces a pure and more expensive phosphoric acid than the wet process, called "white acid" phosphoric acid. This type of phosphate is used for houseplant fertilizers but is generally too expensive for production agriculture.

In the wet process, rock phosphate is treated with sulfuric acid to produce phosphoric acid. Wet process acid is called green or black acid, depending on the amount of impurities in the final product. Gypsum is also produced as a byproduct of the wet process. The impurities in wet process acid are not a problem for crop production. Both the wet and dry phosphoric acid processes produce orthophosphate ($H_2PO_4^{-1}$ or HPO_4^{-2}), which is the form of P taken up by plants. The analysis of white phosphoric acid is about 0-56-0, while the analysis of wet process phosphoric acid is approximately 0-54-0. White and green acids are sometimes used directly in the production of liquid clear starter grades, while green or black acid is sometimes used to manufacture suspension fertilizer grades, where color and clarity are not a concern.

Phosphoric acid produced by either process is often heat treated and concentrated to produce superphosphoric acid, with an analysis of about 0-72-0. The phosphate in superphophoric acid contains both ortho and poly phosphates. (Orthophosphates tend to form polyphosphates when water is driven off. Polyphosphates tend to form orthophosphates when water is introduced.) Adding ammonia to the superphosphoric acid produces an ammoniated phosphate known as 10-34-0 or ammonium polyphosphate (APP) liquid. When ammonia is added to white, green, or black acids, diammonium phosphate (DAP, 18-46-0) or monoammonium phosphate (MAP, 11-52-0 or 10-50-0) granules can be produced.

Ammonium phosphates such as MAP or DAP supply nitrogen along with phosphate without adding another blend ingredient. The ammoniated phosphates tend to acidify the soil zone adjacent to the phosphate band over time due to nitrification, which can increase phosphate availability in high pH soils. Ammonium phosphates also increase the radius of diffusion of the phosphate band and tend to be more soluble than calcium phosphates.

Phosphate fertility programs are based on one of two approaches, or a combination of each. The buildup and maintenance approach measures phosphate availability based on soil test levels and the amount of phosphate applied is calculated to replace the amount removed by the crop plus an additional amount to build up the soil if P soil test levels are less than optimum. In the sufficiency approach, fertility trials produce data on the response of crops to added fertilizer at different soil test levels. The results of the years of testing are charted and graphed to produce a recommendation based on soil test level and yield goal. The strength of the buildup and maintenance program is that it prevents mining of soil nutrients and produces a more fertile environment for the crops of the future. The main weaknesses of the buildup and maintenance approach are the expense and the low nutrient efficiency of the process. North Dakota uses a combination of buildup and maintenance and sufficiency. A buildup recommendation is given if soil test levels are low, but once a medium soil test level is reached, a sufficiency rate is recommended, somewhat lower than maintenance rates would be.

The sufficiency approach is less expensive, but if soil test levels are low and environmental conditions favorable for higher yields than expected, fertilizer applications may be insufficient to meet a higher yield goal. In the Red River Valley, where more crops are lost to excess water than to drought, more producers use the buildup and maintenance approach, but in the central and western areas of North Dakota the sufficiency approach is more common. Buildup and maintenance ensures against shortfalls when yield goals are underestimated, whereas the sufficiency approach prevents over-fertilization when yield goals are inflated.

Optimum soil phosphate levels are desirable but may not be economically practical. Application of 40 pounds of P_2O_5 per acre will raise the Olsen soil test level 1 ppm. This general rule is applicable for soils with pH of 7.0 or less. Soils with higher pH and high carbonate levels would require greater P to increase soil test levels. Acid soils may generally require less P to increase soil test levels. Application of P in a band application will provide sufficient P nutrition for North Dakota crops without a costly buildup program. Application of P fertilizer in a starter band has increased tillering and yields of small grains even with high soil P levels. Banding of phosphate also concentrates P in the soil and reduces the ability of soil minerals to react and form insoluble phosphate compounds following application.

Figure 37 shows that for corn, starter fertilizer increases yield regardless of the starting soil test P level. However, maximum yields are only reached when initial soil test P levels are at least in the medium range (11-15 ppm by the Olsen test). Despite higher starter P application levels at beginning soil test levels, the yield levels of medium and high soil P levels are not reached. For this reason, an effort should be made to increase P levels over time to medium soil test levels in order to achieve consistently high yields. Buildup is achieved by applying a little more P than normal for maintenance of soil levels. Buildup need not be an expensive, one-time P application. Application of 20 lb MAP/acre over and above maintenance levels will increase a soil from 5 ppm to 10 ppm in 10 years. Once a medium soil test level is achieved, a sufficiency level of P starter would be all that is needed to achieve near maximum yields, particularly as a starter. Starter P should be added at minimal levels at all soil test levels.

Producers should therefore pay close attention to both long-term and short-term P management. Starter fertilizer application which gives a fast return at a low rate is short-term P management and is important for grassy crops, corn and a few broadleaf crops. Long-term P management is the recognition that maintaining and building soil test P levels over time is important and must be addressed to maintain high yield potential across a rotation.

Special rotations result in dramatic crop responses to P fertilization. Crops respond greatly to P fertilizer application following fallow, regardless of the soil P level. Corn following sugarbeet also is very responsive to phosphate application regardless of soil P level. Buckwheat has a special ability to contribute P to subsequent crops. Buckwheat straw has been shown to contribute the equivalent of about 25 lb/acre P_2O_5 to the following crop.

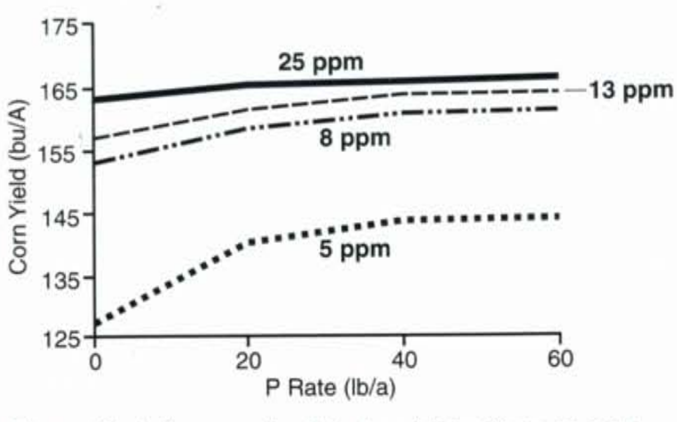


Figure 37. Influence of soil test and P fertilizer on corn yield, Beresford, SD, 1994.

Phosphate fertilizers containing nitrogen

MAP and DAP

MAP is short-hand for monoammonium phosphate. DAP is short for diammonium phosphate. Both products are dry, granular, dark brown, dark grey, or green fertilizers primarily used for their phosphate content. These two fertilizers, however, also contain a significant percentage of nitrogen. MAP can have a guaranteed analysis from 10-50-0 to 11-52-0 (11% N and 52% P_2O_5). DAP is 18-46-0, 18% N and 46% P_2O_5. Both fertilizers contain nitrogen as an ammonium salt. The chemical formula for MAP is $NH_4(H_2PO_4)$. The chemical formula for DAP is $(NH_4)_2HPO_4$. The products can be spread broadcast, injected with an air-seeder (Figure 38), or banded at planting.

If MAP is placed in water the pH of the solution will be slightly acid. If DAP is placed in water, the solution will turn slightly basic. Some have argued that acidic is better than basic and that MAP therefore has an advantage over DAP. In soil, the amount of acid or base produced by dissolution of either compound is insignificant compared with the buffering (resistance to change) capacity of the soil that surrounds the fertilizer pellet. In addition, within two weeks of application, nearly all of the ammonium applied in the application would normally be transformed to nitrate by soil bacteria, with acidity formed as a result. The quantity of acid produced by transformation of ammonium to nitrate is much greater than that produced by dissolution of the fertilizer. If both products were compared on the amount of potential acidity they represent, DAP, having twice the ammonium ions that MAP has, would actually be more acid forming. However, a number of studies comparing MAP and DAP have concluded that these fertilizers are equally efficient at increasing crop yield and supplying P to the plant.

In situations where high rates of phosphate are used next to the seed, MAP would be preferred over DAP because the nitrogen in DAP has a greater tendency to form free ammonia in high pH soils. Rates of up to 100 lb DAP/acre with small grain seed are not a problem, but at higher rates MAP would be preferred. MAP and DAP can be surface applied, but incorporation helps the positional availability of both N and P, as well as limiting runoff of N and P due to snow melt or spring rains. Efficiency of broadcast P is low because of strong reactions of P with soil minerals, especially at soil pH levels higher than 7.0. Efficiency is higher in banded applications for many crops.

Figure 38.
An air-seeder is capable of applying both fertilizer and seed and a variety of configurations, lending flexibility to the seeding and fertilization of a number of crops.

10-34-0 (APP-ammoniated polyphosphates)

The most common liquid phosphate fertilizer is 10-34-0 (10% N and 34% P_2O_5). It is a clear, green fertilizer manufactured from 0-72-0 superphosphoric acid and ammonia. 10-34-0 is usually applied at planting as a starter fertilizer in a band 2 inches below and 2 inches to the side of row crops. Small amounts of 10-34-0 are sometimes also applied in the furrow with the seed as a "pop-up" fertilizer. Rates of 8 gallons per acre or less are usually safe for small grains. Rates of 2-3 gallons are sometimes used with sugarbeet. For certain row crops, no pop-up is recommended. Consult the management guides for different crops for this information. Ease of handling and the ability to blend micronutrients into the liquid and apply them evenly are reasons why 10-34-0 is becoming more popular in certain areas, particularly with growers practicing conservation tillage. Ammoniated polyphosphates have good sequestering ability for zinc, and starter fertilizers containing ammoniated polyphosphates have been shown to be effective fertilizers for zinc deficient corn or dry beans. This material has a higher cost per unit of plant food than dry fertilizer grades.

6-18-6 and other complete liquid grades

Complete liquid grades such as 6-18-6 are available to farm producers wanting N, P, K and chloride in one liquid fertilizer. The products are usually green in color. Micronutrients are easily blended and applied evenly through the planter with these fertilizers. The complete fertilizers have a higher salt index than 10-34-0, so rates used as pop-up fertilizers depend on the total quantity of N + K_2O in the mix and the restrictions of crop sensitivity. Complete fertilizers are usually applied in a 2x2 band to the side and below the seed. Some of the most expensive liquid blends contain P from the white furnace acid process. This material is used as a food additive in soft drinks but is expensive compared to fertilizer grades produced with the phosphoric acid treated rock phosphate contained in most of the commercial fertilizer used today. However, there are fertilizer grades made from this and other more expensive products. There is no evidence that these higher priced fertilizer grades are more available or efficient than the less expensive products. If a producer chooses to use these low analysis fertilizer grades rate for rate per unit of plant food compared to another fertilizer product, they should perform similarly, but farmers should not expect a miracle simply because the material is higher priced. Plants cannot distinguish between price tags.

Phosphate containing fertilizers

Triple superphosphate

Triple superphosphate is a dry, gray granular fertilizer that can be broadcast, banded, or knifed in. It has the basic formula $Ca(H_2PO_4)_2$. The guaranteed analysis varies with the manufacturer from 0-44-0 to 0-46-0. It is seldom used when nitrogen fertilizer is needed along with phosphate, because the nitrogen within MAP or DAP fertilizer is more economical. If soil N levels are high or a crop does not require supplemental N, triple superphosphate would be a good P choice for a build-up or starter P application. The water solubility of triple superphosphate is a little lower than that of MAP or DAP and reactivity with soil minerals is higher, but the solubility is high enough so that triple superphosphate would be a suitable row starter fertilizer. Triple superphosphate has the lowest germination damage potential of any phosphate fertilizer. It is seldom chosen as a starter fertilizer because of economic reasons and local availability. Little triple superphosphate is used in North Dakota compared to other fertilizer grades.

Ordinary superphosphate

Ordinary superphosphate (OSP, 0-20-0) was somewhat popular forty to fifty years ago. It was produced by combining sulfuric acid with rock phosphate. The final product was a combination of gypsum and calcium phosphate. Because of freight costs and general cost of the product at the farm compared to MAP, DAP and triple superphosphate, little OSP is sold today. Derivatives of OSP, such as 0-18-0, may sometimes be found locally. These products are good suppliers of plant usable P and sulfur, although they are usually higher priced than more popular products. Depending on the price of sulfur, OSPs might be a good canola fertilizer given the sulfur they contain. OSPs need to be applied at similar rates of P compared to MAP or DAP so that soil test levels of P do not decrease with time.

Potassium Containing Fertilizers

The need for potassium (K) fertilizer is very low in North Dakota due to the continuous release of interlayer K from between clay sheet layers. Its use as a fertilizer should be based on a soil test. In general, the likelihood of crop response to K fertilizer will be greater with coarse-textured soils. Before undertaking an expensive K fertilization program, banding 20-30 lb K_2O/acre in a 2X2 band for row crops or 15 lb K_2O/acre with the seed in small grains to determine a possible response would be a reasonable approach.

It is impractical to increase K reserves to high levels in sandy soils, because the soils do not have the fertilizer holding ability to retain large amounts for a long period of time. Potassium moves in sandy soil with soil water movement. It is therefore better to apply smaller amounts more frequently than to apply large amounts in a buildup program. In heavier soils, it generally takes 20 pounds of K_2O to raise the soil K levels 1 ppm.

In ridge-till, K uptake is reduced due to the generally dry soil conditions within the ridges. Some producers apply K in a band in the fall directly into the ridges to supply adequate K for the growing season, even with high soil K levels.

Muriate of potash

Muriate of potash, or potassium chloride (KCl), is the most abundant potassium source in North America. Vast deposits of KCl, guaranteed analysis 0-0-60 to 0-0-62, are mined in Canada and in the western United States (Figure 39). Muriate of potash is a white to red dry granule whose size and color are an indication of the mine source and degree of purification the product has received. Impurities tend to be iron oxides, giving it a reddish or pink color, which has no influence on the efficacy of this fertilizer.

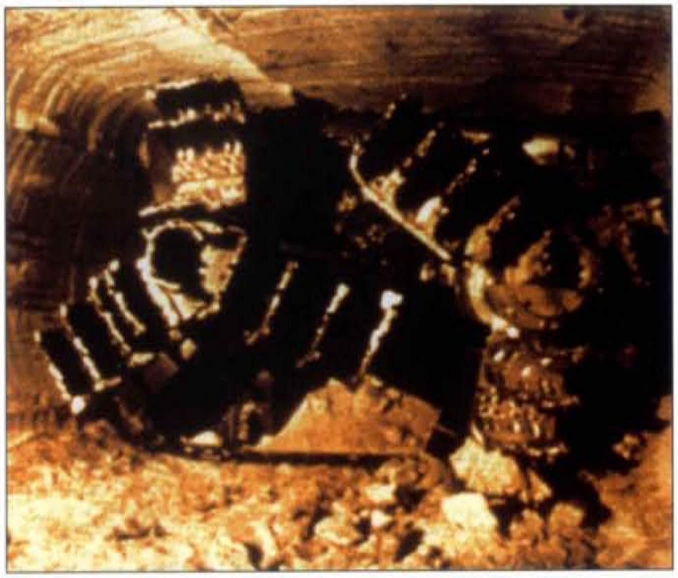


Figure 39. View from inside a Canadian potash mine shaft. These deposits are very deep and the ore requires little processing except granulation to promote more uniform application and decrease particle size separation in a blend.

Refined, white fine granular potash is often called soluble grade potash and is used in the manufacture of liquid grades, which may be either clear solutions or suspensions. Normal size granular potash should not be used to make these liquid fertilizer blends, nor should soluble potash be used in a dry blend. Granular potash is too large and usually contains too many impurities such as iron compounds to blend well even in suspensions. Suspension or solution grade potash is too fine to spread with a spinner spreader and will streak since it will not be thrown far from the spinner disks due to the light weight of its particles. It will also tend to cake inside the tubes of the pneumatic applicators. Muriate of potash is also the cheapest source of chloride for use in small grains. Muriate of potash can injure seedlings if banded with the seed. The total amount of N + K_2O banded with wheat, for example, should be less than 20 lb/acre with a normal press drill on 6-inch centers due to the possibility of salt injury to germinating seed from potassium salts.

Potassium sulfate

Potassium sulfate can be used as a special chloride-free potassium source for sensitive crops such as potato, or in areas needing potassium fertilizer when high chlorides are already present, or for crops needing both K and S. When additional chloride is not a concern, potassium sulfate is seldom used because of cost differences between the two products. The chemical formula is K_2SO_4 and the guaranteed analysis is 0-0-52-17, with 52% K_2O and 17% S.

Potassium magnesium sulfate (K-Mag, Sul-Po-Mag)

Potassium magnesium sulfate is formulated as a dry granule and used primarily in regions south of North Dakota to provide magnesium where dolomitic limestone is not available and where potassium and sulfur may also be required in a field. The available potassium content is about 26% K_2O, magnesium about 8% and sulfur about 15%.

Potassium hydroxide (KOH) and potassium carbonate (K_2CO_3)

This material is often used in the manufacture of high priced liquid starter fertilizers. Potassium hydroxide is highly basic and neutralizes the acidity of phosphoric acid if applied in the right ratio to make a more pH neutral product. The resulting potassium is no more available to plants than potassium chloride derived fertilizers, so KOH use has been limited due to cost. Potassium carbonate has been used as a spray application to alfalfa just before swathing to aid in drying.

Sulfur Fertilizers

Elemental sulfur

Elemental sulfur is normally applied as a 90% degradable S granule. It is also formulated as a fine powder for use in suspension fertilizers, but its use is rare in North Dakota. Since plants use only the sulfate (SO_4^{2-}) form of sulfur, elemental sulfur needs to be oxidized by sulfur bacteria or other soil organisms before plants can use it. Elemental sulfur may take months to break down into sulfate sulfur. The practice of applying elemental sulfur the year before it is needed to allow sufficient breakdown is flawed in that any water moving through soil in the late fall or early spring will leach sulfate out of the root zone and leave any untransformed S as unavailable as if it were applied that spring. The practice of applying elemental sulfur the fall before it is needed is also flawed, since transformation of S to sulfate does not take place in frozen soil when bacteria or fungi or whatever organism transforming S is dormant.

Response of plants to elemental sulfur the year of application is related to how quickly the S fertilizer particle degrades into fine powder and how quickly microorganisms transform the S dust to sulfate. Sulfur fertilizer is usually blended at the factory with a bentonite clay to allow dispersion in the presence of soil moisture. Bentonite clay is a smectite clay with exceptional shrink and swell characteristics. (There are beds of bentonite found in southwestern North Dakota, and there are many fine examples in the Theodore Roosevelt National Parks). The finer particles have a large surface area and are more readily attacked by S oxidizing bacteria and converted to sulfate. Even so, there is a delay between degradable sulfur application and availability of plant usable sulfur following application.

Numerous studies regarding sulfur response by canola have shown that elemental sulfur performance is poor compared to readily soluble forms such as ammonium sulfate. Why elemental sulfur is not very practical in this region is unknown, although Canadian research suggests that low numbers of S oxidizing organisms may be part of the problem. In other parts of the United States and the world that are warmer and wetter than this, elemental S is a proven product, however, it is not recommended in this region due to its slow transformation to sulfate and poor crop response.

Ammonium sulfate

Ammonium sulfate (21-0-0-24S) is discussed in some detail in the nitrogen fertilizer section of this bulletin. It contains 24% sulfur as sulfate and is an immediately available source of sulfur to plants needing immediate help. It is a convenient fertilizer to add to a fertilizer blend. The addition of ammonium sulfate to a starter blend can be very helpful in preventing early season sulfur deficiency. Ammonium sulfate, because of its ease of use and excellent performance in canola S fertility trials in North Dakota and Canada, is the preferred product for use in correcting sulfur deficiency.

Ammonium thiosulfate

Ammonium thiosulfate (12-0-0-26S) is a liquid fertilizer that can be applied in the spring, mixed with 28% or added to irrigation water later in the growing season. It is a good source of sulfur and nitrogen, although it is sometimes higher in price per unit of plant food than ammonium sulfate. It is relatively non-corrosive to aluminum and has a strong sulfur odor. There has been some evidence to suggest that ammonium thiosulfate is a short-term urease inhibitor, so some growers mix a small percentage of 12-0-0-26 with 28% when irrigating to increase nitrogen fertilizer efficiency. It is also a good sulfur source if liquid fertilizers are being used as a preplant chemical carrier. Ammonium thiosulfate should not be used as a seed-placed starter fertilizer ingredient, particularly for row crops. Ammonium thiosulfate is generally not used as a foliar fertilizer because of the severe leaf burns it causes, although foliar rescue treatment of sulfur deficient canola has been successful as long as the canola plant leaves have developed their thick waxy cuticle.

Ammonium polysulfide

Ammonium polysulfide (APS) is a red, strong-smelling fertilizer with an analysis of 20% N and 40-45% S. It is commonly applied with anhydrous ammonia in the Pacific Northwest and is being introduced into North Dakota. APS reacts immediately with the soil to form colloidal elemental sulfur. It forms sulfate in the soil through bacterial processes, but generally at a faster rate than granular elemental, perhaps because of its greater initial dispersion.

Calcium Fertilizers

Calcium deficiency has been seen in tomato, sugarbeet and apple in North Dakota. Deficiencies in most cases are related more to physiological disturbances and high competitive levels of ammonium nitrogen, salinity and bicarbonate levels than to lack of soil calcium. In tomato, a common deficiency symptom is called blossom end rot and can be controlled with a calcium chloride foliar spray. Balanced nitrogen nutrition and proper variety selection will lower the risk of deficiency in sugarbeet. Calcium sprays have been ineffective in reducing sugarbeet deficiency. Calcium chloride sprays are effective in correcting calcium deficiencies in fruit crops. Other formulations of soluble calcium are also possible. If soil calcium correction was needed and pH was low, agricultural grade limestone containing high levels of calcium would be recommended.

Sodic soils (soils high in sodium) with low gypsum levels may sometimes be reclaimed by adding gypsum ($CaSO_4 \bullet 2H_2O$). A quicker acting remedial amendment for sodic soils with high sulfate levels would be calcium chloride ($CaCl_2$). For sodic soil reclamation to be successful, there needs to be a combination of water table management and gradual replacement of accumulated sodium with the calcium from either gypsum or calcium chloride. Gypsum has little effect on soil pH and is not considered a liming material.

Magnesium Fertilizers

Magnesium deficiencies have not been reported in North Dakota. If problems were identified and pH is low, dolomitic limestone would be a good source of magnesium. Limestone is classified as either calcitic or dolomitic depending on the dominant minerals it contains. Calcitic limestone is mostly calcium carbonate, while dolomitic limestone is a mixture of calcium and magnesium carbonate. If soil pH is high, potassium magnesium sulfate (K-Mag, 11% Mg) or a similar product would be a preferred source of magnesium. A liquid magnesium chloride fertilizer has also been recently introduced.

Zinc Fertilizers

There are several forms of zinc (Zn) fertilizers used to deliver plant available zinc. These are zinc sulfate ($ZnSO_4$), zinc oxy-sulfates, zinc oxide (ZnO), zinc complexes, ammoniated zinc and zinc chelates. A broadcast application of zinc sulfate (33-36% Zn in a dry granule) at 10 lb material/acre will correct most deficiency problems for several years. Zinc sulfate is much more soluble than zinc oxide and is more effective in correcting zinc deficiencies in the year of application than less soluble products. Zinc sulfate is most effective when it is distributed throughout the topsoil, preferably by more than one tillage operation. Intact granules of $ZnSO_4$ are less effective, as too little of the root zone is enriched with Zn. Zinc sulfate suspended in 10-34-0 and applied as a starter has been very effective in some studies.

Recent research in Colorado has confirmed the importance of soluble zinc forms. Zinc sulfate was most soluble, while zinc oxide solubility was quite low and perhaps should be a last choice of fertilizer Zn. There is a wide range in solubilities of zinc oxy-sulfate. The higher the solubility, the higher the crop response and the less product would need to be used. North Dakota recommendations assume a highly water soluble product is being used. If water solubility is less than 100%, the rate should be increased proportionally.

Applications of zinc chelates are sometimes used with liquid starter fertilizer blends, but the rates used should be considered as annual treatments. Some chelating agents are also harmful to the germination of several crops, including flax. Labels should be checked before using chelates for information regarding the target crop. Be sure to check the compatibility of a chelated product with the liquid starter before mixing a batch. Some chelates will not mix well with liquid starters. Inorganic Zn sources are normally preferred over chelates because of cost. Generally, Zn chelates are three to five times more efficient in providing Zn to plants as dry materials such as zinc sulfate.

Ammoniated zinc sources are also used as starters and are becoming popular due to the reduced concern regarding compatibility and crop safety when compared to some chelated sources. Higher rates may provide some soil buildup, but costs associated with ammoniated zinc usually limit the rate to the amount required for the current crop. Normally, only small amounts (0.1-0.2 lb Zn/acre) are required for crop response in a banded application. Ammoniated zinc blends well with ammoniated polyphosphate fertilizers.

Zinc complexes are not true chelates. Instead, zinc is associated in the blend with organic materials having weaker binding properties than chelates. With the many complexes available, it is hard to predict the fate of organic-zinc complexes when applied to the high pH soil of this state. Test strips are recommended to check new products before switching to complete farm application.

Zinc sulfate, ammoniated Zn and Zn chelates are sometimes used as foliar treatments to correct deficiencies. Foliar treatment may not be the most preferred method because some damage to crop yields may have occurred prior to deficiency symptom detection. Field variability often masks low Zn areas within a field, making scouting an important diagnostic tool. When deficiencies are diagnosed, yield increases with foliar zinc application are common. Zinc soil tests are very helpful in predicting Zn responses and deficiency.

Manganese and Copper Fertilizers

Manganese deficiency can be induced by soil or foliar iron applications. Manganese chelates have been most effective in correcting deficiency, but their use is tempered due to the difficulty of distinguishing between iron deficiency and manganese deficiency. Application of Mn on plants that are really iron deficient will increase the severity of iron deficiency to the plants. Manganese deficiency is not nearly as common as iron deficiency. Both are caused by higher soil carbonate levels, and both deficiencies may be intensified due to plant stresses caused by high soil salt levels.

Copper deficiencies have been recorded in North Dakota on low organic matter sandy soils. Response to copper has not been consistent, but copper sulfate (25% Cu) has been successful in correcting deficiencies at a 2.5 lb/acre Cu rate when yield increases were seen. Copper chelates may also be used, but they are more expensive and research in Canada has not shown the degree of response as with soil treatments of copper sulfate ("bluestone"). Copper fertilization is expensive, and based on North Dakota research would only be justified by spot-treating suspected low organic matter, sandy soils which have shown copper deficiency symptoms in the past. Crops most responsive to copper deficiency in North Dakota are wheat and barley.

Boron Fertilizers

Boron (B) can be applied using a soluble powder, which may be about 20% boron, or a dry borate granule, usually about 14% B. Either method is effective in supplying B. It is easy to increase soil boron with B fertilizers to the point that they become toxic to crops. Careful soil analysis and fertilizer application can ensure that rates applied are needed and justifiable. Isolated boron deficiencies have been verified in North Dakota, usually under conditions of high humidity, similar to conditions favorable for Ca deficiency or dry soil conditions. Crops with high soil boron requirements include sunflower, cauliflower, sugarbeet and alfalfa. A small but inconsistent yield response to B fertilization was seen at Carrington on one sunflower study. However, this response could not be duplicated at any other site under similar soil B levels.

If B is used, soil applications of 1-2 lb/acre as fertilizer borate would not be excessive in terms of causing toxic soil B conditions. However, the chances of yield response to the treatment, even if soil tests are low (less than 1 ppm B), would be remote. Application of B close to the seed should be avoided.

Molybdenum Fertilizers

Crop deficiencies of molybdenum are unknown in the state. The mixture of ancient seabed sediments within most North Dakota soils suggests that molybdenum should not become a problem for many years. Molybdenum availability increases with soil pH. Given the high pH of most North Dakota soils, the probability of deficiency appears very low. If a deficiency were suspected, a test strip at planting using a molybdenum seed treatment would verify a deficiency.

Chloride Fertilizers

Chloride is usually applied as muriate of potash, KCl. It is often applied to small grains through starter fertilizer. The chloride content of KCl is about 48% Cl^-. A common question is why North Dakota soils are low in chloride when they are high in K. Although fertilizer K from common sources contains chloride, many soil minerals and potassium-bearing soil minerals do not contain chloride. The potassium-bearing minerals incorporated into the glacial material that make up most soils in North Dakota contain high levels of K and low levels of Cl.

Small grains respond to chloride fertilization. The amount of chloride needed is based on a soil test to a 2 feet depth. Although many labs currently recommend supplemental chloride application when soil test levels are below 60 lbs/a 2 ft., the greatest chance of response is at levels below 40 lbs Cl/a 2 ft. (Table 5.). There is not a great incentive to build chloride levels because although it is possible to build

Cl in dry years, chloride leaches as readily as nitrate when soil water movement is high. Buildup levels may not be maintained following a season of heavy water infiltration.

The amount of N + K_2O close to the seed should not exceed 20-30 lb/acre in 6-inch centers. The higher rate could be used in years where there is plenty of moisture, while the lower rate should be used in dry seed beds. There is no compelling reason why potash could not be broadcast to supply chloride. There is little advantage in concentrating chloride in a band.

Suspension fertilizers

Suspension fertilizers are liquid fertilizers manufactured mostly from ingredients previously described in this handbook. Suspensions tend to be more expensive than dry fertilizers, but less expensive than clear liquids. They have many of the advantages of a clear liquid, including broadcast application accuracy compared to dry spinner spreaders, but this advantage decreases as competitive dealers and many growers properly set spinner adjustments to maximize spread pattern uniformity. The growing popularity of commercial pneumatic boom applicators also reduces the advantages of using suspensions over dry fertilizer. A prudent fertilizer dealer may successfully compete with a dry dealer by using cheaper grade materials; not in the sense of nutrient value of the material, but the spreading quality of the material. However, the machinery for manufacturing and blending and logistics of application are much higher for a suspension operation than for a dry fertilizer operation. A grower must make his own decisions concerning what products are used. Generally, if a product is applied accurately, in a timely manner and with the proper management, there is little difference between one form of fertilizer and another.

Limestones and pH management

The soil pH is a measure of the hydrogen ion activity in the soil solution.

The range of pH seen in soil appears in Figure 40. Soil pH is important because crop plants grow best in a relatively narrow range of pH and soil minerals become more or less available depending on the pH.

Limestone is a natural deposit of calcium carbonate and magnesium carbonate. These deposits were originally deposited by microorganisms millions of years ago at the bottom of oceans. Today, these deposits can be hundreds of feet thick. They underlie millions of acres of land in the US. Dolomite is another form of limestone which has a high level of magnesium in the rock. Limestone is important agriculturally because it has the ability to neutralize acidity in acid soils. Most crops grow best in a pH range of 6-7.

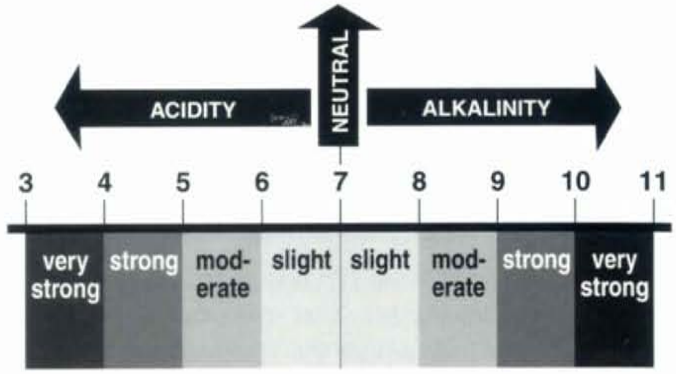


Figure 40. Range of pH encountered in soils.

In North Dakota, the pH ranges from about 4.8 to 8.5, with about two-thirds of the state above pH 7. There are significant areas, however, with pH below an optimal range (Figure 41).

Limestone has the ability to neutralize soils through the following reaction:

$$CaCO_3 + 2H^+ \rightarrow Ca^{+2} + CO_2 + H_2O$$

At the left side is limestone (calcium carbonate) and acidity (hydrogen ions) and the result of the limestone application are calcium ions, carbon dioxide and water. The resulting pH is higher than it was before, because hydrogen ions have formed a compound (water) which is pH neutral. Magnesium carbonate is also effective, since it is not the cation portion of the liming material that is important, but the anion portion which combines with the hydrogen ions in the neutralizing reaction. Gypsum is not a liming material, because the sulfuric acid formed when gypsum dissolves in an acid environment is highly dissociated and hydrogen ions are still in solution.

To be effective, limestone must be ground to a fine powder. Particles not passing more than a 60 mesh screen are not very effective in neutralizing pH after application. Particles small enough to pass a 60 mesh screen are very effective in neutralizing pH the first year after application.

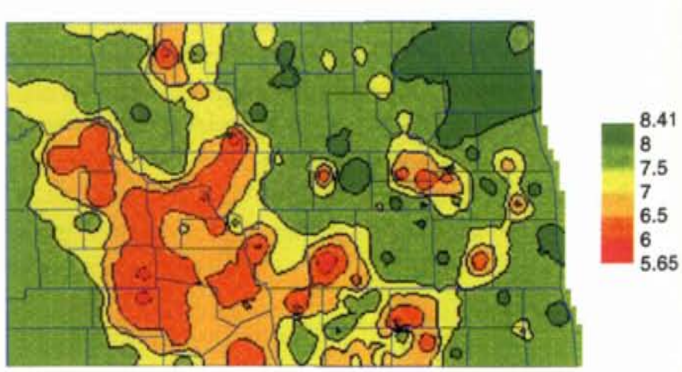


Figure 41. Soil pH of North Dakota upland soils.

The effectiveness of limestone to neutralize pH is called the estimated neutralizing value (ENV).

The ENV = the total fineness efficiency X % calcium carbonate equivalence/100

Limestone quarries usually have a value for the calcium carbonate equivalence and the particle size breakdown of their product. From that information, the ENV can be calculated.

Example:

Limestone is dolomitic, with a calcium carbonate equivalence (CCE) of 105% particle analysis is : 5 % > 8 mesh, 10 % 8-30 mesh, 20% 30-60 mesh, 65 % < 60 mesh.

			Efficiency Factor		
% of particles greater than 8-mesh	= 5/100	X	5	=	0.25
% of particles passing 8-mesh and are held on 30-mesh	= 10/100	X	20	=	2.0
% of particles passing 30-mesh and are held on 60-mesh	= 20/100	X	50	=	10
% of particles passing 60-mesh	= 65/100	X	100	=	65
			Total fineness efficiency	=	77.25

Therefore, ENV = 77.25 X 105%CCE/100 = 81.1

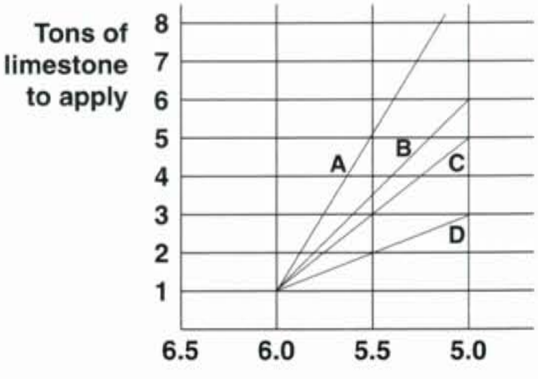
So with this example, if a recommendation suggested 1 ton/acre of limestone, the applicator would need to apply 1/0.811 = 1.23 tons/acre to satisfy the recommendation.

Limestone recommendations are based not only on the ENV, but also on the soil pH and the soil CEC to which they need to be applied. Some states resolve the rate issue by conducting a buffered pH soil test. The buffer acts like soil in resisting a change of pH. Soil resists change because of the reserve acidity in the form of hydrogen ions held to clay and organic matter surfaces. When an acid soil contacts a buffering chemical, the amount of actual hydrogen ions changes the pH in a measurable fashion. An equivalent amount of limestone needed to duplicate the lab findings is then calculated.

Other states have conducted numerous studies which show the result of adding varied amounts of limestone to soils with different CECs. These studies are summarized in charts such as the one depicted in Figure 42, which was adapted from the 2001-2002 Illinois Agronomy Handbook. The rate of limestone needed at a given water-based soil pH is dependent on the texture and relative organic matter of the sample.

Because of the large amounts of material to be applied, trucking is required to dump limestone in the field before spreading. To spread, an end-loader is used to fill the spinner spreader applicator bed with limestone in preparation for application (Figure 43). Never use a pneumatic spreader to apply limestone as the tubes will quickly plug with material.

Figure 43. Limestone stockpiled in the field. A front-end loader is used to fill the applicator bed. Spinner spreaders are used to apply the ground limestone to the field.



A – dark-colored silty clays and silty clay loams (CEC >24)

B – light and medium colored silty clays and silty clay loams and dark-colored loams (CEC 15-24)

C – light and medium silt and clay loams, dark and medium colored loams, dark-colored sandy loams (CEC 8-15)

D – light colored loams, light-medium colored sandy loams, loamy sands and sands (CEC <8)

Figure 42. Limestone recommendation based on soil texture/organic matter.

Fertilizer Application Methods

Winter Application

Because of increasing pressures on farm producers and fertilizer dealers to get more work done in a shorter period of time, the need to spread fertilizer N and P and manure in the winter has increased. When phosphate fertilizer is applied to the soil surface, the concentration of phosphate in the surface layer of soil is very high. When the top layer of soil is removed by water or wind erosion, phosphate applied to that layer is lost. Some of the lost soil is suspended in the runoff water and increases phosphate levels in the ponds, drainage ditches, and streams that receive the runoff water flows. The chance of economic losses to the farmer and degradation of nearby surface water quality is therefore high with surface phosphate applications. In years with little spring rainfall and snowmelt, water erosion is usually not serious. However, movement of soil through wind erosion may move phosphate-enriched soil into ponds and streams. It is impossible to predict rainfall patterns very far in advance. Winter surface phosphate application is therefore discouraged where erosion hazards are great.

Nitrogen fertilizers, particularly urea, are sometimes applied to frosty, but not deeply frozen, soils. Urea is more soluble than phosphate fertilizer and less reactive with soil, so the possibility of runoff and loss is great. Urea needs to be incorporated into the soil. Late in the fall, there are times when soils are firm enough or contain enough frost to allow fertilizer application. Urea can be spread on these fields if the snow will melt within about a week and the meltwater soaks into the soil.

For winter application of urea to be consistently effective and efficient, soils must be thawed so that water can move into them. Urea can hydrolyze into free ammonia completely within 10 days at 35°F. At the high pH of most soils in North Dakota, some ammonia may be lost even at temperatures hovering around freezing within a couple of weeks unless the ammonia soaks into the soil. If urea cannot move into the soil, it is susceptible to runoff. During a thaw, water from meltwater or rainfall may run off of fields. Urea at the soil surface is exposed to runoff losses during this time. There has been enough research to show that winter urea application can sometimes be successful. However, there is also sufficient evidence that there is enough risk involving both efficiency of the practice and offsite movement of nitrogen to discourage application to deeply frozen soils. Research from North Dakota discourages the application of urea on deeply frozen soils (Table 15).

Table 15. Application of urea to frozen soils preceding spring wheat, Carrington. Endres, Schatz and Franzen, 1996.

Application Timing	Yield	Protein
Fall surface applied, incorporated	45.4	14.5%
Soil frosted, not deeply frozen	45.8	13.8
Soil deeply frozen, December	27.6	12.7
Soil deeply frozen, March	33.3	13.0
Prior to seeding, incorporated	49.6	14.6
LSD 5%	**5.0**	**0.5**

Winter application of urea might be considered on unsaturated, thawed soils within a week of a rain or snow which will melt or carry the fertilizer into the soil. Winter application is not recommended to soils that are deeply frozen, which would prevent urea from entering the soil.

Uniform Ammonia Application

Uniform flow of anhydrous ammonia is often not achieved unless special equipment is used to create back-pressure within the manifolds. Special manifolds are now available that will result in more even ammonia flow to each knife. Without these special devices, ammonia flow may be an average rate of what is needed, but each knife may be receiving a different rate based on variability in flow resistance from the manifold.

Banded Applications

Fertilizer applied in a concentrated zone instead of scattered over the soil surface are referred to as band applications. Phosphate fertilization in North Dakota is generally accomplished by banding. Banding concentrates phosphate, reducing the ability of the soil minerals to fix or render less available phosphate ions. It also makes it easier for young roots to absorb phosphate fertilizer. High pH and high soil carbonate levels are factors that normally reduce phosphate availability in broadcast applications.

Crops are normally seeded in cooler than ideal soil conditions to take advantage of early season rainfall and additional heat units. Banding phosphate near the row at planting places it in the path of future root growth, enhancing early root development normally slowed by low soil temperatures.

Banding is practiced using surface banding, pop-up, or row-starter placement applications. Surface banding can be accomplished with a pneumatic dry fertilizer applicator with a tube attached to each boom outlet which drops the fertilizer granules straight down and concentrates them in bands at the soil surface instead of fanning them in a pattern to each side of the outlet. Surface banding is more commonly accomplished with a liquid sprayer which uses a straight stream nozzle directed downward, concentrating the fertilizer in a band at the soil surface instead of spreading it out in a normal fan-type spray pattern. The fertilizer is usually incorporated following application; however, some concentration within the soil is still present following incorporation. Surface banding of 10-34-0 is more successful and practiced more for winter wheat, where over-winter sloughing of the furrows buries the P at the crown depth.

"Pop-up" is fertilizer applied with the seed. Some crops tolerate seed-placed fertilizers and others do not. Small grains in North Dakota are traditionally fertilized with a pop-up row starter. Seed tolerance to high levels of fertilizer is generally low. When using pop-up, the grower should realize that germination is not encouraged by seed-placed fertilizer. Early growth of row crops may be stimulated, but whether it is accelerated faster than with a 2X2 band at planting is debatable. The degree of injury to seedlings when using pop-up fertilizer depends on the crop, variety, soil texture, soil moisture, fertilizer type, and rate. Restrictions on the amount of N + K_2O fertilizer to use with the seed for small grains is shown in Table 16. Use of seed-placed fertilizer should be discussed with a knowledgeable fertilizer company representative, crop consultant or NDSU Extension Service county agent before implementing a program. Severe stand and yield losses are possible if the wrong decision is made.

Most fertilizer at planting is placed some distance away from the seed. A 2 inch to the side and 2 inch below the seed placement is popular and is referred to as a 2X2 band. Placement in a 2X2 band can enable most fertilizer to be applied to small grains and more salt tolerant crops in the band. Crops like corn, which are sensitive to fertilizer salts, should have no more than 50 lbs/acre of N+K_2O in a 2X2 band.

Air-seeder use has encouraged more small-grain producers to apply most of their fertilizers with the seed in a wider spread pattern. A wider spread pattern of both fertilizer and seed compared to a double-disc opener increases the rate of fertilizer that can be applied with the seed (Table 17). When rates of N + K_2O exceed the amounts given in Table 16 for wheat and other crops (Table 18) there should be seed and fertilizer separation, particularly when urea is used. A good seed and fertilizer spread method would be placing the seed apart in two bands at each side of the opener, and placing the fertilizer 2-3 inches below and in the middle of the two seed bands. There are many other possibilities which could be used to separate seed and fertilizer.

Banded application is recommended for phosphate applications because of greater use efficiency. Banding will also increase the efficiency of zinc and potassium, because these two plant nutrients have low mobility in the soil. Banding may also increase efficiency of nitrogen due to less immobilization and slower nitrification in fall-applied ammonium fertilizers. Chloride or sulfate use efficiency would not be expected to increase because of the relative soil mobility of these elements. Broadcast applications of

Table 16. Maximum nitrogen fertilizer (urea or other) rates which can be applied to small grains (wheat, barley or oats) at planting based on planter spacing, planter type and per cent seedbed utilized during placement, assuming medium soil texture. *(From Deibert, NDSU Ext. Bull. EB-62, 1994.)*

		Planter Spacing					
		6 inch		10 inch		12 inch	
Planter Type	Seed Spread	SU,%	lb N/a	SU,% lb	N/a	SU,%lb	N/a
	inches						
Double disc or hoe	1	17	20-30	10	17-23	8	15-20
Hoe	2	33	32-44	20	23-31	17	20-27
	3	50	44-58	30	30-40	25	26-34
Air-seeder	4	66	56-72	40	37-48	33	32-42
	5	83	68-86	50	44-57	44	38-49
	6	100	80-100	60	51-55	50	44-56
	8			80	66-83	67	56-71
	10			100	80-100	83	68-86
	12					100	80-100

SU = Seedbed utilized during fertilizer placement. (Width of fertilizer banded ÷ Width of seedrow)

Table 17. Maximum nitrogen fertilizer (urea or other) rates which can safely be applied with small grain seed at planting based on soil texture and seedbed utilized during planting. *(From Deibert, NDSU Ext. Bull. EB-62, 1994.)*

	Percent of Seedbed Utilized		
	10-20	30-50	60-100
SOIL TEXTURE	Double-disc, Hoe or Air- Seeder 1 inch	Hoe or Air-seeder 2-3 inches	Air-seeder 4-12 inches
	lb N /acre		
Loamy sand	5	10-20	25-40
Sandy loam	10	15-25	30-45
Loam	20	25-35	40-55
Silt loam	25	30-40	45-60
Silty clay loam	30	35-45	50-70
Clay loam	35	40-50	55-80
Clay	40	45-55	60-100

nitrogen, chloride and sulfur-containing fertilizers are therefore used extensively throughout North Dakota. Buildup applications of fertilizers, such as zinc, are usually applied broadcast because blending dry products together is easy, saves time, and reduces trips across a field (Figure 44).

Figure 44. A banded fertilizer application at seeding.

Broadcast application

Broadcast is a very common method of fertilizer application across the United States. Its convenience is unmatched by any other application method. Both dry and liquid fertilizers are broadcast applied. The equipment used can be simple or complex. The basic dry broadcast equipment used today can be separated into spinner spreaders, air-flow applicators, or auger-driven boom applicators.

Spinner spreaders rely on hydraulic or PTO-driven fans to fling fertilizer granules away from the center of the fertilizer applicator. Spinner spreaders require good adjustment prior to the season to ensure proper spread patterns and avoid applying finer materials close to the center and more dense materials farther away. The quality of the fertilizer products in a blend affects spread patterns of spinner spreaders more than those of air or auger applicators. When lighter density materials are mixed with denser materials, the fertilizer blend should be double-spread so that streaking is reduced. Fertilizer patterns vary from 45 to 55 feet depending on the model of the applicator and fertilizer material to be spread.

Air-flow or pneumatic dry fertilizer applicators are becoming more popular with retail fertilizer dealers and producers. They carry the advantage of eliminating applicator blend segregation upon release from the machine to the soil. In the pneumatic spreader, fertilizer is augered to a distribution manifold, where air pressure from hydraulicly driven fans carries all components of the fertilizer blend through the manifold and through individual tubes to outlets on the boom spaced approximately 4 feet apart. The fertilizer is blown out of the tube, striking a beveled plate which scatters the fertilizer onto the soil surface in a pattern resembling that of a liquid fertilizer nozzle. Booms are commonly 60 feet wide and usually carry some type of marking system to minimize skipping. Pneumatic applicators apply fertilizer products so evenly that herbicides are often added to the blends either on the machine or at the blending site and applied in one pass to the field with excellent results.

Auger-driven fertilizer boom spreaders are rare in North Dakota, but offer an alternative from the pneumatic applicators. Fertilizer is augered to each boom from the center of the machine through narrow boxes that make up the boom, which is about 55 feet wide. The fertilizer is dropped straight down to the ground by gravity. The application is very accurate and spread pattern is excellent. The popularity of pneumatic spreaders has diminished interest in using the auger-driven boom.

Figure 45. A bulk blender. In the foreground is the weigh-hopper where separate dry products are added. The products are then mixed in the rotary blender in the background. The finished blend is then moved with a conveyor or auger out to a waiting truck for field application.

Banded vs Broadcast Fertilizer P

Phosphorus fertilizer placement is an important issue. Ease of application and efficiency for many crops favors the band approach. However, some crops utilize a broadcast or residual P approach better. Crops that respond well to a concentrated band approach include all of the cereal grains, corn, sugarbeet and canola. The response of small grains and corn has been known and accepted in this region for a long time. Tillering is increased in small grains, and adventitious root development is enhanced in corn through the use of starter P. The response of canola to banded concentrated P has been known and utilized in Canada for some time. The response to banded P in sugarbeets is a newer concept. Both canola and sugarbeet are not associated with mycorrhizal fungi that aid many crops in P uptake. Perhaps the concentration of P in a band is essential for P uptake, unless soil test levels are high. Certainly, research has shown that in the absence of starter fertilizer applications, high P applications are important for sugarbeets.

Many broadleaf crops, including soybeans, field peas, lentils and flax, show little response to starter fertilizer P, unless soil test levels are low. Soybeans have shown the greatest response to starter P when soil test levels are low. Some response is possible with row-placed starter or a 2X2 banded application when soil test levels are low. However, no response is generally seen when soil test levels are medium or higher. Soybeans generally perform best on residual P from prior applications and when soil test levels are medium or higher. Flax, in particular, shows little if any response to P applications of any kind. Residual applications and higher soil test levels are preferable to P application in the flax seeding year. Field peas and lentils may tolerate an application of P in the row, but they do not respond to it.

If producers apply P to field pea, lentils or flax it is usually out of habit, or because it helps keep soil test levels stable. Soil test may be maintained with better economic return if additional P were added to the fertilizer blend of the crop preceding these crops, such as wheat, and the subsequent crop left to feed off the residual, a condition for which it is well adapted. Most fertilizer for soybeans in the Corn Belt goes onto the corn crop, with soybeans left to feed quite well on the residual P fertilization.

Fertigation

Fertigation is the addition of fertilizer to irrigation water. Injector pumps meter a continuous supply of plant nutrients into the irrigation water stream. The practice is an advantage to irrigators, who must manage nitrogen supply more carefully than most producers. Leaching potential on sands and the potential for denitrification losses on heavier soils is much more likely when irrigation is practiced.

Any clear liquid fertilizer can be used to fertigate crops, although UAN (28-0-0) is the most common in North Dakota. Normally, no more than 30 pounds of nitrogen is recommended in any single application. Some nitrogen fertilizer is recommended as a preplant application. Some N application can also be made as a side-dress treatment. Thereafter, the decision to apply additional fertilizer is made based on the progress of the crop, growing pattern, and plant tissue analysis results, which may indicate further nitrogen needs.

In irrigated potato, leaf petiole sampling should be performed weekly and petiole nitrate levels closely monitored after tuber initiation. At tuber initiation, nitrate levels should be at or above 25,000 ppm. At tuber fill, the levels should not go below 15,000 ppm. Without petiole testing, many producers historically applied nitrogen in great excess prior to planting in an attempt to carry enough nitrogen for proper potato development to the end of the season. However, since leaching and denitrification can occur so rapidly, the early fertilizer nitrogen was not consistently the answer to sustained N nutrition. By monitoring petiole nitrate levels and fertilizing through the irrigation water, nitrogen rates are minimized while potato quality and cost efficiency is maximized. Off-site nitrate movement is also reduced by this method.

When planning fertigation, the irrigator should follow state laws, such as the installation and use of check valves between the irrigation stream and the pump and between the irrigation stream and the well head. The pump should have sufficient capacity to deliver about 5-20 gallons of product per acre over the irrigated area within the time it takes to apply from ½ inch to 1 inch of water. Applications of less than 1/2 inch of water per acre may result in more urea volatility than acceptable. The tank containing the fertilizer solution should also be protected by some type of containment, and a method to dispose of rainwater accumulating within the containment should be anticipated and used.

Anhydrous ammonia is not used to fertigate crops in North Dakota. Most irrigation is by overhead sprinkler irrigation, and contact of leaf tissue with ammonia should be avoided. Another reason for not using anhydrous is the effect on the pH of irrigation water. When ammonia is introduced in water, the pH increases. Soil minerals, particularly calcium carbonates, precipitate into the piping, eventually plugging the pipes and ruining the system. Anhydrous ammonia is therefore a very poor choice of fertilizer for fertigation and its use is strongly discouraged.

Table 18. Maximum rates of fertilizer N + K_2O which could be seed placed (double-disc style opener, or air-seeder with 1 in. spread pattern) with various crops and expect a yield increase.

Crop	Row-Spacing	N Fertilizer	Rate, lbs/a
Barley	6 inch	Urea All other N	20-30 30
Buckwheat	6 inch	Any	6
Canola	6 inch	Any	10,(0 on sand)
Corn	30 inch	Any	10
Dry Bean	All	Any	NONE
Flax	All	Any	NONE
Lentil	All	Any	NONE
Mustard	All	Any	5,(0 on sands)
Oat	All All	Urea All other N	15 30
Pea	All	Any	NONE
Potato	All	Any	NONE
Soybean	All	Any	NONE
Sugarbeet	All All	Urea All other N	NONE 2-3
Sunflower	30 inch Solid-seeded	Any Any	10 20

Top-Dressing

Sometimes a wet spring will delay a planned preplant nitrogen application until after the crop emerges. In row crops with rows wide enough to allow movement of tractors and fertilizer trailers without injury to the crop, side-dressing is a common choice. With narrow row crops, small grains and other solid-drilled crops, other methods must be used to apply N.

Ammonia can be applied to small grains after emergence if the ammonia is applied at right angles to planting direction, the outlet is at least 4 inches deep, and a narrow profile knife or eagle point tool is used and spaced about 12-14 inches apart. The soil must be dry or moist, but not muddy, in the application zone. There will be some stand reduction in the application trench. The application must be made when the plants are substantially rooted, but before jointing to decrease injury. The 3-4 leaf stage is probably ideal.

Liquid N fertilizer can also be applied as a topdress application. With broadleaf crops, setting up a sprayer to spray a straight-stream of liquid between the rows and cultivating it in is the best method. For solid drilled broadleaf crops, liquid N sources will probably result in substantial burning if broadcast applied. Other fertilizer sources would probably be better and safer to the crop. In small grains, setting up a sprayer to apply a straight-stream on about 14 inch centers at right angles to the planting direction would limit the burn to the crop. Plant tissue contacted by the fertilizer band would be burned, but the greater part of the field would not be affected. Application of liquid N sources to wet foliage will minimize the damage from fertilizer burning.

A spoke-wheel applicator is also sometimes used to apply liquid fertilizer subsurface into small grain early in the growing season. The liquid is pumped to the application tool and out the spokes of the applicator into the soil. As long as adequate pressure is maintained at the spoke outlet, the prospect of plugging poses little danger.

Although ammonium nitrate is probably a better topdress choice because of low volatility if it does not rain for some time after application, urea is far more available commercially and less expensive per unit of N. Urea can be applied by air or ground to most crops when they are small. Urea is probably not the product of choice for small corn because of the problem of urea getting into the whorl and being trapped, resulting in some leaf burn. Usually this burn causes little if any yield reduction but the appearance of the crop following leaf burn makes topdressing corn with urea a last resort. Other rowcrops can be fertilized with urea if the crop is small and foliage dry. If urea can become caught in leaf axils and trapped, alternate fertilization methods need to be explored. Older sugarbeets are one example of a crop that may be susceptible to leaf burning later in the season through dry fertilizer topdressing.

Small grains can be fertilized with urea at nearly any stage of growth provided that foliage is dry. The yield benefits of N application are reduced as the crop grows. In small grains, the yield benefits to topdressing with urea and other N sources is negligible after the 5-leaf stage of growth. The crop may still benefit from increased protein content, but the economic benefits of yield increases may equal or return less than the cost of the fertilizer after the 5-leaf stage.

Any topdressed application that results in surface N placement requires rainfall or irrigation to incorporate it, or the crop will not benefit from the application. Absorption of foliar materials is very small compared to crop needs. Any fertilizer containing urea will need to be incorporated by water within two to three days of application, or the amount of urea N remaining will decrease rapidly under most growing conditions. Impregnation of urea granules with Agrotain® will result in an additional 10 days of protection from volatility.

Soil Sampling

Importance of Soil Sampling

Soil tests that measure the relative nutrient status of soils are used as a basis for profitable and environmentally responsible fertilizer application. The accuracy of a soil test result is influenced by the laboratory analysis, but the quality of the soil sample may be even more important to the accuracy and repeatability of a soil test. Sample collection is extremely important in the accuracy and repeatability of a soil test. Sample handling following collection is also important. A soil sample which does not represent the area being sampled will be misleading and result in over or under-application of fertilizer. It is therefore very important to collect and handle soil samples properly.

There have been several changes in field sampling methods since the previous edition of this handbook. This revision will help soil samplers in methods for determining a composite soil test but will also introduce site-specific methods for revealing within-field nutrient levels. The challenge has been to provide meaningful information about field and within field nutrient levels with minimal costs to the producer.

When to sample

Soil samples to be analyzed for soil pH, salt content, zinc (Zn) and phosphorus (P) can be taken nearly any time of year. Potassium (K) values from samples taken in frozen soil may test high compared to other times of the year. Sulfur (S) and chloride (Cl) are mobile in the soil, so sampling in the fall or spring is recommended.

Most soil samples in North Dakota are taken for nitrate-nitrogen (NO_3-N) analysis. When samples are collected in the fall before September 15, a sampling date adjustment (SDA) should be used to compensate for additional N releases anticipated from soil organic matter and previous crop residue decomposition. Soil samples for NO_3-N may be taken without sampling date adjustment after September 15. After this date, most additional N release from soil microbiological activity is low. Soil samples may be taken for NO_3-N as early as August 1. The SDA adds one-half pound of NO_3-N per day to the soil test analysis for each day the sample is collected prior to September 15 (Table 19).

Producers should not be reluctant to sample in early August following small grain or canola harvest because of fear of greater N release from organic matter and residues compared to late fall sampling. If yields were relatively high, the SDA adjustment represents potential N release well. Sampling fields before tillage also increases the reliability of the 0-6 inch soil core depth because of more uniform soil conditions compared to tilled fields. Waiting to sample until late fall following small grains increases the risk of N uptake by small grain regrowth, which may contain up to 100 lb N/acre. Sampling fields for NO_3-N while row crops are still standing is not recommended.

Table 19. Sampling date nitrogen adjustments if soil samples are taken in the fall prior to September 15.

Date of Sampling	Nitrogen Adjustment lb NO_3-N/acre
August 1	23
August 15	15
August 30	8
September 5	5
September 14	0

Fall soil sampling results for NO_3-N and S are similar to spring sampling in most years. However, warmer than normal winters followed by an early spring combined with good soil moisture could increase NO_3-N and S levels through organic matter and residue mineralization. Green sugarbeet leaves or other crop residues with relatively high N content may also contribute to early mineralization and increase spring NO_3-N levels compared to a fall soil sampling. In sandy soils with high rainfall or snow-melt following a fall sampling, levels of NO_3-N and S in the spring may decrease because nitrate and sulfate are leached out of the sampling zone. In most situations, however, fall sampling is a good guide to N and S application.

Depth of Sampling

Soil sampling and analysis assumes 2,000,000 lb/acre of soil from 0-6 inches in depth. This weight per unit volume (bulk density) assumes a medium soil texture with some compaction typically found following cropping and harvest. Bulk density differences can make the actual mass of soil range from 1.49 million lb/acre in some clay soils to 2.16 million lb/acre in very coarse textured soils. In commercial soil sampling, bulk density is ignored. However, consistency in soil sampling techniques is important because of soil bulk density differences, especially in surface cores. The depth of sampling required depends mainly on the nutrient of interest, the crop to be fertilized and in some cases, the tillage system used (Figure 46).

0-6 inches –	P, K, Zn, Cu, CEC, salts, all crops
0-2 feet –	NO_3, SO_4, Cl, all crops
0-4 feet –	NO_3 for sugarbeets, malting barley, sunflowers
0-6 feet –	NO_3 for sugarbeets with history of low sugar

Figure 46. Depth of soil sampling depending on the crop to be grown and nutrient.

Nutrients

For soil pH, P, K, Zn, copper (Cu) and manganese (Mn), sampling the 0-6 inch depth is adequate. In long-term no-till fields, soil pH, P, and K may become stratified. Most studies for P and K suggest that stratification is not important as long as the fertilizer P and K rates based on a 0-6 inch value are followed. However, soil pH may be important in the surface 0-2 inch layer because of possible herbicide interaction with lower pH levels. The 0-6 inch depth is also important for soluble salts in addition to the 6-24 inch depth.

To determine soil NO_3-N, S and Cl, samples are taken from at least the 0-24 inch depth. The 0-24 inch sample should be divided into a 0-6 inch depth and a 6-24 inch depth, so that the relative position of N in the soil can be determined. In some years, NO_3-N can be leached to lower depths so that large amounts are in the 6-24 inch layer, but only a small amount may be left in the 0-6 inch layer. Depending on the crop, soil NO_3-N may need to be determined on the 24-48 inch depth (2-4 foot) also. A few areas within the Red River Valley have a history of poor sugarbeet quality due in part to the presence of especially high levels of soil NO_3-N at deep depths. In these special areas, deep N to 6 feet may also need to be checked.

Crop

For most crops, NO_3-N should be determined on the 0-24 inch depth. For sugarbeet and malting barley, the 24-48 inch depth should also be sampled to fine-tune N rates necessary to improve beet and grain quality or as a tool to determine whether growing those N sensitive crops is wise. Sunflower also may use deep N, however, deeper sampling is conducted not to improve quality, but to save money on N fertilizer when there is reason to suspect the presence of large quantities of N at deep depths, such as following years of growing shallow rooted crops, following fallow and when previous crop yields have been low.

Tillage System

Under conventional tillage and conservation tillage, sampling 0-6 inch, 6-24 inch and the 24-48 inch depths described previously are appropriate. Under long-term no-till, stratification of soil non-mobile nutrients and soil pH will occur. Phosphate and soil pH stratification are common, with high P and lower pH levels at the surface 0-2 inch depth and lower P and higher pH levels at deeper depths. If the lower depths become depleted in P, application of more deeply placed P may be beneficial, especially in drier seasons. Soil pH tends to become acid at the surface, especially if N fertilizers are applied to the surface. Separating the 0-6 inch depth into a 0-2 inch depth and 2-6 inch depth would identify these trends (Figure 47), which might be useful in determining herbicide choices for example.

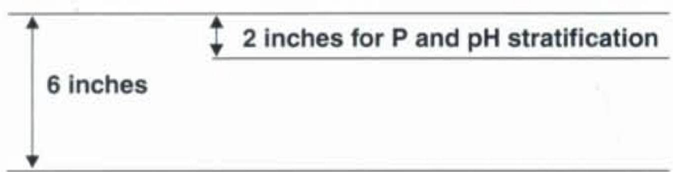


Figure 47. Special sampling for P and soil pH in no-till.

Special sampling situations

Ridge-till is occasionally used in North Dakota, but it is a popular tillage system in some areas of the corn-soybean belt. In ridge till, ridges are built by deep cultivation during the growing season and remain in the field following harvest and through the winter. At planting, the top of the ridge is removed, exposing moist soil for seeding, and soil from the top of the ridge is moved into the middle of the row. Starter fertilizer is often used at planting, and sometimes deep-placed fertilizer is applied below the ridge-top in the fall. Ridge-till should be sampled 6 inches to either side of the ridge-top and straight down into the ridge (Figure 48).

Fields with a history of large band applications of P and K are special problems, especially where within-field P and K levels are to be determined. When band rates greater than about 30 lb P_2O_5 or K_2O are used, there may be a residual effect of the fertilizer band for several years. If the bands can be located, they should be avoided when sampling. In North Dakota, high reproducibility of P levels

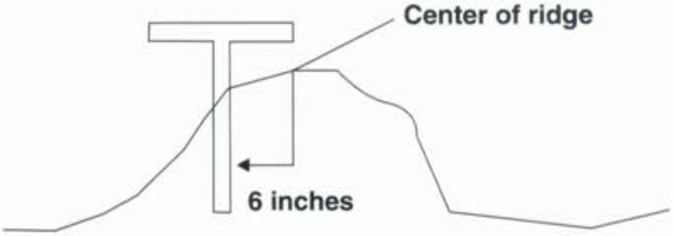


Figure 48. Special sampling for P, K and soil pH in ridge-till.

has been achieved in grids or zones using 8 to10 soil cores where 20-30 lb P_2O_5 has been applied annually. For sampling whole fields, the 20 cores per field recommendation is appropriate.

Sampling tools

Soil is variable not only over an area, but also with depth. A proper soil sample is taken from a uniform volume from the top of the sample depth to the bottom. Wedge shaped samples, or a handful of soil from the surface and one at depth are not appropriate and will not give consistent results. The best sample is taken using a soil probe (Figure 49). There are hand-probes and automated probes available at nearly every price range. The probe should be designed to gather soil from the appropriate depth.

After a recent tillage operation sometimes an automated probe has difficulty obtaining a consistent 0-6 inch sample. The consistency of a surface sample may be improved by sampling in wheel tracks, but it is sometimes difficult to find a wheel track when the probe is centered in the cab. Hand probes may be a better method to take a 0-6 inch sample, because the soil can be firmed with pressure from a footprint and a consistent sample can be taken. Automatic probes are very good at taking a 6-24 inch and 24-48 inch core even following tillage. Automatic probes take a much more consistent surface sample when fields have not yet been tilled.

Figure 49. Soil probe.

In many soils, a lubricant is needed to prevent soil plugging in a soil probe. Table 20 shows the effect of lubricants on soil analysis. For most soil nutrients, the use of lubricants, especially the most popular lubricants, should not affect soil test results. Exceptions would be certain micronutrients, iron (Fe), Zn, Mn and Cu. For these micronutrients, obtaining a 0-6 inch core without a lubricant is suggested, especially where deficiencies are suspected.

Soil sample handling

Samples intended for NO_3-N sampling should be stored in coolers during transport. Moist samples subjected to heat will increase microbial N mineralization and test values will increase during transport/storage. Samples intended for NO_3-N determination should be air-dried immediately after collection to prevent alteration of NO_3-N concentrations due to microbial activity. Samples should be spread uniformly on clean paper in a dust free area. Another procedure is to transport the samples immediately to a soil testing laboratory in a cooler. Usually, the soil laboratory charges for drying wet soil samples. Rubber gloves should be used to handle samples intended for chloride analysis to prevent contamination from chloride in perspiration.

Soil samples intended for Zn analysis should not come into contact with any galvanized surface, including the soil sampling tool, bucket, drying container or grinder.

Soil sample collecting, where and how

Where to collect a soil sample and how many samples to collect depends on the goal of soil sampling. Traditionally in North Dakota, the goal has been to provide one soil test level to describe a field. This approach works well in some situations, especially when the test value is low. However, because of the variability of nutrients in the field, one test level from a field may not represent a large part of the field. Some producers, having received a high soil test report, continue to apply the same fertilizer rates as in the past because of lack of confidence in the test. Recent research has developed methods to increase the confidence in soil test values while keeping sampling costs low.

Sampling goals can be separated into two categories; determining nutrient levels in Whole Fields, or determining Within Field Values.

Table 20. Effects of soil probe lubricants on soil chemical analysis. *(Blaylock et al., 1995. Wyoming.)*

Lubricant	Organic Matter	NO_3-N	P	K	Fe	Mn	Zn	Cu
	%	ppm						
No lubricant	1.67	1.4	14	249	11.4	1.5	0.8	1.7
WD-40	1.59	1.3	16	248	13.2	1.8	1.0	2.0
PAM	1.66	2.1	16	263	13.5	3.8	1.1	2.3
Dove dishwashing liq.	1.67	2.6	14	280	10.1	1.3	0.7	1.2
Motor oil	1.63	1.6	16	265	12.5	1.4	0.9	2.0
Silicone	1.62	1.3	16	246	9.9	1.3	0.6	1.0
$LSD_{0.05}$	NS	NS	NS	NS	0.7	0.8	0.2	0.3

Sampling for whole field nutrient values

Collecting a selectively random sample composite is the traditional North Dakota sampling strategy for determining whole field nutrient values. A field composite sample should consist of at least 20 selectively random soil cores. A field sampled in this manner should give the field mean plus or minus 15% at least 80% of the time (Figure 50). Selectively random sampling means that the field is sampled only in areas which represent most of the field area. Unusual landscape features such as eroded areas, saline or sodic zones and old building lots are not sampled. Also, avoid sampling in dead furrows or back furrows, under old manure or hay piles, sugarbeet tare piles, animal droppings, next to ditches, sloughs and roads, known banded fertilizer locations, and small depressions.

There are often questions about what constitutes a "field." Some samplers collect one composite sample per section or one per quarter-section. Others separate the field into large landscape zones and treat each as a field.

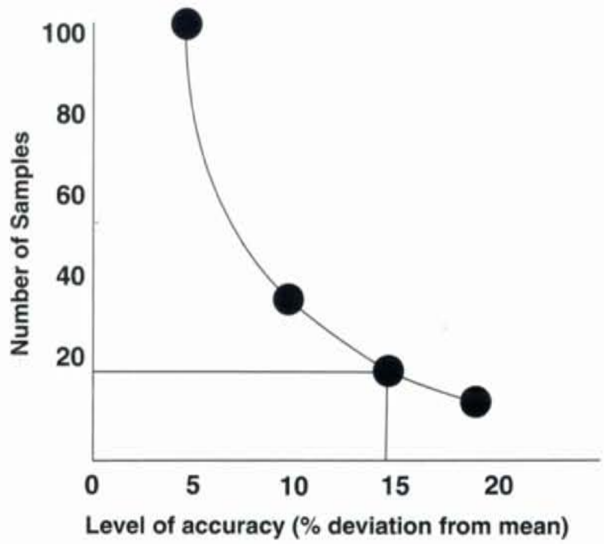


Figure 50. Number of subsamples required for a composite soil sample for NO_3-N with various levels of accuracy for an 80 % precision level. *(Adapted from Swenson et al, 1984.)*

Some may divide a quarter into three to four equal subfields and sample each individually. Generally, the smaller the area, the more representative of the area the sample values will be. Figure 51 shows two examples of the suggested ways to obtain representative samples from fields.

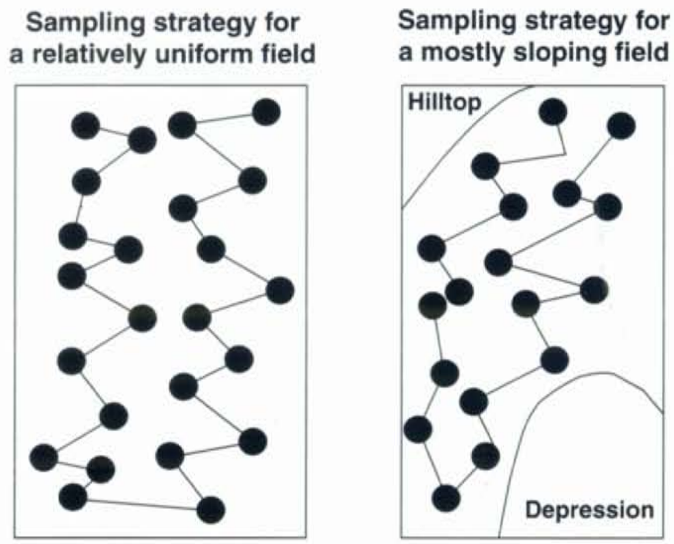


Figure 51. Two suggested strategies for composite soil sampling fields.

Using a composite soil sample to direct fertilizer recommendations has several advantages:

1. It is relatively inexpensive. Soil sampling is relatively quick, only 20 to 30 cores are needed to represent a field, and only one analysis is required for each field.
2. Results are mostly reproducible.
3. Results can easily be tracked from year to year.

Composite soil samples, however, have several inherent disadvantages.

1. "Unusual areas" not sampled may comprise significant acreage in a field.
2. Large portions of the field may be over- or under-fertilized.

3. There is a low level of confidence that high soil test values represent most of the field.
4. Sometimes it is difficult to distinguish which locations are unusual.

Composite sampling is most representative when within-field variability is low. Low within-field variability is most common when composite soil test levels are low. A field composite test of 20 lb NO_3-N/acre means that at least 95% of the area sampled contains levels between 10 and 30 lb NO_3-N/acre.

Collecting at least 20 soil cores from a field results in a large amount of soil being collected. In some soils, such as fine sandy loams, the soil may break up easily in a bucket, enabling thorough mixing before a ⅔ pint subsample is obtained for analysis. However, many soils do not break up easily. It may be necessary to take the entire sample out of the field, dry and grind it to obtain a good mixture. The resulting sample, whatever the method of collection and preparation, must represent the 20 core locations to provide the most accurate and reproducible results.

Sampling for Within-Field Nutrient Levels

Because of the limitations of composite soil testing, and because of the growing popularity of site-specific farming, different methods of obtaining nutrient values within fields are needed. Sampling for determining within-field nutrient levels can be accomplished through two different methods; **grid sampling** and **zone sampling**. Grid sampling reveals fertility patterns through dense systematic sampling, while the directed sampling method assumes there is a predictable and logical reason for fertility patterns to exist and uses this reason to reduce sample number while maintaining high quality information compared to dense grid sampling. Directed sampling has also been called "zone sampling," "smart sampling"and "smart zone sampling."

Grid sampling

Grid samples were first taken in a regular, predictable pattern across the field (Figure 52).

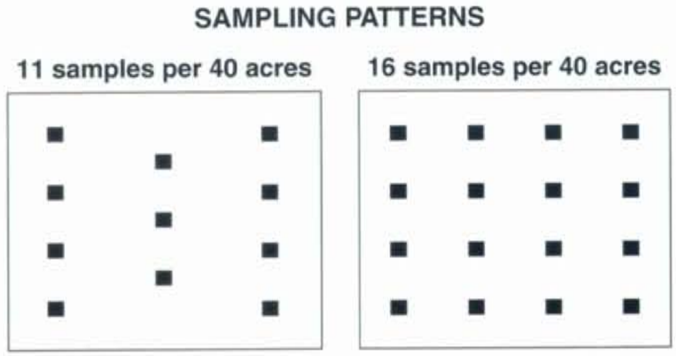


Figure 52. Regular grid sampling patterns, 3.3 acre and 2.5 acre grids.

However, the regular grid can easily contain bias because of streaking of fertilizer or manure applications in the past. With GPS (Global Positioning Satellite receivers) technology, grid sampling need not be regularly spaced. Irregularly spaced interval positions can reproducibly be located as accurately as regularly spaced grids. Irregular grids, such as the systematic unaligned grid, also provide the opportunity for greater statistical evaluation through a process called "kriging" (pronounced kreeging). Kriging is preferred by many researchers as an estimator of values between actual samples because it carries an estimate of error along with the estimated value. Other estimators such as inverse distance, polynomial and triangulation carry no such estimate of error. Other grid sampling types are random, random stratified, staggered start, and the diamond/triangle/hexagon grid pattern.

Grid sampling can be a good tool for sampling within-field nutrient levels if samples are taken densely enough. The accepted grid spacing from recent research, including in North Dakota, is about one sample per acre. This approach, however, is very expensive and time-consuming and has forced many commercial soil samplers and producers to accept less information about their fields and use a 2.5 acre grid or larger. In North Dakota, even a 2.5 acre grid is considered expensive and prohibitive. A 4-5 acre grid is more commonly used. The 4-5 acre grid has been used to reveal variability in soil test levels, but it may not be very accurate in representing within-field nutrient levels nor does it represent fertility patterns well (Figure 53). The use of a 4-5 acre grid should not be considered a dense systematic grid.

Zone sampling

Landscape/topography sampling

A more practical approach for North Dakota producers that combines low cost with a high degree of meaningful nutrient information is directed sampling. Directed sampling is based on some prior knowledge of the field, or some logical basis. The basis of most North Dakota directed sampling is the effect of landscape position on soil nutrient levels, particularly nitrogen. Soil pH, P, K, and Zn are non-mobile factors or nutrients in soil. The levels and patterns of non-mobile nutrients within fields are similar

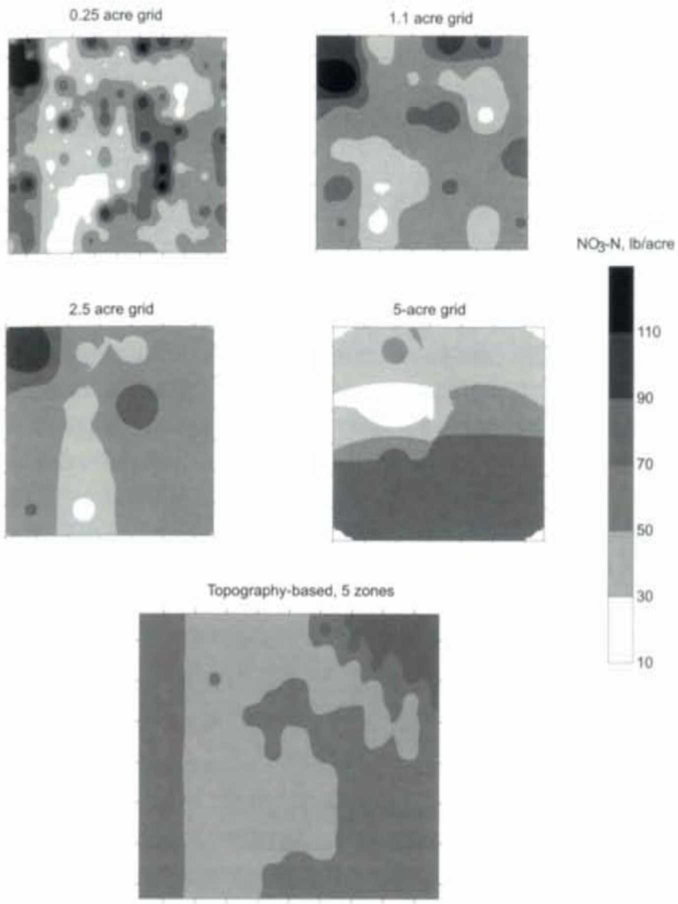


Figure 53. Comparison of a base grid of 0.25 acres with a 1.1 acre, 2.5 acre, 5 acre grid, and topography-based zone sampling with 5 zones. Valley City, N.D.

from year to year. North Dakota research has also shown that patterns of NO_3-N, S and Cl, which are mobile soil nutrients, are also stable between years because the patterns are affected by the landscape (Figure 54).

Directed sampling based on landscape, or topography, has been shown to be similar in providing within-field nutrient levels as a one-sample-per-acre grid, while requiring only a fraction of the sampling time and expense. Topography sampling of several fields across North Dakota only required 4 to 7 samples per 40-acre field, compared to 36 for the one-sample-per-acre grid approach.

Additional methods for directed sampling

Directed sampling should be considered an iterative process; a process that takes more than one attempt, in which information is added progressively to the general knowledge of the field. Producers will not have a densely gridded sample research base to back up assumptions on where important management zones are located and where the boundaries might be. Several methods of determining management zones in addition to topography should be used to help the producer judge what areas are important.

Aerial photography and satellite imagery can be used to show differences in soil color and differences in crop growth patterns and crop color. In years that are very dry or very wet, these areas will probably be related to topography. Aerial photography and satellite imagery have been shown to reveal patterns in sugarbeet leaf color, which is especially useful to soil samplers.

Old FSA (ASCS) aerial photographs in slide format are available for most fields in North Dakota because of verification photography taken during the last 20 years of federal farm programs. These photographs may reveal not only past field boundaries and long-abandoned building sites, but provide patterns from past crops that align with present-day information. This information is inexpensive to acquire and can be scanned into computer software for use in decision making.

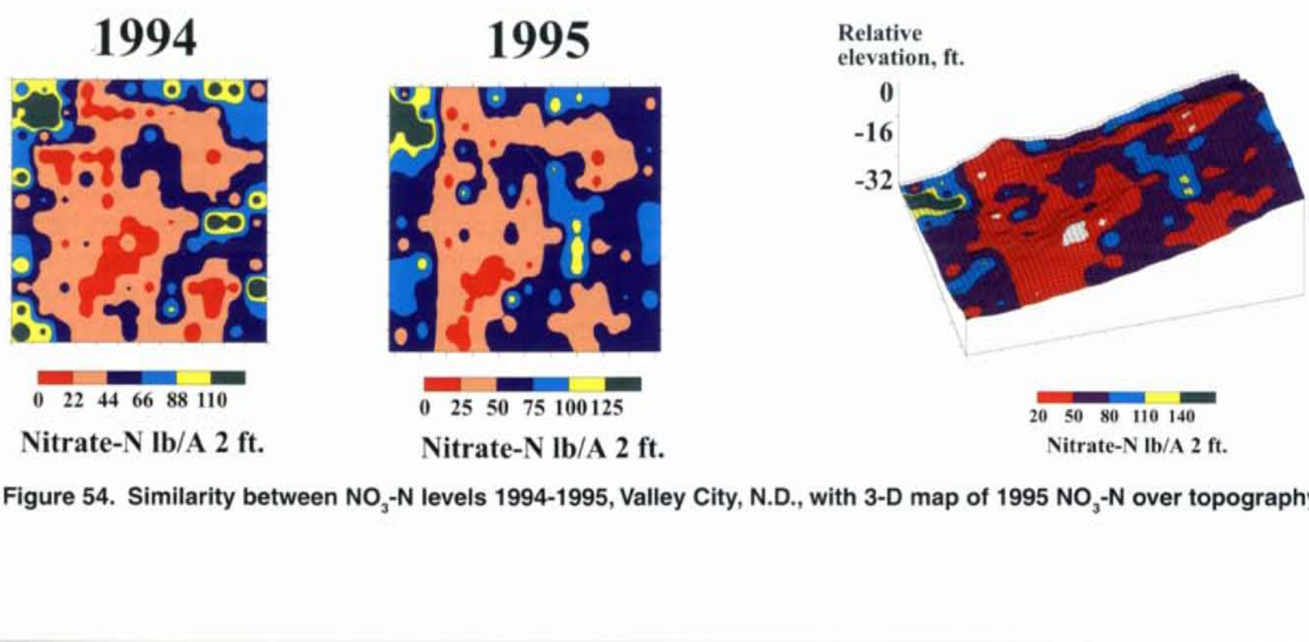


Figure 54. Similarity between NO_3-N levels 1994-1995, Valley City, N.D., with 3-D map of 1995 NO_3-N over topography.

Yield monitor data may be useful to define nutrient boundaries if yield was influenced most by nutrients. However, there are so many factors that affect yields that the usefulness of yield maps as primary nutrient zone delineators is probably limited. Yield monitor data has been most useful in recent North Dakota studies by identifying particularly poor yielding areas. These areas may have abnormally low fertility levels causing the poor yields, or they may have unusually high fertility levels if another factor is limiting yields, resulting in accumulation of excess nutrients in that location.

On-the-go soil electrical/electromagnetic soil conductivity sensors may help define management zones. It is not possible to determine directly what the different levels of conductivity mean without sampling to ground-truth the areas. However, this information can reveal patterns that initially direct, reinforce or redefine existing layers of information regarding zone boundaries.

Digitized GIS soil survey maps should be used with caution only to delineate zone boundaries with the aid of other layers of information. Although soil surveys give generally reliable information useful in determining the general productivity of farms, the information is usually not fine enough in scale to direct site-specific decisions.

Pros and cons of different within-field sampling methods

The following are criteria for choosing grid sampling over a directed sampling approach:

1. The field history is unknown.
2. Fertility levels are high due to high rates of fertilizer application.
3. There is a history of manure application.
4. Small fields have been merged into large fields.
5. Non-mobile nutrient levels are of primary importance (P, K, Zn).

The following are criteria for choosing directed sampling methods over grid sampling:

1. Yield monitor data or remote imaging show a relationship with landscape.
2. There is no history of manure application.
3. Relatively low fertility levels are present, or low fertilizer rates of non-mobile nutrients (less than maintenance) have been applied over the most recent years.
4. Mobile nutrients, especially N, are important to map.

Another strength of the grid approach is that the procedure requires a lower level of interpretive skills by the sampler. Grid locations are imposed on a field map by the computer with a prompt to drive to the next location. Anyone who can drive and read a map can sample a field in a grid. The drawback is the expense of sampling and analysis, which may result in a less than adequate grid size needed to represent a field.

Directed sampling requires a much more intelligent approach. By using the zone method, either the sampler or the sampling supervisor who provides the sample location map to the sampler must have a high degree of agronomic savvy. It takes time to review aerial photography, satellite imagery, topography maps, soil survey data and other layers of information, manipulate the maps to look for complementary patterns between different layers and decide where the best management zone boundaries are located. Although the sampling and analysis expense of a directed approach to soil sampling is far less than a one-sample-per-acre grid approach, the expense of interpretation is considerably higher.

The value of determining within-field nutrient levels

Determining within-field nutrient levels allows the variable-rate application of fertilizers. When considerable variability is present, immediate economic returns are possible, provided the variability is on a portion of the yield/nutrient curve which allows increased yield or quality if application rates are varied. The rapid movement toward variable-rate N application in sugarbeets has been driven by the relationship between N levels and crop value.

Another important reason for determining within-field nutrient levels is to reveal the range of levels and location of the levels. In determining soil pH, for example, composite tests from 95% of North Dakota fields show a pH level greater than 7. This led one author to announce that North Dakota "does not have an acid soil problem." However, in site-specific studies on five fields, the three fields in the Red River Valley all contained small areas (2-3% of total area) with values less than 7 and the fields outside the Red River Valley contained over one-half of each field area with pH levels lower than 6. In one field, pH varied from 4.9 to 7.8. The pH ranges have implications on herbicide carryover, herbicide activity and the performance of some major crops with pH sensitivity. So what is the level of pH on the 20 million acres of crops west of the Red River Valley? A survey of soil pH levels in North Dakota in 1996 showed that large areas near the Missouri River in the western part of the state had pH values less than 7, and many had levels lower than pH 6. Parts of fields in the Red River Valley and the Lake Agassiz beach lines also had lower pH.

When a soil test shows high levels of nutrients in a composite soil test, does that mean that the whole field does not require fertilizer? Many producers have run on-farm tests in the past and found that application of nutrients when composite soil test show that none is needed result in yield increases. Some producers simply do not trust a composite soil test. By sampling in a more intelligent manner using a directed approach, soil test results should be more accurate. The high soil test areas will be separated from the rest of the field and areas needing fertilizer will be revealed. Whether or not variable-rate fertilization is used, more confidence in the soil test will result.

Sample core number and confidence in the sample value

Cell sampling or point sampling can be used to gather soil from a grid or management zone. Cell sampling (Figure 55) is a method where samples are gathered randomly from the grid or zone area, while point sampling limits the sample collection area to a 10-20 foot radius from a central area location. Point sampling is most often used in grid sampling, whereas cell sampling appears to better represent zone levels. Both methods require multiple soil cores. There is enough small-scale variability in most areas of fields that single cores are not likely to represent a grid or zone well (Table 21). Research on small-scale variability suggests that 8 to12 soil cores may be required to represent a grid or zone.

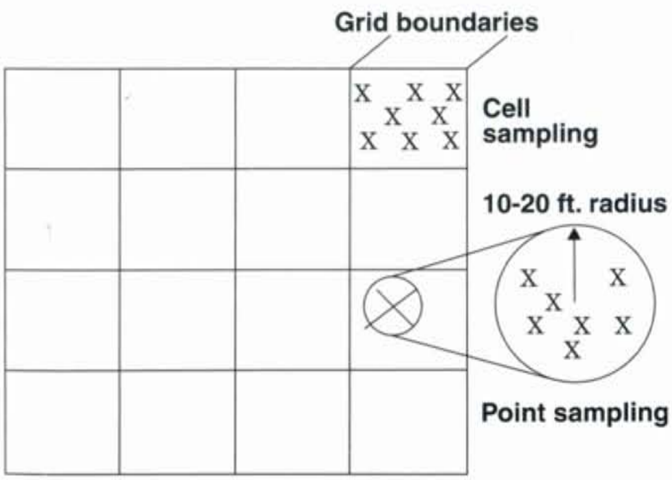


Figure 55. Cell and point sampling.

Table 21. The percentage of composite NO_3-N values falling into a range of the mean ± 20% with the cores taken in a random manner throughout a 60 foot X 60 foot plot area with individual sample cores obtained in a ten-foot grid. *(Franzen and Dennis Berglund, 1997.)*

		Number of sample cores used to estimate a sampling area mean				
Site	Mean	1	3	5	8	10
	lb/acre	percent of composite values falling into the mean range				
1	15.6	26	44	50	62	62
2	54.7	0	52	70	86	88
3	60.6	30	56	78	86	92
4	27.6	54	82	90	98	98
5	12.3	52	78	90	96	98

Once a sample value is obtained through careful sampling and analysis, what does that value mean and how much of the grid or zone is represented by that value? The lower the sample value is for NO_3-N, the more confidence there is in the value. For example, in a 10-acre zone, if a value is 20 lb NO_3-N/acre, then it would be expected that 9.9 acres of the zone tests 10-30 lb NO_3-N/acre. However, if the value in the 10-acre zone were 100 lb NO_3-N, then only about 6.5 acres would test between 70 lb and 130 lb NO_3-N and the remaining 3.5 acres would have values above or below that range.

Some producers have become disillusioned with determining within-field nutrient levels because on closer inspection some areas have small-scale variability as great as the variability in the entire field. However, careful analysis of a field shows that even though some areas have extreme variability, most others do not.

Consider a 100-acre field with a NO_3-N composite test of 80 lb/acre (Figure 56) with a range from 10-200 lb NO_3-N/acre. Forty acres has a test level of 30 lb, 20 acres tests 50 lb, 20 acres tests 80 lbs and 20 acres tests 120 lbs. Using the 80 lb/acre composite test over-fertilizes 20 acres while under-fertilizing 60 acres. The within-field method fertilizes 40 acres in the lowest category correctly, fertilizes 18 out of 20 acres testing 50 lb correctly, 15 of 20 acres at the 80 lb level correctly and 10 of 20 acres at the 120 lb level correctly. The composite sample only represented only 20 acres out of 100 correctly, while the within-field sampling method represented 83 acres out of 100 correctly. Even though some areas of the within-field approach were highly variable, the majority of the field benefits from revealing within-field variability.

Soil testing is the basis for fertilizer recommendations in North Dakota. A composite soil sample is a good first step in understanding relative levels among fields. Within-field management of nutrients based on grid sampling or directed sampling may inspire more confidence in soil test recommendations and provide more accurate field nutrient level information.

A composite field test requires from 20 to 30 cores to represent a field. By sampling three to four zones in the field, each with 8 to 12 soil cores, the time spent sampling in the field and the cost of analysis is only increased a small amount, while the information gathered about the field is greatly increased.

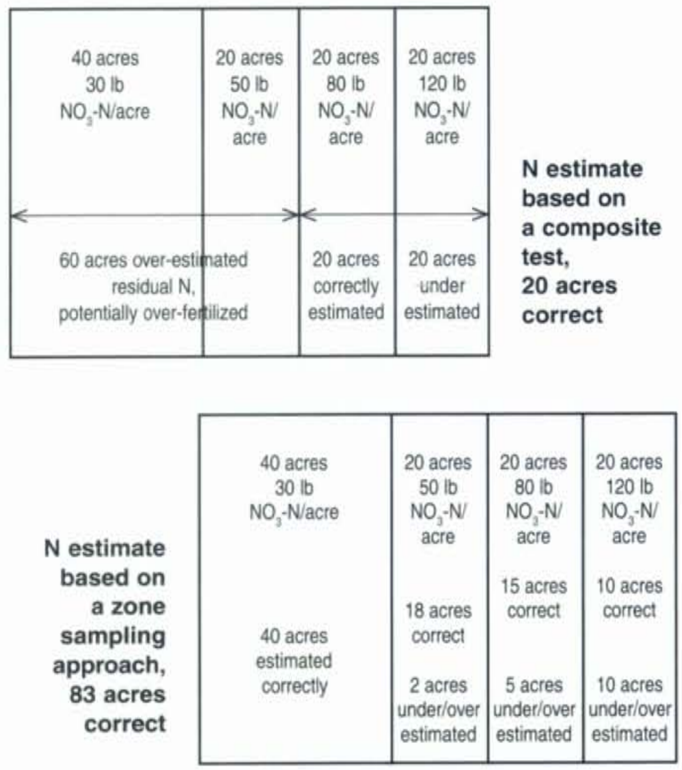


Figure 56. An example of the residual nitrate-N levels correctly and incorrectly characterized using either a composite soil test-based or zone soil test based approach. A 100 acre field with a composite test of 80 lb NO_3-N/acre and a range of 10-200 lb NO_3-N/acre.

Fertility Requirements of North Dakota Crops

Although North Dakota has a reputation as a wheat state, farm producers grow millions of acres of other crops which require unique fertilizer recommendations. A summary of current recommendations in table form is presented following the crop fertilization descriptions.

Hard red spring wheat and other wheats

The major fertility requirements of spring wheat and durum in North Dakota are N (nitrogen) and P (phosphorus). Nitrogen is best supplied to wheat before or at planting to promote tillering in the early stages of growth. If nitrogen rates are low at planting, yield can still be increased by applying fertilizer N up to the 6 leaf stage. After 6 leaf, yield increases with fertilizer N applications are greatly reduced. Protein premiums are sometimes paid by millers for high protein wheat. Protein is enhanced through proper nitrogen fertility, and may also be increased by application of 28% or urea at post-anthesis, watery-ripe growth stage. Research at Carrington has shown that 30 lbs/a of N can increase protein levels about one point (example: from 13% protein up to as high as 14% protein). Care needs to be taken to apply liquids when leaves are wet with dew and temperatures are as cool as possible to avoid burn. Apply urea when leaves are dry and precipitation is expected within a few days for best effects. Test weight and yield may be reduced if foliar N application results in leaf burn.

To plan for protein as well as yield for wheat, instead of the normal N fertilization equation of 2.5 X Yield Goal less credits, the equation 3 X Yield Goal less credits is more appropriate if yield goals are not unrealistically high. Wheat will not contain extra protein at harvest until the minimum requirements needed for yield are first met. Any N remaining and available to wheat after meeting these requirements then goes into protein. In years with conservative N rates and higher yield due to favorable weather conditions, protein levels of wheat are low. In years with similar N rates but low yields due to drought, grain protein is often high. Normal yields of wheat require aggressive N rates to meet the needs of yield and protein.

Phosphate is very important for early wheat growth. Planting often begins when soil is cold and frost is in the ground. Phosphate in a band at planting is more effective than broadcast application in colder soils. Phosphate is particularly important following fallow. A concentrated phosphate band will increase the availability of P to the plant significantly more for fallow than recrop.

Wheat also responds to sulfur if sulfur tests are low. Wheat has also been seen to respond to sulfur following canola, especially if sulfur nutrition of the canola crop was inadequate. Low sulfur levels can reduce both yield and protein level. Chloride has been shown to increase wheat yields an average of 4.5 bu/a where soil test levels are below 40 lbs/a in the top 2 feet of soil. Responses to zinc and other nutrients are rare and should be directed by soil and plant analysis or replicated on-farm testing if deficiencies are suspected.

Copper deficiency has been documented and corrected through applications of 2.5 lb/acre copper as copper sulfate in North Dakota trials on sandy, low organic matter soils. However, the number of yield increases on seemingly appropriate soils has been small in percentage of the number of trials. Yield increases were generally in the 4-5 bu/acre range. With the expense of copper, it is at best a site-specifically applied nutrient to suspect soils, with a low chance of recovering costs the first year. Copper application reduced the incidence and severity of scab in wheat, but the reduction was not adequate to protect the crop without aid of a timely fungicide application.

Spring wheat is best fertilized with nitrogen before or at seeding because tillering depends in part on adequate levels of N. Winter wheat is best fertilized with phosphate in the fall with minimal amounts of nitrogen to increase winter survival. Winter wheat should be topdressed in the early spring when soils are firm enough to support application equipment, but not so frozen that significant runoff and loss of N can take place if it were to rain or flood. If winter wheat is grown in the west, the dry soils and periodic warm weather during late winter may make this possible. In the east, where soils are frozen and often wet in the spring, it may be best to apply needed N in the fall, seeding into residue to encourage snow cover and protection from winter winds. Waiting to spring top-dress winter wheat in the east may result in stand damage due to application equipment, and unacceptable risks of volatilization and/or surface N runoff.

Barley

Barley is difficult to fertilize because too little nitrogen will decrease yields while too much N will increase protein and significantly lower quality from malting to feed grade. Stem strength of barley is also low, so higher soil levels of N often cause lodging.

An important management practice in producing malting barley is planting before May 15. Planting after May 15 increases the chances for higher protein due to yield reductions and greater relative amounts of N per bushel of grain produced. In some seasons, planting is delayed due to wet weather conditions. If barley is planted late, the amount of N applied should be significantly reduced, with due consideration to variety and yield potential.

Phosphate is important for barley as well as wheat and should be applied in a band at planting. Barley also responds to chloride at soil test levels below 40 lbs/a in the top 2 feet of soil. Common root rot disease of barley can be reduced by chloride fertilization. Barley is somewhat susceptible to copper deficiency, but as in wheat, application should only be attempted on low organic matter, sandy soils. Consistency of response would be similar to wheat.

Canola

Canola requires adequate amounts of nitrogen, phosphate and potassium as do many other crops in North Dakota. Canola is a tap rooted mustard family plant. It cannot tolerate more than 7 lbs N/acre with the seed through a double-disc drill seeding. Phosphate is best applied in a band below the seeding zone because of the tap-root nature of the crop and because canola seed is placed so shallow that dry weather easily reduces diffusion of P to the roots. However, banded application of P in some form is important for canola, which is a characteristic not shared by many other commonly grown broadleaf crops. Perhaps this is because canola exhibits a low level of mycorrhizal activity compared to other crops. Table 22 shows the limits of N +K_2O that may be placed with the seed under medium moisture conditions. Under dry soil conditions, limits are reduced. Clearly with a double-disc opener, it is not possible to blend ammonium sulfate with phosphate safely at the rates required to supply S to the crop. However, it is possible to use a one-pass fertilization/seeding method when using wide fertilizer spread with narrower spacings with an air-seeder, especially in medium or heavy soils.

Canola has a special requirement for sulfur. Canola takes up about twice as much sulfur as a comparable wheat and barley crop. A range of 20-30 lb S/acre is recommended for canola regardless of soil test values. The sulfur soil test is very poor in predicting response to sulfur and the composite soil test masked the tremendous variability in sulfur in many of our soils. Sulfur should come from a soluble sulfate-S source such as ammonium sulfate. Degradable elemental sulfur in trials in North Dakota and Canada have performed more poorly in trials than soluble forms. There is no reason to blend elemental sulfur and sulfate sulfur together. If sulfur is blended, the entire canola needs should be satisfied as sulfate sulfur first, and then additional S may be added for whatever reason.

If S is not applied at or prior to seeding, it is possible to rescue the crop with a top-dressing of ammonium sulfate as granules or liquid, or liquid ammonium thiosulfate. If liquids are used, application should be delayed until the leaves have taken on their waxy cuticle, usually by the fifth true leaf. Some leaf spotting may occur with liquid applications, but this is cosmetic damage only. Sulfur is not easily taken up through the leaf. Rainfall must follow application so roots can take up the S. Sulfur is not volatile, and so a delay in the interval between application and rainfall is only important in that it delays the movement of S into the plants.

In Canada, limited research showed some response of canola to boron fertilization when soil levels were low. However, responses to boron in North Dakota have not been demonstrated. Canola is tolerant to low soil levels of other micronutrients.

Table 22. Maximum rates of seed-placed N + K_2O for canola, crambe and mustard.

Soil Texture	Disc or knife (1 inch spread) Row Spacing			Spoon or Hoe (2 inch Spread) Row Spacing			Sweep (4-5 inch Spread) Row Spacing		
	inches								
	6	9	12	6	9	12	6	9	12
	Lbs N + K_2O / Acre								
Light	5	0	0	20	15	10	30	20	15
Medium	10	5	5	25	20	15	35	25	20
Heavy	15	10	5	35	25	20	45	30	25

Corn

Nitrogen is the most limiting mineral nutrient for corn. The N recommendation for corn is 1.2 X Yield Goal less adjustments. Nitrogen can be broadcast before planting, or applied sidedress with ammonia, urea, or liquids. Side-dressing is one option for nitrogen application when corn rows are 30 inches or wider. Side-dress is useful in sandy soils for delaying major N applications to avoid the greatest risk of loss due to leaching. It is also useful in poorly drained soils in wet years when early season denitrification occurs due to soil water saturation. It also helps to lengthen the application season in years when planting season time is at a premium. Application knives can be set to go between every row, or every other row, called skip-row application. If using skip-row, it is important to check knife openings frequently since each knife provides all the N to two rows instead of 1/2 to two rows.

Phosphorus is also very important for corn. Phosphate may be broadcast, but even greater performance has been recorded when P was banded at planting. Pop-up fertilizer (down the tube with the seed) should be limited to less than10 lb N + K_2O/acre with the seed. An even better method is the use of a band 2 inches to the side and 2 inches below the seed. If configured in a 2X2 band, any practical rate of N and other nutrient may be applied without injury to germination. However, if a starter effect from the P is needed, then N should be limited to 50 lb N + K_2O/acre in a 2X2 band. If levels of N exceed 50 lb/acre, the band becomes too "hot" for young roots to go near and the P in the band remains unrecovered until the ammonia in the band is transformed to nitrate and roots can begin to grow near the fertilizer P. Remaining N should be applied in another manner.

Potassium may be a problem in certain irrigated sands and sandier areas of the beach ridge and interbeach areas. These soils are more susceptible to low K levels because of the low K retention on these low organic matter loamy sands. Soil testing of these sensitive areas will reveal the need to apply fertilizer K.

Corn is also sensitive to low soil sulfur and zinc levels. Zinc fertility should be checked with routine soil tests when normal soil testing for nitrate, phosphate and potassium is performed. Sulfur soil tests are not accurate. Sulfur deficiency would not be expected in depressional areas on landscapes, nor on medium to heavy soils with organic matter greater than 2.5 %. Sandy loam and coarser soils with low organic matter would be a better indication than a soil test in many situations. An application of 10 lb S/acre would be sufficient for a large corn crop. Zinc sulfate would be a good source to correct zinc and sulfur deficiencies when they occur together.

Table 23. Response of canola to ammonium sulfate and degradable elemental sulfur on three soil types, on conventional till and no-till. Rocklake, N.D.
(NDSU, Halley and Deibert, 1996.)

			Yield, lb/acre Soil Types		
Rate	Source	Tillage	Buse	Barnes	Svea
lb S/acre					
0		CT	400	1020	1180
20	AS	CT	1810	1980	1860
40	AS	CT	1890	1670	1980
40	ES	CT	1260	1290	1470
0		NT	30	240	1450
20	AS	NT	1650	1680	2100
40	AS	NT	1810	1870	1810
40	ES	NT	620	1060	1630

LSD 5% within tillage treatments 155 lb/acre.

Sources – AS= ammonium sulfate (21-0-0-24S)
ES= degradable elemental sulfur (0-0-90S)
Tillage – CT= conventional tillage NT= no-till

Zinc status should be checked using a soil test. If soil test levels with a DTPA soil extractant were less than 1 ppm on a composite soil sample basis, some Zn fertilizer should be applied. It is especially important to add Zn to low testing soils when P is applied at any rate in a banded application at seeding. Zinc is the only micronutrient that has caused a yield response for corn in North Dakota. Application of Zn in a 2 X 2 band with 10-34-0 has been shown to be a good way to provide Zn for corn.

Buckwheat

Buckwheat has a reputation as a good scavenger of fertilizer, but buckwheat responds well to phosphate and potassium when soil test levels are low to medium. Nitrogen is important for good buckwheat yields, but rates which are too high can promote lodging. In limited North Dakota studies, addition of 40 lb N/acre did not cause lodging, while 80 lb N/acre caused lodging. Nitrogen recommendations are 2.2 X Yield Goal in bu/a less soil test nitrate to 2 feet. Levels of N + K_2O applied with the seed should not exceed 5 lbs/a. Buckwheat performs well on residual P fertilizer, so many times it is not added to the crop, but it is important to supply extra P to previous and/or subsequent crops so that soil test levels remain stable. Buckwheat takes up about twice the P as wheat and most is returned to the soil in the residue. Because buckwheat is a good scavenger of nutrients and a provider of those nutrients when its residues decompose, it is a popular crop with organic growers. Sulfur may occasionally be a limiting factor to production.

Dry bean

Dry bean is a legume and when the proper rhizobia are present and environmental conditions are favorable, it has the ability to fix a significant amount of nitrogen. However, the relationship between dry bean rhizobia and dry bean roots is weak. The longevity of inoculum in the soil and the effects of dry, hot weather during the growing season reduce the potential for the crop to fix all of the nitrogen required for top yields. In addition, to control seedling bacterial blight, most dry bean seed is treated with a seed treatment containing the anti-bacterial agent streptomycin, which is also toxic to many strains of dry bean rhizobia. Inoculation has not been very successful in the past in providing consistent N-fixing power to the dry bean crop.

The current dry bean N recommendations are 0.05 X Yield Goal in pounds. This includes both the sum of soil test nitrate N and N fertilizer needed. For a 2000 lbs/a dry bean crop, for example, a total of 100 lbs N/a is required from both residual soil nitrate N and supplemental N fertilizer. Recent work suggests that newer rhizobium strains can supply 20-30 lbs N/a if seed is inoculated in the planter box directly prior to seeding. There is no current general recommendation, however, regarding modification of N levels when inoculating with these newer strains. It is understood in making N recommendations for dry beans that the yield goal is conservative. If a grower is normally growing 1,500 lb/acre of pinto beans, the N recommendations should be based on this yield, not a more aggressive goal. In certain crops, it is necessary to be aggressive in choosing N rates for quality reasons, but not for dry beans. Also, if the history of raising dry beans on certain fields has shown consistently good nodulation, as is often the case in fields with a long history of dry beans in medium, high organic matter soils, no additional N would be needed, and neither would inoculation.

Dry bean is not very responsive to P or K fertilizer unless levels are low. No fertilizer should be put in contact with dry bean seed. Using a 2X2 band at seeding would be the best method to apply zinc (Zn) at seeding.

Dry bean is very sensitive to iron and zinc (Zn) deficiency. Dry bean usually grows out of early season iron deficiency, but Zn deficiency can cause major yield losses. Most dry bean growers should apply some zinc if soil test levels are less than 1 ppm. A Zn deficiency in the field can be corrected by application of about ¼ -½ lb/acre Zn as a foliar spray.

Flax

Nitrogen rates on flax are 3 X Yield Goal in bushels, less soil test nitrate N in the top 2 feet. It is assumed by these recommendations that yield goals will be conservative. New growers and those growing 20-30 bu/acre flax should set goals of 30 bu/acre maximum to avoid lodging due to excessive N rates.

Flax is not very responsive to fertilizer P. Flax does better feeding off residual P rather than banded or broadcast P the year of seeding. If P must be added at seeding as a carrier for Zn, use as low a rate as possible. Ideally, no fertilizer should be added with the seed at planting. It is important to maintain soil test P levels even when no fertilizer is added to the flax crop. More responsive rotational crops such as small grains and canola could be supplemented with additional P over their normal rates to help maintain soil tests.

Flax is susceptible to iron and zinc deficiency. Iron deficiency symptoms are usually seen in cool, wet springs, in susceptible soils (significant carbonates and soluble salts present). If certain fields have a history of chlorosis, selecting more chlorosis tolerant varieties would be the preferred method of alleviating the problem. Foliar sprays of ferrous sulfate can sometimes effectively reduce symptoms until warmer, drier weather takes care of the problem. Iron applied directly to the soil is very inefficient and has induced manganese deficiency in flax, so this method of treatment should be avoided.

Zinc deficiency reveals itself in flax as a condition called "chlorotic dieback" (Figure 57), in which the growing points of the flax die and the plant branches into several new leaders. Zinc deficiency can be reduced with soil zinc applications prior to planting. Zinc sulfate foliar sprays may also be effective.

Figure 57. Chlorotic dieback in flax. Fertilizing with zinc will prevent this problem.

Lentil

Lentil is a legume and requires a proper inoculant mixed with the seed before planting to supply needed nitrogen. If properly inoculated, no additional nitrogen is required. Lentils are very susceptible to fertilizer injury to the seed. Although many farmers apply some phosphate with lentils at seeding, field trials have shown no benefit to this practice. Lentils are very good scavengers of P and would perform very well on residual applications from previous crops. Fortifying the P rate of the crop preceding lentils or the crop subsequent the lentil crop would maintain soil P levels.

Lentil has not been shown susceptible to micronutrient deficiencies in North Dakota. Lentil contributes N to the subsequent crop at a rate of about 1.25 X Yield in bu/acre, or about 40 lb N/acre.

Millet and canary seed

The nitrogen recommendation for millet and canary seed is 0.035 X Yield Goal in lbs/a less soil test N to 2 feet. A 2000 lbs/a yield goal would require 70 lbs N/a less soil test nitrate N, for example. Millet and canary seed will respond to P and K fertilizer when soil test levels are low to medium. Sulfur deficiencies have been noted on very coarse, sandy soils. A history of sulfur problems on these soils within a farm as well as low sulfur soil test levels would be reasons to apply sulfur. Levels up to 10 lbs S/a could be applied in low sulfur soils. Millet and canary seed are sometimes grown as last resort crops in fields that dry up too late in the season to plant a longer season crop. In these situations, little fertilizer is normally applied. However, the producer who is serious about raising a productive crop should give equal attention to millet and canary seed soil fertility as for other crops.

Oats

Nitrogen application to oat should be directed by soil test. The nitrogen recommendation is 1.3 X Yield Goal less soil test nitrate N to 2 feet. Oat will respond to fertilizer P and K in low to medium soil test levels. Usually, all fertilizer N is applied prior to or at seeding. Oat has not been responsive to micronutrient applications in North Dakota.

Oat-pea forage or hay

Properly inoculated, the pea fraction of the hay does not require fertilizer N. However, the oat crop does not benefit from the N fixed by pea during the growing year. Nitrogen recommended for the oat fraction should be 50 % of the rate recommended for a normal crop of oats. Apply the P and K needed for a full oat crop and inoculate peas before seeding.

Pea, field

Field pea seed needs to be properly inoculated before planting to supply its N needs. Each crop needs a specific inoculum for proper nitrogen fixation, so ask for inoculum specifically adapted to pea. Pea is susceptible to fertilizer salt injury. No fertilizer should come in contact with the seed. Many field pea growers have applied some P with the seed, but research trials across North Dakota have not demonstrated a benefit to this practice. Field peas are good scavengers of P and perform well on residual application from previous crops. Soil test P can be maintained by adding supplemental P to the previous crop or subsequent crop in the rotation.

Fertilizer K is needed only when soil test levels are low, usually on sandy, leached soils. Sulfur deficiencies may be seen, usually on low organic matter, sandy, eroded soils. Rates of S of 10 lb/acre would be sufficient if applied as soluble sulfate form to alleviate deficiency. Field pea has not been shown to be susceptible to micronutrient deficiencies in North Dakota, except for iron chlorosis in more poorly drained areas.

Potato

Potato is a very high value crop. The price paid to growers is a reflection of both quantity and quality, with quality being the number one factor. Potato quality is dependent on sustained N fertility throughout the growing season. The traditional method to accomplish this was to over-apply nitrogen fertilizer early in the season, hoping that enough N would last until late in the season. However, under irrigation, water will leach nitrates out of the rooting zone regardless of concentration, leaving low N levels in the root zone despite high initial N rates.

Many producers now rely on split N applications, with some applied preplant, some at emergence and the rest at hilling. In addition, leaf petiole samples are taken weekly beginning at tuber initiation to monitor nitrate levels within the plants and enable producers to apply small amounts of nitrogen through irrigation water (fertigation) to keep levels up to standards and keep tuber quality high. Petiole sap nitrate levels at initiation to bulking are kept at least 25,000 ppm, while after bulking petiole sap nitrate levels are kept above 15,000 ppm. This procedure minimizes off-site losses of nitrate and increases the efficiency of nitrogen fertilizer applied.

Nitrogen recommendations for potato are 0.4 X Yield Goal in hundred-weight, less soil test nitrate to 2 feet. The advent of precision fertilizer application is another tool that potato growers could use to even out the N applied to potatoes and reduce residual nitrate left in the field that could have adverse effects on subsequent crop quality or groundwater quality.

Potato responds to both P and K fertilizers for soils that test low to high for these nutrients. Although P and K requirements are large, fertilizers need to be separated from the seed at planting. A typical application of banded starter is placed over the seed pieces, so that roots growing in the hill formed later in the season will be close to the fertilizer nutrients. Zinc and S are also required and are sometimes deficient in the region. Soil testing is a good indicator of Zn status, while sulfur levels would be expected to be low in low organic matter, sandy soils. Tissue analysis during the growing season is also be a good indicator of sulfur status and remediation could be made through an irrigation pivot.

Rye

Fertilizer recommendations for rye are similar to those for wheat. Refer to wheat for fertility information. Rye is resistant to copper deficiency and would show a very low response rate for this nutrient compared to wheat, barley and oats.

Safflower

Safflower nitrogen recommendations are identical to sunflower and dry bean; 0.05 X Yield Goal in lbs/a less soil test nitrate N to 2 feet. Safflower is also the deepest rooted of all of our annual crops, equal or greater than sugarbeet. Safflower would likely take advantage of deep N (N found at the 2-4 foot depth), so some consideration for this should be made in recommendations. Growers receive payment for safflower based on percentage oil, which decreases with added N. N rates should therefore be rather conservative due to the possibility of deep N not tapped by other rotational crops. If the soil is not too rocky, selected areas could be sampled more deeply to screen for deep N prior to fertilization. Safflower will respond to P and K fertilizers when soil test levels are low to medium.

Sorghum, grain

Grain sorghum requires relatively high levels of N. The N recommendations are 1.1 X Yield Goal in bu/a less soil test nitrate N in the top 2 feet. Sorghum will respond to P and K when soil test levels are low to medium. Levels of N greater than 10 lbs/a with the seed should be avoided. Growing varieties with more iron chlorosis tolerance will reduce problems with iron deficiency symptoms on high pH soils. Sulfur recommendations should be directed by soil test in the top 2 feet.

Sorghum, forage and sudangrass

Sorghum and sudangrass require very high nitrogen fertility for high yields. The N recommendations are 25 X Yield Goal in wet tons/a less soil test N in the top 2 feet. Refer to production literature on prussic acid formation in sorghum family forages for effects of frost on forage quality and animal safety. Sorghum and sudangrass forages will respond to P and K fertilizer up through high soil P and K levels.

Soybean

Soybean is a legume and therefore produces its own N when properly inoculated under low stress conditions. Growers with a history of soybeans and little if any chlorosis should not need supplemental N, and if soybeans have been well nodulated in the past and the rotation is less than four years, there should be no need for annual inoculation. However, new soybean growers and growers with a history of chlorosis and early season stress should soil test for N. If levels of nitrate are less than 50 lb/acre, then application to reach the 50 lb/acre level has been shown beneficial.

Soybeans are effective scavengers of P. On low testing (Olsen P< 8 ppm) soils, soybeans have been shown to respond to P in both banded and broadcast applications. Broadcast applications usually yield more than banded applications. Soybeans seldom respond to P at medium or higher soil test levels. No fertilizer should be applied in the row when rows are wider than 15 inches. On solid-seeded soybeans, rates up to 10 lb N/acre in a 6-inch band (5 lb/acre in a 12-inch band) may be applied. However, in medium or high testing soils, soybeans perform well by utilizing application of P. The most common fertilizer program in the Corn Belt is to apply all of the P for both, corn and soybeans to the corn crop and the soybean grows on the residual. Applying extra P on the previous crop or the following crop would help maintain soil test levels and feed soybeans well.

If soil test K levels are less than 150 ppm, soybeans respond to K fertilizer. Broadcast application of K is recommended. Soybean is susceptible to iron chlorosis at high soil pH levels. Iron chlorosis sometimes lingers for many weeks into the summer growing season in North Dakota. Other factors which may complicate iron chlorosis are salinity, tillage history, compaction and water table depth. It is important to grow the most iron chlorosis and salt tolerant variety available for the maturity. If soil salt levels exceed 1.5 mmoh/cm, soybean performance will be low. Other methods of reducing chlorosis are cultivation, increased seeding rates, planting in wider rows, avoiding solid seeding, and the use of no-till.

Sunflower

Sunflower is a deep-rooted annual crop with a relatively large requirement for N. Nitrogen recommendations are 0.05 X Yield Goal in lb/a less soil test nitrate N to 2 feet. The recommendations assume up to 30 lbs/acre of nitrate N from the 2-4 foot depth, which a sunflower can easily root into. If the soil is sampled at the 2-4 foot depth, and greater than 30 lbs/a of N is found, then the N recommendation may be reduced by 80% of the N found in the 2-4 foot zone that exceeds 30 lbs/acre. For example, if a 2-4 ft. nitrate test came back 50 lbs/a, then 16 lbs N/a (50-30)X 0.8) could be subtracted from the original nitrogen recommendation.

Sunflower will respond to P and K fertilizer when soil P and K test levels are low to medium.

The amount of N + K_2O allowable with the seed before severe stand loss is possible is about 10 lb /acre in a 30 inch row. Some sunflowers today are solid-seeded in rows from 6 to 14 inches in row-spacing. Using the same rate per length of row as in a 30-inch row spacing, the limits for a 15-inch row would be 20 lb/acre and for a 7.5 inch row, there would be a 40 lb/acre limit. Although research overseas has shown that sunflower is one of the most responsive crops to fertilizer boron application, and local research has shown that B soil test levels are generally low in the state, especially in the western part of the state, there is no reason to generally regard B deficiency as a problem. Boron applications to low testing soils in western North Dakota and in the central part of the state have shown no consistent response to B application.

Sugarbeet

Returns from sugarbeet production are related to quality of beets as well as tonnage. Quality of sugarbeet comes from a high percent sugar and a low percentage of impurities, particularly loss to molasses. Sugarbeet needs adequate nitrogen early in the growing season for root production, but needs decreasing levels of N beginning about six weeks before harvest to increase sugar content and decrease impurities in the roots. Overfertilization with N can result in poor quality beets and reduced net returns.

New N rates are based on growing a profitable crop of sugarbeets, not on yield goal. It is assumed that the grower will be raising at least 20 ton beets. In good years, extra mineralization of organic matter N will contribute to higher yields. A rate of 130 lb N less soil test nitrate-N to a 4 foot depth is required for this yield. About 65 lbs/a of residual soil nitrate N plus fertilizer N should be in the 0-2 foot depth prior to seeding regardless of the amount below 2 feet. 10-15 lbs/a of N should be in the top 6 inches to establish the crop. Broadcast N applications greater than 100 lbs/acre are not recommended at seeding due to stand reduction potential due to salt or ammonia effects.

Sugarbeet seed and seedlings are sensitive to fertilizer salts. Nitrogen + potassium (K) levels should not exceed 5 lbs/a with the seed. Banded starter fertilizer applications have been successful in increasing yields some years. A popular fertilizer P application consists of 3 gallons (about 40 lb/acre) of 10-34-0, diluted with an additional 3 gallons of water per acre. Research trials have recently shown that this low rate was equivalent in sugarbeet return to much larger broadcast applications of fertilizer P. Producers using low rates of P need to be mindful of decreasing soil test P levels over time and should strive to increase rates to other crops so that soil test levels are stable. There should be at least 2 inches of fertilizer and seed separation if starter rates have high levels of N + K. Most fertilizer P and K is applied as a broadcast application.

Sugarbeet is sometimes sensitive to low zinc levels. Soil tests for zinc may indicate fields that need zinc. Calcium deficiencies have been reported, but these are physiological in nature and are not the result of any true soil supply problem. When soils are dry, or when the weather is humid, water is not translocated aggressively throughout the plants as normal. Calcium and boron, which are two nutrients drawn chiefly to new growing tissue through the transpiration stream may become deficient under these conditions. Plant growth usually continues normally when weather patterns change.

Lately, some areas of sugarbeets have experienced stunting early in the season, usually evident by the six-leaf stage of growth.Increases in growth have been associated with P fertilization in areas where plant P levels are low and large increases in growth have been seen with lime application to low pH soils (pH 5.5).

Grassland fertilization

Rangeland is seldom fertilized in North Dakota. It is often cheaper to rent more land than pay for fertilizer. However, there is substantial evidence to encourage fertilization of both tame and native grasses.

Native grass (blue grama, needle and thread and buffalo grass, for example) and tame grass (crested wheatgrass, bromegrass and Russian wildrye, for example) respond to nitrogen fertilization. Forage yield increases of 200% are common in the literature, as well as beef gains of 300% per acre over no fertilizer N. Additions as low as 50 lbs N/a are sufficient to provide these large increases in forage yield and beef gain. Fertilization with nitrogen not only increases stocking rate of pastures, but keeps forage cover longer on fields thereby reducing weed competition. By increasing the productivity of existing pastures, the total maintenance associated with needing additional pastures, such as water pipe and fence repair, are reduced, increasing the overall efficiency of operations.On the down side, if nitrogen fertilizer is applied to a native grass and forb pasture, the grass will tend to take over at the expense of the forbs. If this is not desirable, then nitrogen fertilizer should not be applied to native grass and forb pastures.

Native grasses do not respond to phosphorus fertilization. Native grasses are good scavengers of phosphate, and are able to use residual phosphate more than tame grasses. Tame grasses respond to phosphate fertilization. Phosphate applications of 30-40 lbs P_2O_5/a when applied with nitrogen, can increase forage yields and beef gain per acre more than nitrogen alone if soil P levels are low to medium.

Nitrogen and phosphorus applications to rangeland can be made in the late autumn after soil temperatures at the 4 inch depth falls to 50°F or lower. However, sandy loam or coarser soils, and rangeland with slopes greater than 5% would best be fertilized in the spring during green-up to avoid runoff or leaching losses. Appropriate nitrogen fertilizers for fall application would include urea, if precipitation falls within two to three days after application, or ammonium sulfate. Spring nitrogen fertilizers could include urea, if precipitation falls within two to three days of application, ammonium nitrate or ammonium sulfate. A good phosphate source would be DAP because of cheaper total N than a similar phosphate application with MAP, but MAP can be used if DAP is not available.

Alfalfa

Alfalfa is a very important hay crop in North Dakota, but its fertility needs tend to be neglected. Alfalfa requires pH of 7.0 or higher for best growth, with high levels of calcium and potassium available as well. These standards are often met by the native pH and potassium levels of many soils in North Dakota. However, about 30% of the cropland in North Dakota has pH levels lower than 7. Land near and west of the Missouri river in particular tends to be low in pH, with some levels bordering on pH 5. Long-lived, healthy alfalfa growth is not possible under low pH conditions. Producers should investigate lime sources from quarries or from the sugarbeet industry to find affordable lime. Quantities of ground limestone in the range of 1-4 ton/acre would be required to increase pH to acceptable levels if pH is low.

Alfalfa hay removal also carries away large amounts of potassium. Around 50 lbs/acre of K_2O are removed for each ton of alfalfa hay. These levels can be excessive for unfertilized sandy soils if not replaced annually.

Alfalfa also has a high boron requirement compared to other crops. Addition of B fertilizer is not normally critical for most crops in the state, but levels of soil B should be checked through soil sampling before alfalfa establishment to make sure that adequate amounts are available to the crop.

Phosphorus levels should be checked before seeding and enough phosphorus applied to build soil levels to a recommended level. If build-up is not possible, then annual applications of phosphorus should be made each fall to replace that removed by each years' crop.

Soil testing and proper soil fertility will increase the alfalfa yield and extend the productivity of the stand. The amount of nitrogen and organic material returned to the soil will also be increased.

Soil Salinity

Soil salinity is caused by the presence of soluble minerals in the rooting zone of plants. Soil salinity is a problem in North Dakota because of the lack of adequate drainage of our landscapes and the climate which results in historically greater evaporation/transpiration in the spring/summer/fall months than precipitation. Depending on landscape and the geological stratification of sediments, salinity may or may not always be present. Where water tables are high due to the surrounding landscapes which move water from higher elevations to depressions, salinity may be a problem even in extended dry periods. However, when rainfall increases over successive years, salinity may invade areas that normally do not show or have salinity problems. During dry years, water table levels drop. In sandy soils, once water tables drop below about 3-feet, salinity cannot wick to the surface with groundwater and salinity is not a problem to crop growth. In clay soils, the water table needs to over 4-feet deep to prevent salinity from wicking up into the root zone. In wet years, water tables rise. When the water table reaches the threshold depth, salt-laden groundwater reaches the surface through capillary action, the water evaporates leaving the salts behind, and the rooting depth becomes increasingly saline.

The solution to saline soils is water management. Reducing fallow with continuous cropping can reduce salinity. In already continuously cropped fields, adding a more water intensive crop to the rotation, such as sunflower or corn, or even alfalfa, is beneficial. Often, salinity creeps into the field from the road ditches. When road ditches fill with water, they exert pressure into the field, since the water cannot easily cross under the compacted roadway. The flow of water is into the field, decreasing water table depth and allowing salts to come to the surface. Seeding a strip of alfalfa 30 feet wide along the road ditch will intercept and lower the water table inside the field so that salts do not reach the surface. This strategy has been successful in reducing salinity along road ditches.

Research at Langdon has shown that adoption of no-till increased water percolation through the soil, reducing the concentration of salts at the surface and promoting leaching of salts through the root zone during periods of excess rainfall. This allowed crops to be established, which in turn used water and helped to dry the soil, reducing overall salinity.

It is a common practice to till around and through saline areas. It would be better to let weeds grow and mow them rather than to till. Tillage creates a fallow situation and results in increased water tables and additional salts. Any growing plant, including kochia, would tend to decrease water tables and salinity.

There are no amendments to neutralize the affect of salts. Gypsum is already the primary salt present in many saline areas of the state, so application of more gypsum would certainly not be effective. Some farmers have seen improvement in crop growth in saline areas with manure application, but this alleviation is only temporary, caused by dilution of the salts. As soon as the manure decomposes, the level of salts usually increases due to the addition of salts from the manure.