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NUTRIENT MANAGEMENT for AGRONOMIC CROPS in Nebraska




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Nutrient Management for Agronomic Crops in Nebraska

The University of Nebraska
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Preface

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Nebraska is blessed with fertile soil and vast supplies of groundwater which combine to create an environment well-suited to the production of corn, wheat, grain sorghum, alfalfa, edible beans, and other agronomic crops used for human or animal consumption. Much of the Nebraska economy is based on producing agronomic crops and the livestock to which they are fed. In 2011, Nebraska's total cash receipts from agricultural products were $21.81 billion, which placed it fourth in the nation behind California, Iowa, and Texas. Cash receipts from crops were $11.75 billion, and from livestock, $10.06 billion in 2011. Nebraska ranks among the 10 leading states in corn, grain sorghum, alfalfa hay, dry edible beans, soybean, oats, rye, and sugar beet production.

For most Nebraska crops, at least some fertilization is required to supplement soil nutrient levels for optimum yield potential. Much of the required fertility has come from commercial fertilizers, although Nebraska producers in recent years have become increasingly aware of the need to account for nutrients from a variety of sources such as manure, compost, legumes, and irrigation water, and have accounted for these resources prior to applying fertilizer. In 2011, Nebraska producers purchased 3.58 million tons of all types of fertilizer. Of this, the largest share was for 2.32 million tons of nitrogen (N), mostly as anhydrous ammonia and nitrogen solutions. Over the past 20 years, producers have more carefully managed nitrogen fertilizers, as well as irrigation water on irrigated fields, to minimize nitrogen loss to ground and surface water. Consequently, even though average crop yields continue to increase, the rates of nitrogen applied to corn have tended to plateau or even decline. Producers have continued to adopt practices such as delayed nitrogen fertilizer application, crop rotation, band application, nitrification inhibitor use, efficient irrigation water application, and others that have increased fertilizer efficiency throughout the state.

This manual is a guide to nutrient use from all sources for the production of Nebraska's major agronomic crops: corn, winter wheat, grain sorghum, oats, alfalfa, dry edible beans, soybean, sugar beets, popcorn, sunflower, millet, potatoes, and cool and warm season grasses for hay and pasture. Part I of the manual contains information focusing on basic principles of soil fertility for the primary, secondary, and micro nutrients, as well as chemical and physical properties of soil and soil management. Part II contains chapters devoted to each crop, with information on current fertilizer recommendations for each.

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Part I

Principles of Fertility

Nutrient Management for Agronomic Crops in Nebraska

1 Nitrogen

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Nitrogen (N) is one of the most abundant elements on earth, and after carbon (C), hydrogen (H), and oxygen (O), the element living creatures need most. The atmosphere over each square foot of the earth's surface — which is 78% dinitrogen (N_2) gas — contains approximately 6,000 pounds of nitrogen. However, the majority of the earth's nitrogen (98%) is in rock, sediment, and soils. The amount of nitrogen in rocks is about 50 times more than that in the atmosphere, and the amount in the atmosphere is approximately 5,000 times more than that found in soils (Stevenson, 1982). Biological fixation of nitrogen and atmospheric deposition are the primary means by which nitrogen is added to soil. (Fixation is the conversion of dinitrogen gas — which is chemically unreactive — to nitrogen combined with other elements, such as oxygen or hydrogen, which can readily undergo chemical reactions.) The atmosphere contributes approximately 11.4 pounds of nitrogen per acre to soils annually (Stevenson, 1982). Biological nitrogen fixation accounts for 8.2 of the 11.4 pounds of nitrogen per acre per year. Biological nitrogen fixation occurs symbiotically (dinitrogen-fixing bacteria, such as *Rhizobium,* in conjunction with legumes) and non-symbiotically (free living organisms such as photosynthetic bacteria, blue-green algae, and free-living *Azotobacter* species). The balance, 3.2 pounds of nitrogen per acre per year, consists of various sources of ammonium (NH_4^+), nitrate (NO_3^-) and nitrite (NO_2^-) deposited in precipitation. The amount of nitrogen added each year from atmospheric deposition varies considerably with climate and proximity to industrial sources of atmospheric nitrogen, but generally it is too small to significantly affect crop production.

Forms of Nitrogen in Soil

In addition to nitrogen occurring as atmospheric dinitrogen gas in soil pore spaces, nitrogen occurs in both organic and inorganic forms in the soil.

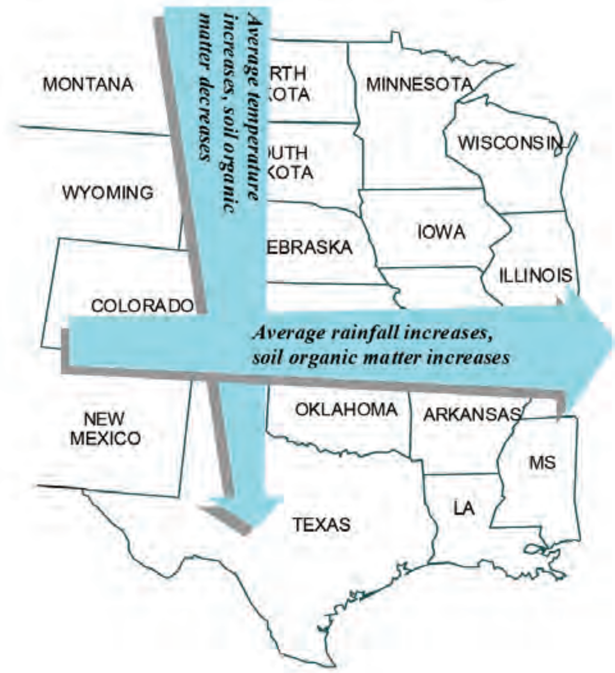
Organic nitrogen

Several organic compounds (compounds containing carbon), grouped into humic, fulvic, and amino acids, amino sugars, and other proteins, compose the organic fraction of nitrogen in soil. Soil organic matter exists as decomposing plant and animal residues, relatively stable products of decomposition-resistant compounds, and humus. Nitrogen has accumulated in these various organic fractions during soil development.

Organic matter formation and stability is largely related to long-term moisture and temperature trends. With higher average temperatures, soil organic matter decreases. As moisture increases, soil organic matter increases. Higher temperatures lead to more rapid and complete organic matter decomposition to soluble products which can leach from soil. Increasing moisture causes more plant growth, resulting in more organic residue. Trends of moisture, temperature, and organic matter in soils in the Midwest and Great Plains are shown in Figure 1-1.

FIGURE 1-1

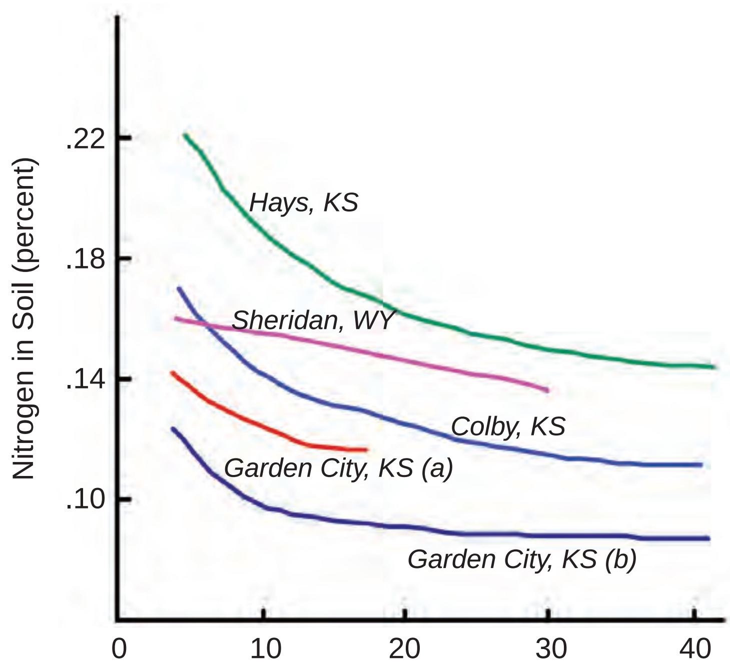
Soil organic matter in relation to temperature and moisture. Soil organic matter decreases with higher average temperatures. It increases as moisture increases.



Through thousands of years of development, soils in the Midwest have accumulated significant quantities of organic matter; yet organic matter levels have declined by cultivating virgin soils, thereby increasing organic matter oxidation and decreasing soil organic matter nitrogen through crop uptake (Figure 1-2). Soils that once contained 4% to 5% organic matter may contain only 1% to 2% after 50 years of cultivation. However, soils under cultivation in the Midwest have, for the most part, reached a new equilibrium of organic matter levels with widespread commercial fertilizer use. Reduced tillage techniques in combination with legume rotations and judicial fertilizer use may increase organic matter levels with time.

FIGURE 1-2

The influence of long-term cropping on organic nitrogen in soils in the Midwest (adapted from W.J. Hase et al., 1957; Nitrogen and carbon changes in Great Plains soils as influenced by cropping and soil treatments; Technical bulletin 1167, USDA, Washington D.C.).



The nitrogen cycle

Ammonium and nitrate are the predominate inorganic forms of nitrogen in soils. Ammonium exists as exchangeable and nonexchangeable forms. Nitrite and nitrous oxide (N_2O) are present in soil in lesser quantities. Plants normally use nitrogen in only the ammonium and nitrate forms. Nitrite is actually toxic to plants. The nitrogen cycle (Figure 1-3) shows reactions that various inorganic nitrogen compounds undergo in soil. The nitrogen cycle begins with nitrogen in its simplest stable form, dinitrogen (N_2), and follows it through the processes of fixation, mineralization, nitrification, leaching, plant assimilation, ammonia volatilization, denitrification, and immobilization.

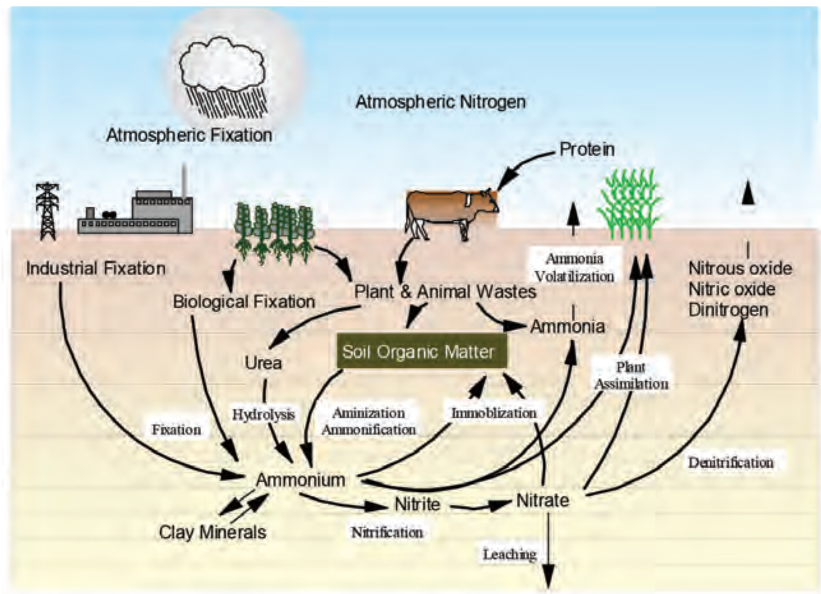


FIGURE 1-3

The nitrogen cycle.

Fixation

As described earlier, fixation is the process of converting dinitrogen gas to chemically reactive forms — where nitrogen combines with other elements such as oxygen, hydrogen, and carbon. Energy is required to convert dinitrogen to ammonia or other forms of fixed nitrogen. Lightning fixes nitrogen into various oxides that rain and snow deposit, typically less than 10 pounds of total nitrogen per acre per year. Bacteria can convert nitrogen to organic forms through fixation. Fixation can occur either in free-living organisms or symbiotically in association with legumes.

Nitrogen is also fixed industrially through several processes using fossil fuel as an energy source.

Mineralization

Once nitrogen is fixed, it is subject to several chemical reactions which can convert it to different organic or inorganic forms. Mineralization occurs in soil as microorganisms convert organic nitrogen to inorganic forms. The first step of mineralization is called aminization, in which microorganisms (primarily heterotrophs) break down complex proteins to simpler amino acids, amides, and amines. *Heterotrophic* microorganisms require preformed organic compounds as sources of carbon and energy. *Autotrophic* microorganisms can derive energy from the oxidation of inorganic elements or compounds such as iron (Fe), sulfur (S), ammonium, nitrite, or from radiant energy; they derive their carbon from carbon dioxide (CO_2). For example, urea is an amide added directly to soil either in animal urine or as commercial fertilizer.

EQUATIONS 1-1 AND 1-2

Mineralization.

$$\text{Aminization: } Proteins \rightarrow R^{*}\text{-}NH_2 + CO_2$$

(*R designates a carbon chain of indefinite length.)

Ammonification is the second step of mineralization in which amino (NH_2) groups are converted to ammonium. Again, microorganisms (primarily autotrophic) accomplish this action.

$$\text{Ammonification: } R\text{-}NH_2 + H_2O \rightarrow NH_3 + R\text{-}OH$$

Nitrification

Microbial activity is also responsible for the two steps of nitrification. *Nitrosomonas* (obligate autotrophic bacteria) convert ammonium to nitrite. Nitrification inhibitors, such as nitrapyrin (N-Serve®) or dicyandiamide (DCD) interfere with the function of these bacteria, blocking ammonium conversion to leachable nitrate. The second step of nitrification occurs through *Nitrobacter* species, which convert nitrite to nitrate. This step rapidly follows ammonium conversion to nitrite, and consequently nitrite concentrations are normally low in soils.

EQUATIONS 1-3 AND 1-4

Nitrification.

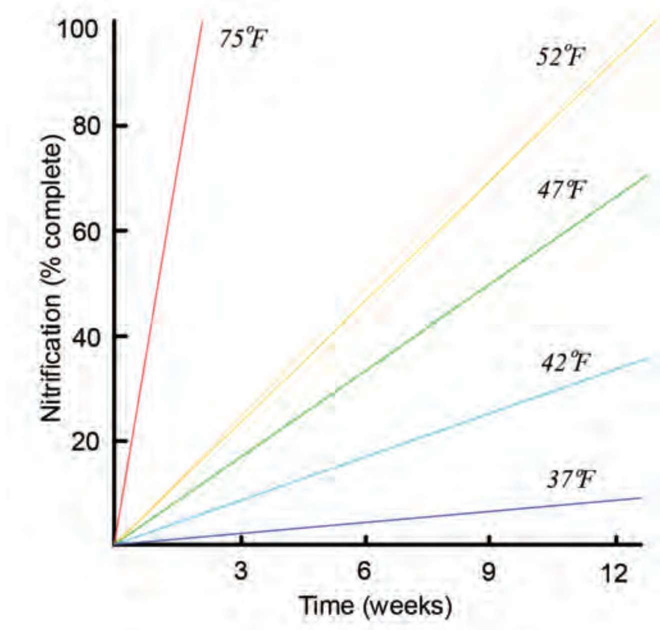
$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+$$

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

Mineralization and nitrification are influenced by environmental factors that affect biological activity such as temperature, moisture, aeration and pH. Nitrification, for example, occurs very slowly at cold temperatures and ceases once the temperature declines below freezing (Figure 1-4). The rate increases with increasing temperature until the point at which bacterial viability is reduced, (around 95°F to 100° F) and then nitrification begins to decline with increasing temperature. Moisture is necessary for microbial function in both the mineralization and nitrification processes. Excessive moisture limits oxygen availability, reducing mineralization and nitrification rates, which, perhaps, lead to anaerobic conditions in the soil. Rates of mineralization and nitrification proceed most rapidly at pH levels near 7, and decline as soils become either excessively acid or alkaline.

Figure 1-4

Reductions in nitrification based on temperature.



Denitrification

Denitrification — the conversion of nitrate to various gaseous forms of nitrogen which can be lost to the atmosphere (nitric oxide, nitrous oxide, dinitrogen) — occurs under oxygen-limiting conditions when anaerobic bacteria use nitrate in respiration in the presence of a carbon source such as organic matter.

Low areas of fields that are subject to ponded water for sustained periods during the irrigation season often exhibit nitrogen deficiencies related to denitrification losses.

Equation 1-5

Denitrification.

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

Denitrification losses from saturated soil will vary with temperature and the amount of carbon (organic matter) available. Table 1-1 illustrates the effect that time and temperature can have on potential nitrogen losses from denitrification.

Table 1-1

Denitrification rates from saturated soil*.

Time	Temperature	N loss
days	*degrees F*	*percent*
5	55 - 60	10
10	55 - 60	25
3	75 - 80	60

*Denitrification loss will be less with soils having less than 1% organic matter.

Ammonia volatilization

Ammonia (NH_3) loss to the atmosphere is called ammonia volatilization. Technically, ammonia volatilization is different from gaseous loss of applied anhydrous ammonia, which is not retained in the soil. Instead, ammonia volatilization occurs when ammonium in the soil, because of pH, is converted to ammonia, which can be lost as a gas. Ammonia volatilization is normally only a problem in Nebraska with fertilizers containing urea, such as urea or urea ammonium nitrate (UAN) solution. Urea in soil is decomposed, or hydrolyzed, enzymatically by the enzyme urease to ammonium.

EQUATION 1-6

Ammonia volatilization.

$$CO(NH_{2\ \text{urease}})_2 + H^+ + 2H_2O \longrightarrow 2NH_4^+ + HCO_3^-$$

$$+ H^+ \leftrightarrow CO_2\uparrow + H_2O + NH_4 \leftrightarrow NH_3\uparrow + H^+$$

Ammonia loss can be significant where the producer surface-applies fertilizers containing urea without incorporation, particularly if significant amounts of residue are present and conditions are warm and moist (Figure 1-5). The amount of total nitrogen loss from fertilizers containing urea due to ammonia volatilization can vary considerably, from no loss to 50% or more of the applied nitrogen. Typical losses from urea broadcast to a silt loam soil in the spring, without rain for at least a week following application, may be in the range of 10% to 20% of the applied nitrogen. The potential for ammonia volatilization is influenced by soil moisture, temperature, soil pH, soil buffering capacity, urease activity, residue cover, precipitation, wind and other factors. Warm, moist soil with heavy residue and urea broadcast to the surface are ideal conditions for ammonia loss. Precipitation or irrigation of ½ inch or more is adequate to move urea far enough into the soil to minimize volatilization loss potential.

FIGURE 1-5

Urea granules on corn residue.

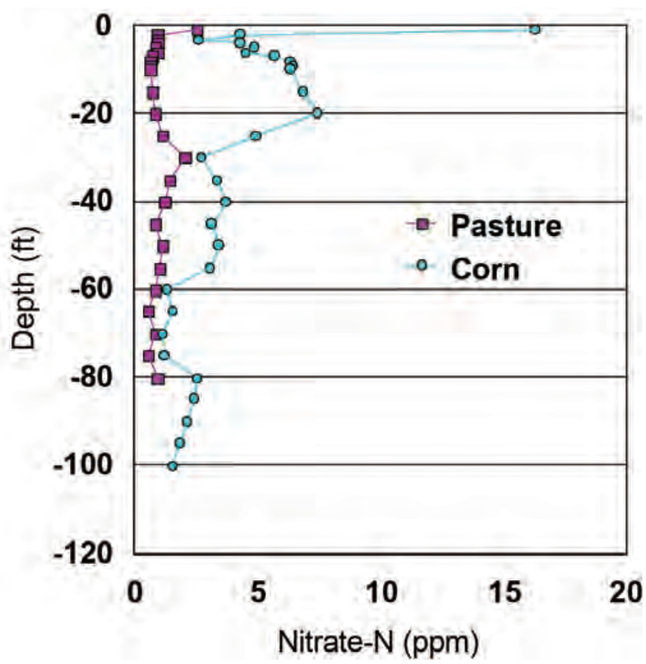


FIGURE 1-6

The effect of nitrogen fertilization and irrigation on vadose zone nitrate levels (Upper Big Blue Natural Resources District — Mid-Nebraska Water Quality Demonstration Project).

Leaching

In order for leaching to occur, nitrogen must be in a water soluble, mobile form and abundant enough to transport nitrogen through the soil. Although urea and nitrite are mobile, neither exists in significant concentrations in soil. Nitrate is the form of nitrogen most susceptible to leaching loss. Nitrate leached below the root zone (4 to 6 feet) of most agronomic crops will eventually leach downward until it reaches a saturated zone, either an aquifer or aquitard. Nitrate leached below four to six feet is generally unrecoverable by most crops except deep rooted species such as alfalfa. The rate of nitrate movement downward depends on a variety of factors, including soil texture, precipitation and irrigation amounts, crop uptake of water and nitrate, and so on. Nitrate leaching from relatively sandy soils overlying coarse-textured vadose zones and shallow aquifers (such as in the Central Platte Valley) can leave the root zone and enter the aquifer in a matter of months, while nitrate leaching from upland, silt loam soils overlying aquifers 100 feet or more below the surface can take 25 to 30 years to reach the aquifer.

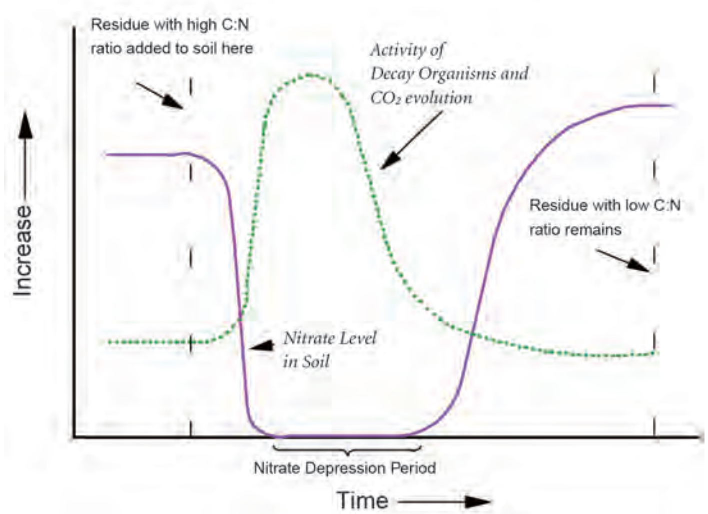
Figure 1-6 shows the nitrate levels in the vadose zone of a 35-year continuous irrigated corn field and a native grass pasture. In this example from Seward County, the native grass pasture contains 307 pounds of nitrate-nitrogen per acre to a depth of 80 feet, while the continuous corn field contains 1,224 pounds of nitrate-nitrogen per acre to a depth of 100 feet.

Immobilization

Immobilization, or the temporary tying up of inorganic nitrogen by soil microorganisms decomposing plant residues, is a recycling process. Immobilized nitrogen will be unavailable to plants for a time, but will eventually become available again as residue decomposition proceeds and populations of microorganisms decline (Figure 1-7). Fertilizer nitrogen immobilization can be reduced by placing fertilizers below crop residues, instead of incorporating fertilizer into the soil with residue. The producer can accomplish this most directly by knifing in anhydrous ammonia or solutions.

FIGURE 1-7

Levels of nitrogen available to plants based on microbial decomposition.



The duration of the nitrate depression period during immobilization is dependent on environmental factors such as moisture and temperature and the carbon-to-nitrogen (C:N) ratio of the residue. Soil organic matter contains an average of approximately 50% carbon and 5% nitrogen. This ratio (10:1) is relatively constant for organic matter. The C:N ratio of plant residue ranges from 10:1 for young leguminous plant tissue to as high as 200:1 for straw of some grains.

Plant tissues low in nitrogen generally are more resistant to decomposition and require a longer time before the nitrogen is available to plants.

TABLE 1-2

Typical carbon-to-nitrogen ratios for selected organic materials.

Source	C:N ratio
Organic matter in undisturbed top soil	10:1
Alfalfa	13:1
Cattle manure	20:1
Corn stalks	60:1
Wheat straw	80:1
Coal and shale oil	124:1
Oak	200:1

FIGURE 1-8

Field example of immobilized urea (chlorotic area where urea was incorporated with crop residue) next to NH_3-injected field (darker green area).

When a high C:N ratio plant residue is incorporated into the soil, microbial decomposition of the residue starts. Microorganism populations increase rapidly, evidenced by increased release of CO_2 leaving the soil through respiration. The microorganisms take nitrogen from the soil for synthesis. Consequently, for a period of time the concentration of inorganic nitrogen in the soil declines and may be deficient for plant growth. As residue decomposes, the C:N ratio becomes narrower. At a ratio of approximately 17:1, nitrogen becomes available for plant use. Decomposition continues until the ratio is approximately 10:1 to 15:1.

Plant assimilation

Plants use nitrogen in primarily the nitrate or ammonium forms. If any preference exists, it is usually for ammonium early and nitrate late in the growing season. Research has shown that growth is optimized with a mixture of both ammonia and nitrate, with ammonium used preferentially for synthesis of amino acids and proteins. Some plants can also directly use urea (Harper, 1984), although in most cases urea-nitrogen will hydrolyze to ammonium-nitrogen prior to uptake. In order to take up nitrate-nitrogen, plants require that nitrogen move with water toward the root — a process called mass flow. Consequently, nitrate-nitrogen that has moved below the root zone has potential to move up into the root zone, as surface horizons of soil dry out and crops use water deeper in the profile. Conversely, plants may exhibit symptoms of nitrogen deficiency even though the soil contains adequate amounts of nitrogen, if moisture, and consequently mass flow of nitrogen, is limited.

Nitrogen Fertilizer Management

Nitrogen is a nutrient easily lost from soil through several pathways, as already discussed. Consequently, plants use nitrogen most efficiently if the producer applies it as close as possible to the time of crop uptake. Ideally, this might include multiple applications of nitrogen during a growing season. Center pivot irrigation systems equipped for fertigation and high clearance applicators are two methods to accomplish multiple nitrogen applications. The use of center pivot irrigation systems for fertigation also facilitates the use of a chlorophyll meter to detect nitrogen deficiency and apply nitrogen according to crop demand. Sidedress nitrogen application also allows for more efficient fertilizer use since the producer applies nitrogen close to the period of maximum nitrogen uptake for corn and sorghum. Nitrogen application prior to or at planting is still more efficient than fall application for row crops such as corn and grain sorghum. Fall application may still be a viable option on some soils for row crops. In that case, the producer should only apply anhydrous ammonia in the fall (because it initially is not leachable), if soils are fine-textured and when the soil temperature is 50°F, on average, for a week or longer. With either fall or spring preplant application, nitrification inhibitors, such as N-Serve or DCD, help reduce the potential for leaching or denitrification losses of nitrogen. For nitrogen application to winter wheat, late winter or early spring topdress application allows the producer to assess moisture status and crop condition before deciding on the appropriate nitrogen rate.

Crops use nitrogen more efficiently when it is placed beneath the soil surface. Broadcasting nitrogen on the soil surface increases the likelihood that some nitrogen will be lost due to ammonia volatilization or runoff. This is one reason

Figures 1-9 and 1-10

Nitrogen fertilizer application timings: preplant (top) and at planting (bottom).

Figures 1-11 AND 1-12

Nitrogen fertilizer application methods: sidedress (top) and broadcast (bottom).

why anhydrous ammonia, which must be injected, sometimes appears to be a better nitrogen source than urea or UAN solution, which can be applied on the soil surface. In general, as long as nitrogen fertilizers are correctly applied, all are agronomically equal. If the farmer must apply nitrogen fertilizers to the soil surface, he can increase efficiency by banding, which concentrates the fertilizer and reduces soil/ fertilizer contact. Sprinkler irrigation water application is another efficient method, as long as application rates are not excessive.

The primary nitrogen fertilizers available in Nebraska are anhydrous ammonia (82% nitrogen), urea (44% to 46% nitrogen), UAN solution (28% to 32% nitrogen), ammonium nitrate (33% to 35% nitrogen), and ammonium sulfate (21% nitrogen). Other fertilizers can contain significant amounts of nitrogen, but they are used primarily as sources of nutrients other than nitrogen. All of the above are effective fertilizers when properly applied. Anhydrous ammonia is historically the least expensive nitrogen fertilizer, but it requires injection into the soil, which is a more expensive application method than broadcasting or surface banding. Tillage, irrigation, and rainfall soon after application reduces the potential for significant ammonia loss from urea fertilizers. A recent management option for urea fertilizers is the urease inhibitor Agrotain®. This material contains the active ingredient N-(nbutyl) thiophosphoric triamide (NBPT), which inhibits the function of the urease enzyme (responsible for breaking urea down into ammonium and potentially ammonia) for up to several weeks, depending on temperature. This delay in decomposition of urea can increase the chances of rain or tillage moving the urea into the soil where it is protected from volatile loss. Using a urease inhibitor reduces the risk of applying urea fertilizers on the surface in minimum-tillage, high residue conditions which otherwise have considerable potential for ammonia loss. Urease inhibitors, like nitrification inhibitors, will not guarantee a yield increase every year, but they can protect against yield reductions in years when climatic conditions are conducive to nitrogen loss.

Nitrogen Accounting and Credits

Efficient nitrogen fertilizer use requires that the producer gives proper credit for sources of nitrogen other than the fertilizer before selecting the appropriate nitrogen rate. Significant sources of nitrogen include soil residual nitrate (determined by deep soil sampling), manure, and organic materials (determined by analyzing a sample of the material), legumes (determined according to the previous crop), and irrigation water (determined by irrigation water sampling). Actual nitrogen credits from these sources can vary widely, but in many cases the nitrogen fertilizer rate can be reduced significantly after accounting for these credits. More information on nitrogen accounting is available in the resources listed at the end of this chapter.

Crop Rotations

Whenever possible, the producer should practice rotating crops such as corn and grain sorghum with crops that intensively use nitrogen such as soybeans, alfalfa, and clover. Aside from reducing fertilizer nitrogen requirements, crop rotations provide other proven benefits in terms of reduced insect and weed infestation levels and disease pressure. The nitrogen credit to corn following soybeans is not only because of the additional nitrogen in the soil from the soybeans, but also because the low C:N ratio of soybean residue immobilizes less soil nitrogen and mineralizes nitrogen from residue sooner the following season; this allows more soil nitrogen to be available to the subsequent crop. Legumes such as alfalfa or clover that are tilled in prior to planting corn do increase the level of available nitrogen in the soil as the legume residue mineralizes. Legumes are efficient scavengers of soil nitrate, and can substantially reduce soil nitrate levels following corn. Figure 1-13 illustrates the effect of an annual corn-soybean rotation on the amount of nitrate in the vadose zone. This example, from vadose zone soil cores taken in 1992 from the Long-Term Tillage Study at the University of Nebraska South Central Research and Extension Center Farm, shows the effect of implementing a corn-soybean rotation in 1984.

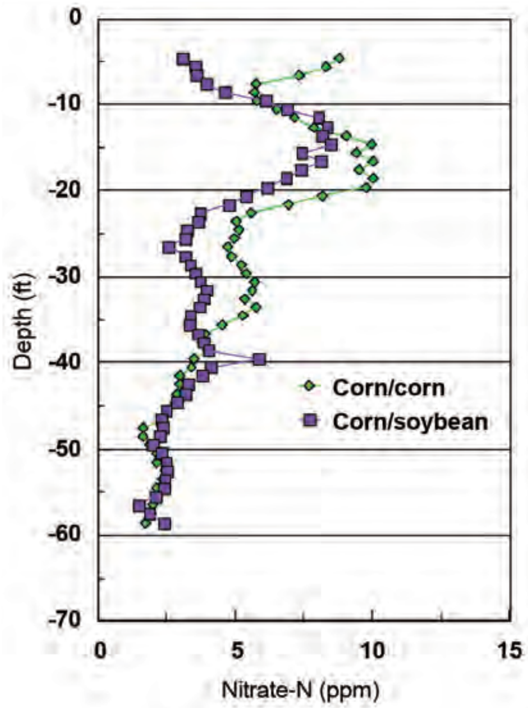


FIGURE 1-13

The effect of an annual corn/soybean rotation on the amount of nitrate found in the vadose zone (A. Katupitiya, 1995; Long-term tillage effects on nitrate accumulation and movement and denitrification in the root and intermediate vadose zones; Ph.D. dissertation, University of Nebraska).

Monitoring Crops for Nitrogen Deficiency

Nitrogen deficiency in plants is fairly easy to diagnose because of the unique symptoms expressed in plants: initial yellowing of lower leaves with the leaf tip and margin affected first. However, by the time such deficiency symptoms become evident, yield reduction may have occurred, depending on the stage of growth. Crop canopy sensors are relatively new tools for nitrogen management which can detect developing nitrogen deficiencies before they are visible, and before they can significantly reduce yield. Other methods for detecting nitrogen stress are the lower stalk nitrate test (which indicates after the season if the nitrogen supply to the crop has been adequate or limiting), chlorophyll meters, and remotely sensed imaging (which can detect developing nitrogen stress similar to the chlorophyll meter). The producer may be able to use a chlorophyll meter or remote sensing to detect nitrogen stress in time to correct a deficiency during a growing season, and then apply necessary nitrogen through high clearance applicators or via fertigation through center pivot irrigation systems.

FIGURES 1-14 AND 1-15

Nitrogen deficiency symptoms in corn.

Summary

Nitrogen is usually the nutrient most limiting to cereal crop production in Nebraska. It is subject to a variety of transformations in the soil. Some of these transformations are necessary to convert nitrogen into forms which plants can use. Other transformation or transport processes limit the availability of nitrogen to plants by converting nitrogen into forms which plants cannot use, or moving nitrogen away from the root zone. Management factors, such as choice of nitrogen source, nitrogen placement method, irrigation management, tillage and residue management all can affect how efficiently crops use nitrogen.

Resources

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2 Phosphorus

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Phosphorus (P) fertilizers are second only to nitrogen (N) in importance for growing crops in Nebraska. However, the principles affecting efficient phosphorus use are totally different. Nitrogen is a mobile nutrient, both inside the plant and in the soil, while phosphorus moves very little in the soil. Additionally, total plant phosphorus requirements are much lower than those for nitrogen. In cereal crops, for example, leaves commonly contain 10 times more nitrogen than phosphorus. However, phosphorus is concentrated in the grain so that only about 2.5 times more nitrogen is removed in harvested grain compared to phosphorus.

FIGURE 2-1

Wheat growth response to phosphorus fertilizer bands.

Availability of Phosphorus

Nebraska soils are generally well supplied with phosphorus. Total phosphorus content averages about 4,700 pounds of phosphate (P_2O_5) per acre for each foot of soil. Assuming a root zone of 6 feet, most Nebraska soils contain about 28,000 pounds of total phosphorus as phosphate. If crops could use all of this phosphorus, Nebraska producers would have a 500-year supply for growing 150 bushels of corn per acre each year. Unfortunately, only a very small amount of this total phosphorus supply is available each year. It must undergo weathering before it becomes available to plants. Even with 28,000 pounds of total phosphorus present in the root zone, phosphorus is often deficient for maximum crop yields.

Deficiency Symptoms

Visual crop symptoms sometimes show phosphorus deficiencies. The classic phosphorus deficiency symptom is a reddish-purple coloring of leaves and stems, usually associated with stunting or small non-thrifty looking plants. Such deficiency coloring usually occurs early in the growing season. While these classic deficiency symptoms are often associated with phosphorus deficiency, reddish coloring of leaves and stems also can be induced by any disruption of plant sugars. Such coloring often appears naturally in sorghum and sometimes during cold wet springs on corn when no real deficiency exists. Therefore, the producer should not rely on visual symptoms as a sole indicator of phosphorus deficiency, although phosphorus deficient grain crops may be smaller and grow more slowly than plants with adequate phosphorus.

FIGURE 2-2

Phosphorus deficiency in grain sorghum.

Fixation

While a phosphorus fertilizer may be completely water soluble (completely plant available), it does not remain this way very long after it is applied to the soil. This process of available phosphorus becoming unavailable to plants is called phosphorus fixation.

The degree of fixation is regulated to a large extent by soil pH. Phosphorus is least available at high and at low soil pH. At soil pHs above 7.2 to 8.5, phosphorus fixes as insoluble calcium phosphates; at soil pHs below about 5.5, iron and aluminum phosphates form, reducing phosphorus availability. Phosphorus availability is greatest at a pH between 6.5 and 7.0.

The producer can do several things to reduce phosphorus fixation and increase soil phosphorus and fertilizer phosphorus availability to plants. Such practices include liming acid soils to increase soil pH to between 6.5 and 7.0, applying small amounts of phosphorus fertilizer frequently rather than large amounts at one time, minimizing soil-fertilizer contact, and placing phosphorus fertilizers in soil areas where roots are most active.

Soil sample collection can have a profound influence on soil test results. The sample should give the average phosphorus status for a given field or part of a field. The sampler must divide fields in such a way that each sample represents a uniform tract of land. Soil parent material, degree of erosion, past cropping and fertilizer history, and manure application should all be uniform. The sampler should collect 10 to 15 cores from each soil area (not to exceed 20 acres) and composite them for one sample. This assumes that previous phosphorus fertilizers have been broadcast uniformly. If phosphorus has been applied in bands, the method of soil sampling changes from a system of random samples to one of systematic sampling. Recent research has indicated a distinct advantage to taking a soil sample equal to the band width perpendicular to the band direction in no-till systems or where bands are not disturbed by tillage. Soil from this sample (at least 1 inch wide, 6 to 8 inches deep and a length equal to the band spacing) should be mixed thoroughly and sub-sampled. This method also reduces the number of samples needed for analysis compared to samples taken at random.

Soil Testing

Soil testing is the best tool available for assessing soil phosphorus needs. Chemical analysis assesses the soil's ability to supply phosphorus. Like a soil test for potassium (K), a soil test value for phosphorus is not a measure of the total amount of phosphorus available for plant use; it is only an index of availability.

Although several phosphorus extraction procedures exist, two methods are most common for Nebraska soils. The weak acid method (Bray-1 P) is the most common and is well-correlated with plant available phosphorus in acid and neutral soils. The Olsen P extraction (sodium bicarbonate) procedure is better adapted for calcerous soils and is more suitable for Nebraska soils where free lime is present or the soil pH is 7.3 or greater. Two other extractants common in Nebraska, Mehlich 2 and 3, lack direct correlation-calibration data, but are correlated with the Bray-1 P or the Olsen P tests. These extractants are generally used as multi-extractants for nutrients in addition to phosphorus. Bray-1 P is approximately equal to 0.9 of Mehlich 2 and 3-colorimetric. Mehlich 3 ICP gives relatively high soil test P values and Bray-1 P can be approximated by substracting 10 and 15 ppm when Mehlich 3 is less and greater than 20 ppm, respectively.

Interpreting soil tests

With several ways to interpret soil test results, many differences exist for the kinds and amounts of fertilizer recommended by various soil testing laboratories.

The method used by the University of Nebraska Soil Testing Laboratory, called deficiency correction, suggests kinds and rates of fertilizer to correct these nutrient deficiencies that are likely to limit yield. For phosphorus, the laboratory suggests applying fertilizer for crops grown on soils where the response to applied phosphorus is probable. Laboratory results showing high soil phosphorus levels indicate a doubtful response to applied phosphorus. This method of making fertilizer recommendations results in minimum usage with optimum yields, but it requires accurate soil sampling and analysis. Furthermore, soil test correlation and calibration information must be adequate for proper interpretation. Application of deficiency correction recommendations over time will tend to increase soil test values for phosphorus in the surface of most Nebraska soils.

The crop removal or maintenance method of making fertilizer recommendations may or may not require a soil test. By this method, crop removal determines nutrient requirements, but recommendations are usually adjusted for high or low levels in the soil. This method results in much higher phosphorus fertilizer recommendations than deficiency correction because the recommendations increase as yield level increases. Nebraska research has not supported increasing phosphorus rates for higher expected yields except for winter wheat. Common phosphorus removal rates in harvest include: 38 pounds P2O5 in 100 bushels of corn and sorghum grain; 35 pounds P2O5 in 10 tons of corn silage; 4 pounds P2O5 in 1 ton of corn residue; 40 pounds P2O5 in 50 bushels of soybean; and 63 pounds P2O5 in 5 tons of alfalfa.

Most commercial laboratories and several university laboratories in the eastern United States use a modified crop removal concept for phosphorus fertilizer recommendations where phosphorus fertilizer recommendations are equal to crop removal on soils testing between 15 and 30 parts per million (ppm) Bray-1 P. For soils below 15 ppm, the laboratories suggest additional phosphorus to build soil levels. Above 30 ppm, the laboratories suggest reducing phosphorus rates to use more of the soil phosphorus. This approach appears inefficient and needlessly expensive for Nebraska soils.

Application Methods

Various methods of banding fertilizer phosphorus will effectively increase fertilizer efficiency. Banding can either reduce the rate of application or provide for higher yields and increased profits on most Nebraska crops. The most common methods are banding, knifing with ammonia, or using a starter applied either with row crops or with the seed for wheat and other small grains. Broadcasting phosphorus is an acceptable application method on alfalfa and grasses. Research has indicated that broadcast phosphorus in no-till row crops, especially under sprinkler irrigation, or with ridge tillage, may be nearly as effective as banding.

Sources of Phosphorus Fertilizer

The original source of phosphorus fertilizer for Nebraska farmers was rock phosphate from Florida and the western United States. This phosphorus is similar in form to much of the total phosphorus found in Nebraska soils. While rock phosphate is sometimes used as a phosphorus fertilizer, research indicates that its low availability restricts its economic use.

To increase the availability of phosphorus in rock phosphate, it is treated with acid. The amount of available phosphorus in a fertilizer varies depending on the kind and amount of acid. Regulations exist to guarantee phosphorus content and availability of phosphorus in fertilizers. These laws require the manufacturer to state the amount of available phosphorus in the fertilizer.

The term “available” can be confusing. Availability infers plant availability, but it is very difficult to measure true plant availability. Therefore, fertilizer phosphorus availability is expressed in terms of a weak acid solubility. The available phosphorus designated by the fertilizer grade (0-46-0) is measured by extracting with a weak citric acid solution. This extraction is related to plant availability.

Most of the phosphorus in fertilizers today is water soluble because these fertilizers are made by treating rock phosphate with phosphoric acid. Depending on the phosphoric acid concentration (55% or 79% P_2O_5), phosphorus fertilizers contain varying amounts of ortho and polyphosphates. Standard triple super phosphate (0-46-0) or dry ammonium phosphates (16-48-0) are examples of orthophosphate fertilizers while 10-34-0 is a liquid fertilizer containing ortho and polyphosphates.

The fertilizer values of orthophosphates and polyphosphates are considered equal. Whether a phosphorus fertilizer is a polyphosphate or an orthophosphate should not dictate fertilizer choice. Other factors such as price are usually more important. However, applying a liquid polyphosphate can increase the availability of some micronutrients such as zinc and iron. This allows the producer to use relatively inexpensive zinc and iron compounds, such as zinc oxide and iron sulfate, to correct deficiencies of these micronutrients.

Contrary to popular belief or advertising claims, liquid fertilizers do not have increased availability or agronomic value over their dry counterparts. There is essentially always adequate water in the soil to dissolve dry fertilizers. Therefore, the producer should judge a liquid or a dry phosphate fertilizer on the cost of its nutrient content and not on a difference in phosphorus availability.

Organic sources of P

Crop residues are a source of phosphorus for the next crop. Crop residue phosphorus becomes available earlier than nitrogen. Approximate 30% and 67% of non-grain phosphorus at physiological maturity, for corn and soybean, is returned to the soil by late fall. The return is earlier with soybean residue because of early senescence of leaves that fall to the ground and have close contact with the soil and, therefore, decomposed early compared with corn crop residues.

Nutrients in this manure are sufficient to meet 25% of the P required for U.S. crops. Manure is a bulky P source and P content varies widely among manure types. Poultry manure may have 80 to 100 pounds P_2O_5 per ton whereas feedlot manure may contain to 10 pounds P_2O_5 per ton or less. Most manure P is in inorganic forms (50% to 95%), such as calcium phosphates and dissolved orthophosphate. Estimates of manure P that becomes available to the first crop after application vary with 60% a conservative estimate to protect against inadequate phosphorus availability.

Phosphorus and Surface Water Protection

Phosphorus is often the limiting nutrient to the growth of vegetation in surface freshwater bodies. In these water bodies, increasing P concentration will increase growth of aquatic vegetation resulting in depletion of oxygen, reduction of light transmission and water clarity, and production of algal toxins. These water quality changes can hurt fish populations, reduce water quality for recreation, and impart undesirable odors and tastes resulting in increased cost of treating water for domestic use.

Soil erosion and runoff are the main transport mechanisms of delivering phosphorus to water bodies. Delivery is increased when phosphorus concentration at the soil surface is increased. Stratification of soil test phosphorus with soil depth is a consideration with surface application of phosphorus. Soil test phosphorus in the 0- to 2-inch soil depth, the soil most exposed to erosion and runoff, is often 150% more compared to the 0- to 8-inch soil depth with surface application of phosphorus and no or little tillage. In addition to avoiding excessive soil test phosphorus levels at the soil surface, phosphorus delivery is reduced by practices that reduce erosion losses such as tile outlet terraces and no-till, maintaining good ground cover, and passing runoff through vegetative filter areas.

Resources

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2. Wortmann, C.S., C.A. Shapiro, L.J. Johnson, R.F. Hancock. 2012. The Nebraska Phosphorus Index (2012): Background and Users Guide, Extension Circular EC195. University of Nebraska–Lincoln Extension, Lincoln, NE.

3
Potassium

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Potassium (K) is an essential plant nutrient. Next to nitrogen (N), crops absorb potassium in greater amounts than any other nutrient.

Most major soils are mineral soils and this is true for soils in Nebraska. Mineral soils are formed from minerals such as feldspar, mica and hornblendes as well as secondary minerals and clays. The potassium content of different minerals and clays is variable because soils were not all formed from the same minerals or parent materials. Total potassium varies widely in soil, and therefore, soil test values also vary greatly as shown in Table 3-1.

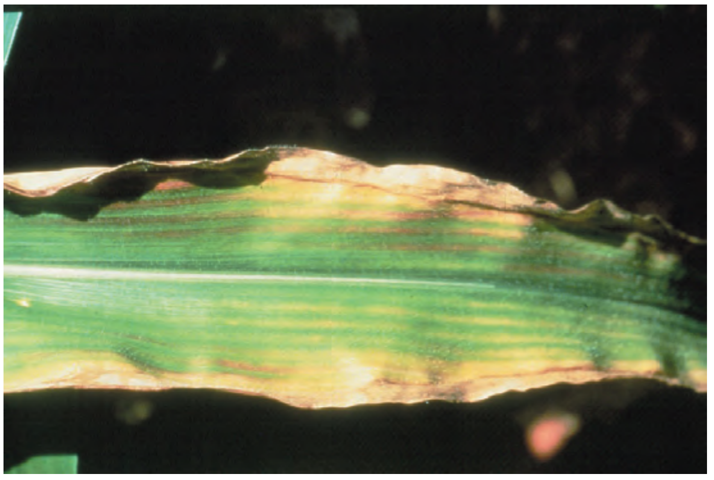


FIGURE 3-1

Potassium deficiency in corn. Photograph courtesy of the Potash Phosphate Institute.

Form and Availability of Potassium

Potassium, unlike nitrogen and phosphorus (P), is not associated to any great extent with organic matter, but it is more dependent on the type and content of minerals and clay in different soil series. Total potassium in soil varies from 0.3% to more than 2.5%. While total potassium content is important, it has little value in determining how well a given soil can supply potassium to growing plants. The general terminology used to describe the potassium reaction in soil is shown in Figure 3-2.

■ *Relatively unavailable forms (pools)*

Depending on soil type, from 90% to 98% (Figure 3-2) of soil potassium is in relatively unavailable forms. Feldspar and mica minerals contain the most potassium. While these minerals are the source of soil potassium, in these crystalline-insoluble forms, potassium is not available to plants. Over time, these minerals weather and release potassium very slowly to more available forms where potassium is then removed by crops or leaching.

Slowly available (nonexchangeable) forms

Potassium in the slowly available form is part of the internal structure of clay minerals forming the soil colloidal fraction. Slowly available potassium cannot be replaced by ordinary cation exchange processes, making it nonexchangeable. As shown in Figure 3-2, nonexchangeable potassium is in equilibrium with available forms and it acts as an important reservoir of potassium.

An equilibrium exists between nonexchangeable, exchangeable and soil solution potassium as shown by the arrows in Figure 3-2. Because of this equilibrium, some potassium applied as fertilizer can be temporarily converted to the nonexchangeable form. This reaction is important because it helps reduce leaching of potassium from applied fertilizer, especially in sandy soils.

Readily available forms (exchangeable and soil solution potassium)

Readily available potassium includes exchangeable and soil solution potassium. Exchangeable potassium is absorbed on the soil colloid surfaces and is available to plants; however, plants obtain most of their potassium from the soil solution.

As shown in Figure 3-2, these three forms of soil potassium are in dynamic equilibrium where an interchange between the different forms occurs. Therefore, the amount of potassium in the different forms ranges from 1% to 2% for readily available, 1% to 10% for slowly available and from 90% to 98% in unavailable forms.

Exchangeable potassium values vary considerably with location and soil type as shown in Table 3-1.

FIGURE 3-2

Relationship among the three types of soil potassium.

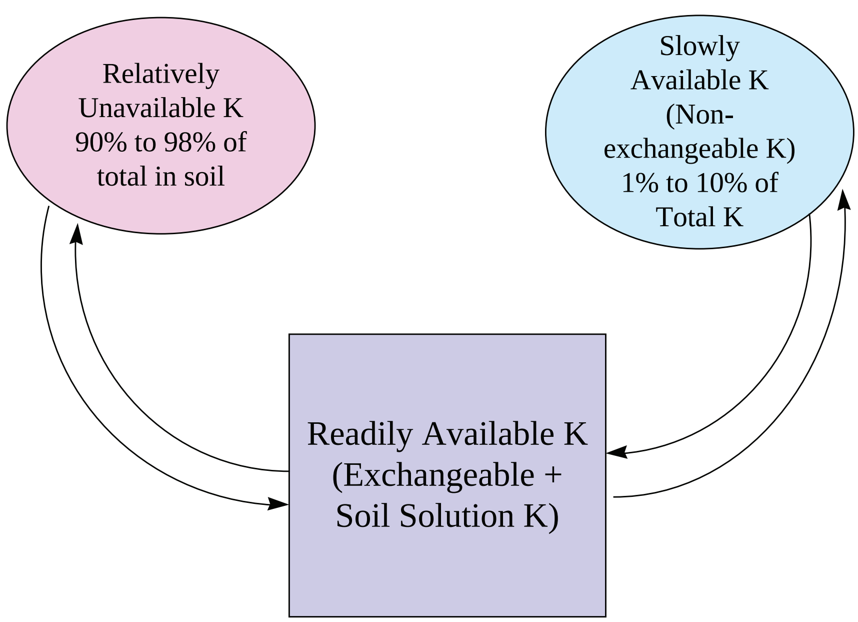


TABLE 3-1

Exchangeable potassium for crop-producing soils.

	Soil Series and Location (County and State)			
Soil Depth	Clarion silt, Story, IA[1]	Hall silt loam, Dawson, NE	Thurman loamy sand, Merrick, NE	Milaca fine sandy loam, Benton, MN
	Exchangeable K (Field-moist Samples)			
inches	*ppm*			
0-6	72	744	124	34
6-12	49	496	78	16
12-18	31	363	44	15
18-24	17	356	36	12
24-30	15	510	35	15
30-36	17	679	45	16

Source:

[1]North Central Regional Potassium Studies, Research Bulletin 494, Iowa State University, Ames, IA, July 1961.
Note that the numbers above are for elemental potassium. Fertilizer potassium is given as the oxide form, K_2O, which is 1.2 times greater than elemental potassium.

Estimating the Ability of Soils to Provide Potassium to Crops

The purpose of developing a soil test for potassium is to estimate the ability of soil to supply potassium from the readily available potassium pool to different crops during the growing season.

A chemical soil test procedure for potassium *does not measure total potassium* in the soil. The value from the chemical analysis is an *index* of the soil's ability to supply potassium to different crops.

Data for the Thurman loamy sand (ls) in Table 3-1 provides an example of the relationship between potassium forms shown in Figure 3-2 in terms of pounds of potassium (shown in Table 3-2) and why the soil test for potassium is an index and not a measure of total potassium. For this example, the following assumptions are:

- Thurman soils weighs 4,000,000 pounds per acre foot,
- Readily available potassium equals exchangeable plus soil solution potassium, which equals 2% of the total potassium (e.g., 124 pounds of potassium per 1,000,000 pounds of soil x 2,000,000 pounds of soil per acre – 6 inches = 248 pounds of potassium per acre – 6 inches),
- Slowly available potassium equals 10% of total potassium,
- Corn plants will draw potassium from the top 3 feet of soil,
- A 200-bushel corn crop will require about 265 pounds of potassium during the growing season.

Table 3-1 shows 722 pounds of exchangeable potassium in the top 3 feet of the Thurman loamy sand soil (362 x 2). From Figure 3-2, 10% of this is in the soil solution (slowly available) (0.1 x 722 = 72 pounds). Therefore, at any given time only about 27% of the total potassium requirement is available for the 200-bushel corn crop (72 / 265 x 100).

The most commonly used chemical extracting agent to estimate exchangeable and solution potassium is 1.0 molar ammonium acetate at pH 7. Field research is required to correlate the soil test index values into ranges where different crops

TABLE 3-2

Pounds of potassium in the top 6 inches of the Thurman loamy sand soil of Table 3-1 present in the various forms of Figure 3-2.

Type of Potassium		Pounds of K per acre at a 6-inch Soil Depth for the Thurman Loamy Sand Soil in Table 3-1
Soil solution K + exchangeable K	=	248 lb/acre = Readily available K=2%
Total K	=	Readily available K/2% = 12,400 lb/A
Slowly available K	=	10% of total K = 1,240 lb/acre
Relatively unavailable K	=	90% of total K = 11,160 lb/acre

respond to applied potassium. The numerical value of the index with a corresponding rating varies across states as shown in Table 3-3. Once the index ranges are established, numerous field studies with rates of potassium are required to calibrate the soil test for different soils and for individual crops.

Recently (2012), more attention has been focused on the analysis of field moist samples compared to dried soils. Field moist soils are more "realistic" than those dried and ground but may introduce variability since moisture is not controlled. In Iowa, research has compared the two methods and found that the field moist samples may have lower ppm potassium when soil levels are lower in the range of optimum potassium levels, but that difference disappears at very high levels (Mallerino, 2012 *www.extension.iastate.edu/CropNews/2012/0924mallarion.htm*, verified April 21, 2014).

Potassium

Table 3-3 shows that for a given soil test potassium index value, the potassium recommendation can change for different crops. Also as shown in Table 3-3, for a given potassium index level, the potassium recommendation will vary across states for the same crops. Wisconsin recommendations are more complex than they appear in Table 3-3 because potassium recommendations in that state will vary for the same crop depending on the soil type.

■ *Why potassium recommendations vary*

Potassium recommendations vary because conditions change. A primary influence on a specific soil's ability to provide potassium to plants is the type of potassium minerals found in the soil.

Additional factors influencing potassium availability and uptake are soil moisture, soil aeration and oxygen (O) level, soil temperature, soil cation exchange capacity (CEC) and rooting depth, and subsoil potassium levels.

Table 3-3

Potassium recommendations (pounds per acre) for selected crops by state according to soil test index values. The index values given are in parts per million (ppm) using 1 M ammonium acetate as the extracting agent.

NEBRASKA	(No specific expected yield)				
	0 - 40	41 - 74	75 - 124	125 - 150	>150
Index (ppm)	Very low	Low	Medium	High	Very high
	K_2O (pounds per acre)				
Corn	120 + 20 row	80 + 10 row	40 or 10 row	0	0
Edible Beans	60	40	20	0	0
Soybeans	60	40	20	0	0
Sorghum	80	60	40	0	0
MINNESOTA[1]					
	0 - 40	41 - 80	81 - 120	121 - 160	>160
Index (ppm)	Very low	Low	Medium	High	Very high
	K_2O (pounds per acre)				
Corn 200 bu/acre	205 or 105 row	160 or 80 row	90 or 55 row	30 or 10 - 15 row	0 or 10 - 15 row
Edible Beans 2,401 - 2,900 lb/acre	65	25	0	0	0
Soybeans 50 - 59 bu/acre	100	60	30	0	0

WISCONSIN[2]						
	0 - 70	71 - 100	101 - 130	131 - 160	161 -190	>190
Index-Corn/ Soybeans (ppm)	Very low	Low	Optimum	High	Very high	Excessively high
	K_2O (pounds per acre)					
Corn 231 - 250 bu/acre	115	100	70	35	20	0
Soybeans 66 - 75 bu/acre	145	130	100	50	25	0
	0 - 90	90 - 110	111 - 140	141 - 170	171 - 240	>240
Index - Alfalfa (ppm)	Very low	Low	Optimum	High	Very high	Excessively high
	K_2O (pounds per acre)					
Alfalfa (established 5.5 - 6.5 ton/ acre)	415	400	360	180	90	0

[1] Minnesota has a formula for K_2O recommendations: K_2O REC = 1.166 – 0.0073 * (soil test K, ppm) X Exp. Yield

[2]The index values are for crops grown on loamy soils with “medium” potassium in the subsoil.

Soil moisture

Factors such as potassium diffusion rate, soil oxygen content, root growth, and potassium release and fixation from soil colloids are influenced by soil moisture. Because factors governing potassium uptake by plants are interdependent, there is no universal agreement among researchers on the influence of soil moisture on potassium uptake by plants. Generally, potassium uptake increases as soil moisture increases. Soil moisture content influences the ratio of potassium to calcium (Ca) plus magnesium (Mg). Research has shown that as soil moisture decreases, the K:Ca+Mg ratio decreases in the soil solution as well as in the plant. Also, potassium diffusion coefficients increase as soil moisture increases, resulting in increased potassium uptake by plants.

FIGURE 3-3

Spreading fertilizer on alfalfa.

Soil aeration and oxygen levels

Oxygen is necessary for root respiration and potassium uptake. Therefore, factors such as soil compaction and excess moisture that reduce oxygen levels in the root zone decrease potassium uptake. Researchers agree that the oxygen percentage required for adequate potassium uptake is not the same for all plants. For example, tobacco plants show a decrease in potassium uptake at 10% oxygen, while barley shows no deficiency in potassium uptake until the oxygen level reaches 5%.

Soil temperature

In general, the optimum soil temperature for potassium uptake by plants is between 60°F and 80° F; however, potassium uptake is also influenced by the way temperature affects different crops. Soil temperature influences potassium uptake by plants in two ways. First, as temperature increases, release of potassium from the nonexchangeable to the exchangeable form increases. Second, as temperature increases, plant root metabolic activity increases, resulting in more potassium uptake until the point where roots become damaged by heat.

Cation exchange capacity (CEC)

According to recent research in Ohio, higher levels of exchangeable potassium are required for maximum yields on soils with higher cation exchange capacity levels; however, according to numerous research trials in Nebraska CEC is not a factor in potassium availability to plants. This is undoubtedly due to the large amount of potassium feldspar and trioctahedral mica, its derivatives and other potassium silicate minerals in Nebraska soils. These relatively unweathered soils release potassium from nonexchangeable forms almost as rapidly as plants utilize potassium. Predominant soils in the eastern and southeastern United States, and parts of Minnesota and Wisconsin do not have this ability to quickly release potassium to rapidly growing plants.

Some crop consultants recommend balancing potassium applications with other nutrients. This balance approach is based on the theory that the relationship between potassium, calcium and magnesium influences the ability of a soil to supply potassium to plants. Research in numerous states has shown that the K:Ca:Mg ratio approach has little basis for making potassium, calcium or magnesium recommendations (Rehm, 2009).

■ *Rooting depth and subsoil potassium levels*

Subsoil potassium can be an important potassium source for plants especially where rooting depths are not limited by physical factors such as compaction or by chemical factors such as extremely acid subsoils. Exchangeable potassium varies with depth depending on soil type (Table 3-1). In Nebraska, subsoil potassium is not a factor in potassium recommendations, but it is in Wisconsin and other states. Considering that the Clarion soil in Table 3-1 is representative of a large area of highly productive soils in northern Iowa and southern Minnesota, it is understandable why potassium recommendations for crops grown on soils in those areas would be different than even the Thurman sands of Nebraska.

Losses of Soil Potassium and Sources of Supplemental Potassium

Losses of potassium from soil are caused primarily by crop removal, fixation by clay minerals, and leaching. Under Nebraska conditions, leaching may be a minor factor in very sandy soils. Fixation is not a problem with Nebraska soils.

Crop removal accounts for the largest loss of potassium from soil. As shown in Table 3-4, grain crops remove less potassium than alfalfa or crops harvested for silage.

Several sources of supplemental potassium are available. Table 3-5 contains general fertilizer sources. Potassium chloride (KCl) is the source producers use most often. However, in soils needing magnesium and sulfur (S), potassium magnesium sulfate is a possible choice. There are some who are using potassium thiosulfate (KTS) because it is a liquid and can be applied easily in small doses.

Manure is an excellent source of potassium. The potassium content of manure varies depending on the source of manure and the way the manure is handled. For example, liquid pumped from lagoons can be high in potassium. Continued pumping of lagoon effluent on the same area of land can lead to excessive potassium buildup relative to other cations. The high K:Ca ratio can alter the physical and chemical properties of the soil. Similarly, manure application to satisfy nitrogen needs will cause exchangeable potassium accumulation in the soil.

Irrigation water is another source of potassium. Potassium content of Nebraska irrigation water is relatively stable, but varies with location. Usually, a chemical analysis every 10 years is sufficient to determine irrigation water potassium concentration.

Figure 3-4 summarizes the nature of soil potassium. Available soil potassium is associated with the clay complex and soil solution. It is in equilibrium with slowly available minerals which are constantly supplying available potassium. Fertilizers and crop residues add potassium to the soil. Fertilizer potassium may be fixed and become slowly available or it can be lost by crop removal, leaching or erosion.

Table 3-4

Average removal of potassium by crop production.

Crop	**Yield**	**K_2O Removed**
		pounds per acre
Corn stover	200 bu/acre	54
	1200 lb/acre	213
Wheat straw	60 bu/acre	23
	3600 bu/acre	53
Soybeans	50 bu/acre	66
Alfalfa	6 ton/acre	270

Various sources.

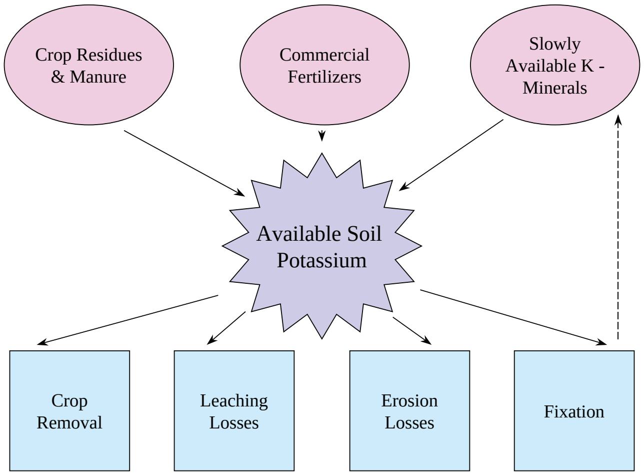
Table 3-5

Principle potassium fertilizer sources.

Material	**K_2O**
	percent
Potassium chloride (KCl)	60 - 62
Potassium sulfate (K_2SO_4)	50 - 52
Potassium magnesium sulfate ($K_2SO_4 \cdot MgSO_4$)	22
Potassium nitrate (KNO_3)	44
Potassium thiosulfate [KTS ($K_2S_2O_3$)]	25

Figure 3-4

Available potassium in relation to additions and losses.



Potassium Deficiency Symptoms

Potassium is a mobile nutrient in plants, and can be translocated from older to younger tissue. Consequently, deficiency symptoms will normally show up on older, lower leaves first, and then progress up the plant. In corn and sorghum, potassium deficiency will first be visible as yellowing or necrosis of leaf margins of lower leaves. Potassium deficient plants also may be prone to lodging late in the season, and may exhibit poorly filled ear tips. For wheat and small grains, chlorosis due to potassium deficiency will initially be uniform on lower leaves, and then become streaked with yellow or bronze, or leaves will become necrotic at the edges.

For soybean and alfalfa, potassium deficiency is noted initially as irregular yellow mottling around the leaf margins of older leaves. Further deficiency results in necrosis of chlorotic areas and downward cupping of leaf margins.

Figures 3-5 and 3-6

Potassium deficiency in alfalfa (left) and soybean (right). Photographs courtesy of the Potash Phosphate Institute.

Resources

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2. Kaiser, J. Lamb, and R. Eliason. 2011. Fertilizer Recommendations for Agronomic Crops in Minnesota. BU-06240-S. Minnesota Extension, University of Minnesota, St. Paul, MN. *www.extension.umn.edu/nutrient-management/*
3. Rehm, George. 2009. Soil Cation Ratios for Crop Production. University of Minnesota North Central Regional Extension Publication 533

4
Calcium and Magnesium

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Calcium (Ca) and magnesium (Mg) are secondary nutrients, but they are secondary only in the probability of deficiencies, and plants require them in quantities similar to phosphorus (P).

The range of calcium and magnesium in plant tissue will vary considerably within a given crop and among crops as shown in Table 4-1. Generally wide variation in the same plant species occurs because varieties differ in the amount of nutrients they take up. The different suggested levels of sufficiency among states is generally due to soil differences (Table 4-1). For example, the range of calcium and magnesium for soybean in Nebraska is considerably higher than in Georgia, because most Nebraska soils, especially subsoils, are high in calcium and magnesium, while Georgia soils tend to be acid and have acid subsoils.

TABLE 4-1.

Concentration range for calcium and magnesium in plant tissue at different plant growth stages for various crops.

Crop	Plant Part	Calcium		Magnesium	
		Nebraska[1]	*Georgia*[2]	*Nebraska*	*Georgia*
		percent			
Wheat	Whole plant at boot stage	0.3 - 2.5	0.2 - 0.5	0.12 - 0.8	0.15 - 0.5
Grain Sorghum	3rd leaf from top, boot stage	0.15 - 0.3		0.1 - 0.2	
Corn	Ear leaf, early silk	0.2 - 0.6	0.25 - 0.5	0.15 - 0.3	0.13 - 0.3
Alfalfa	Top 6-inch, early bloom	1.8 - 3.0	0.8 - 3.0	0.3 - 1.0	0.25 - 1.0
Soybeans	Newest mature trifoliate leaf from top	1.2 - 2.5	0.5 - 1.5	0.3 - 1.0	0.25 - 0.8

Sources:
[1]Wiese, R.A. Plant Tissue Analysis; Capabilities and Limitations. University of Nebraska, Department of Agronomy, Lincoln, NE.
[2]Plank, C.O. Plant Analysis Handbook for Georgia. University of Georgia, Athens, Cooperative Extension, Athens, GA.

Availability of Calcium and Magnesium to Plants from Soil

Calcium and magnesium, like potassium (K), are positively charged ions (cations) held to the surface of clay and organic matter in the soil by electrostatic charge. These cations are exchangeable because they exchange with cations in the soil solution. The total number of charges on the soil complex is the cation exchange capacity (CEC) of the soil. It is expressed in units of milliequivalent per 100 grams of soil (meq/100g).

Because calcium and magnesium are only available to plants in the exchangeable form, soil tests measure only exchangeable calcium and magnesium.

Plants take up almost all calcium and magnesium though mass flow rather than by root interception. With root interception, the exchange of calcium and magnesium takes place when the root grows in close proximity to clay and organic matter particles holding cations. With mass flow, calcium and magnesium on the exchange sites exchange with other cations in the soil solution. As plants transpire water, the soil solution moves the calcium and magnesium to the roots. Considerably more calcium and magnesium moves to roots by mass flow than plants actually take up.

Do ideal Ca:Mg:K ratios exist in soil?

Scientists first studied the concept of an ideal ratio between calcium, magnesium, and potassium in 1901 while producing tomatoes on sandy soil. They considered using ratios of *total* calcium, magnesium, and potassium. However, they quickly recognized that total amounts were not a good indicator of available nutrients to plants. Therefore, they used exchangeable (extractable) levels of calcium, magnesium, and potassium. Early work in New Jersey determined that an "ideal alfalfa soil" should have a 65-10-5-20% saturation of calcium, magnesium, potassium, and hydrogen (H) respectively.

The pure ratio concept is very misleading. A Ca:Mg ratio of 5:1 is a statement of relative proportions of available calcium to magnesium. Two soils, one with 100 and 20 parts per million (ppm) of available calcium and magnesium and the other with 300 and 60 ppm available calcium and magnesium respectively, both have the same 5:1 ratio. However, the first soil would be marginally low to deficient while the second soil would have adequate amounts of both calcium and magnesium.

Scientists have conducted considerable research on calcium, magnesium, and potassium saturation percentages in soil since the 1901 New Jersey experiments. Some of those researchers include Allaway (1945), Bear, et al. (1945), Eckert and McLean (1981), Hunter (1949), McLean, et al. (1983), Simson, et al. (1979), Schulte and Kelling (1985) and Schulte, et al. (1987).

Research Summary

1. Total soil calcium, magnesium, or potassium content is not a good measure of availability to plants.
2. Exchangeable calcium, magnesium, and potassium are good estimates of the soil's ability to provide these nutrients to plants; however, optimum yields can be produced across a wide range of calcium, magnesium, and potassium ratios in soil. Parent minerals and soil texture greatly influence saturation percentages for calcium, magnesium, and potassium by influencing cation exchange capacity.

a. Under Nebraska conditions, on soils with a pH of 7.3 or lower (and no excess free lime) the sufficient saturation ranges are shown in Table 4-2.

TABLE 4-2.

Acceptable saturation ranges for exchangeable calcium, magnesium, and potassium and suggested minimum soil test levels for non-calcareous soils.

	Acceptable Saturation	Minimum Soil Test Levels
	percent	*ppm*
Calcium[1]	50 to 70	—
Magnesium	10 to 35	50
Potassium[2]	2 to 5	120

[1]For Nebraska soils, yield response at as low as 40% Ca saturation would not be expected unless the low Ca saturation is associated with low soil pH. Lime should be applied to correct soil pH.
[2]Experiments on some sandy soils in Nebraska have shown no response to potassium at soil test values of 80 ppm exchangeable K.

b. Excess levels of potassium can alter the saturation percentage of magnesium, especially on sandy soils lower in CEC than silt and silty clay loam soils (Table 4-3).

c. Adding an excess amount of magnesium does not appreciably change the potassium saturation percentage (Table 4-3); however, the calcium saturation percentage can be changed by excessive amounts of potassium and magnesium.

d. The percent saturation for the Ortello soil in Table 4-3 adds up to more than 100 because the soil is slightly calcareous. The Crete and Hall soils are acid; consequently, their saturation percentages are less than 100 because of hydrogen on the exchange sites. The zero pounds of magnesium and 2,560 pounds of potassium per-acre treatment decreased corn yield on the Ortello soil in 1973, but it did not decrease corn yield on the Crete and Hall soils even though the Mg:K ratios were 0.8, 0.8, and 0.9 for the Ortello, Crete and Hall soils respectively. McLean et al. (1983), also reported reduced corn yield when sufficient potassium was added to decrease the Mg:K ratio.

e. Saturation percentages of calcium were not changed uniformly across the three soils in Table 4-3; however, yields over the three-year period for these experiments were not influenced by changes in the saturation percentage of calcium, potassium and magnesium (as long as the levels were in the sufficient range).

TABLE 4-3.

Influence of high rates of potassium and magnesium on the saturation levels of potassium, magnesium, and calcium three years after application on three Nebraska soils with different cation exchange capacities.

Treatment			Exchangeable Cation			Base Saturation		
Mg	K	CEC	K	Mg	Ca	K	Mg	Ca
pounds per acre		*meq/100g*	*meq/100g*			*percent*		
Ortello fine sandy loam								
0	0	5.0	0.4	0.9	4.3	8.6	17.6	85.0
0	2,560	4.2	0.7	0.6	3.4	16.0	13.0	80.0
640	0	4.7	0.4	1.5	3.8	8.4	31.6	80.0
640	2,560	5.5	0.8	2.6	3.4	15.0	46.0	61.0
Crete silt loam								
0	0	16.0	1.6	2.5	9.5	10.0	15.2	58.8
0	2,560	16.0	2.6	2.0	7.9	15.8	12.6	48.9
640	0	16.0	1.6	2.7	8.7	9.8	16.6	53.7
640	2,560	16.0	2.8	2.6	7.9	17.4	16.2	49.0
Hall silt loam								
0	0	20.3	1.4	3.1	12.5	6.8	15.0	61.6
0	2,560	20.3	1.9	1.8	13.9	9.4	8.6	68.5

Calcium and Magnesium Deficiency Symptoms

Calcium and magnesium deficiencies in agronomic crops are unlikely in Nebraska. Calcium deficiency has not been documented in the state. Deficiencies of either nutrient are favored by very acid, sandy soils. Magnesium deficiency in corn is expressed as interveinal striping of leaves, with older leaves becoming reddish purple with necrotic margins as magnesium is translocated to newer tissue. Grass tetany in animals is a result of feed or forage which is deficient in magnesium and can be a concern with forage grasses such as fescue. Such deficiency, however, is unlikely in Nebraska.

Depending on the crop, soils in Nebraska should be limed once the pH reaches 5.4 to 5.8. Soils require lime application primarily to address availability of other nutrients, to enhance soil microbial activity, improve legume nodulation, and to eliminate the possibility of aluminum or manganese toxicity, rather than to correct deficiencies of calcium or magnesium.

FIGURE 4-1

Magnesium deficient corn, Nebraska Sandhills, 1996 (organic matter 1%, CEC 8 meq/100g, pH <5.2).

Recommendations for Potassium, Calcium, and Magnesium Ratios in Nebraska

If a calcium deficiency occurs in Nebraska, it is most likely on a sandy soil with an acid subsoil.

Research data do not support the additions of calcium, such as gypsum, or a single source of magnesium, such as magnesium sulfate, to the soil for the purpose of changing the Ca:Mg, the Mg:K or the Ca:K ratios to a preconceived ideal.

In low cation exchange soils, magnesium deficiency may occur if excess potassium, or possibly if excess calcitic lime, is added.

Adding dolomitic lime is preferable to adding calcitic lime to sandy soils because the potential for magnesium deficiency is higher in sands than it is in finer textured soils.

Calcium and Magnesium as Liming Materials

In addition to calcium and magnesium serving as plant nutrients, calcium, primarily, and magnesium, secondarily, are factors influencing soil pH. Under natural processes, hydrogen replaces calcium and magnesium held on clay and organic matter exchange sites. The primary liming materials to correct soil acidity are calcitic or dolomitic limestone. A secondary source of calcium and magnesium is irrigation water. Crop producers should have irrigation water analyzed for nutrients because calcium and magnesium content of groundwater and surface water varies across Nebraska.

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5 Sulfur

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Sulfur (S) is an essential plant nutrient important for protein formation in plants. Gypsum (calcium sulfate) can also be applied as a soil amendment for improving sodium-affected soils. The amount of sulfur required as a plant nutrient is low (10 to 30 pounds per acre), whereas the amount of sulfur required to reduce sodium saturation of a soil is high (1,000 to 2,000 pounds per acre). The focus of this chapter is understanding sulfur as a plant nutrient. Information about sulfur and gypsum as soil amendments is available in other references (DeSutter, 2008; James, et al., 1982; Keren and Miyamoto, 2011; Richards, 1954).

Deficiency Symptoms

Sulfur-deficiency appears as a light green to yellowish color and appears similar to nitrogen (N) deficiency on young plants. Typical sulfur deficiencies in corn and alfalfa are shown in Figures 5-1, 5-2, 5-3 and 5-4. On grasses, yellowing from sulfur deficiency first appears on upper leaves, while most nitrogen deficiency symptoms appear first on older, lower leaves. On corn, sulfur deficiency is evident by marked yellowing along the entire length of the leaf and between the veins but, especially on the younger plants, yellowing on upper leaves is common. Sulfur deficiency in wheat appears as a general yellowing of the plant. On crops such as alfalfa or soybean, sulfur deficiency causes newer growth to be pale yellow-green and older growth to be darker green. Most sulfur deficiency symptoms in Nebraska occur on sandy soils in spring and early summer.

Figures 5-1 and 5-2

Sulfur deficiency symptoms in corn. In the lower photograph, the normal corn leaf is on the right; the sulfur-deficient leaf is on the left.

FIGURES 5-3 AND 5-4

Sulfur deficiency symptoms in alfalfa.

Sources of Sulfur

Sources to meet plant sulfur requirements include soil, irrigation water, atmospheric deposition, manure, and commercial fertilizers. Figure 5-5 shows some of these sources and their reactions in the soil.

■ *Soil organic matter*

About 95% of the total sulfur content of most soils is contained in organic matter. As with nitrogen, each year some of the soil organic matter breaks down or decomposes. This process mineralizes organic sulfur into the sulfate (SO_4^{-2}) form (written SO_4-S) which plants take up. Returning crop residue to soil adds sulfur to the organic pool.

■ *Soil minerals*

Several minerals in the soil contain sulfur in different forms. As these minerals weather as part of natural soil formation, part of the sulfur is transformed to sulfate-sulfur.

■ *The atmosphere*

Most fuels burned for heat, power, and transportation contain some sulfur. When these fuels are burned, sulfur escapes as sulfur dioxide (SO_2) gas or as fine dust particles. Sulfur dioxide dissolves in rainwater and reaches the soil as sulfate-sulfur. Sulfur dioxide in the atmosphere is highest in industrialized areas. Emissions standards for fossil-fuel burning facilities has generally reduced sulfur levels extensively since the 1980s, so only small amounts of sulfur (<5 lb/acre) are being added by atmospheric deposition.

Pesticides

Some pesticides contain sulfur; however, their contribution to sulfur for crop growth is relatively small.

Organic materials

Manure has always supplied sulfur to crops, although its contribution is often overlooked. The amount of sulfur in manure on a dry-weight basis can vary from as little as 0.45% to as high as 0.70%, providing 9 to 15 pounds of sulfur per ton. Poultry manure contains more sulfur than cattle manure. The sulfur content of other compost materials or sludges varies considerably and should be determined by laboratory analysis.

Irrigation water

Sulfur is present in irrigation water as sulfate-sulfur and is an important source of sulfur for crops in much of Nebraska. Waters in Nebraska vary widely in sulfate content, and the producer should test the water supply to accurately determine concentration. Most groundwater is high in sulfate except in the Nebraska Sandhills. Most surface water (namely the North Platte, South Platte and Republican rivers) contains sufficient sulfate to meet crop requirements.

Fertilizers

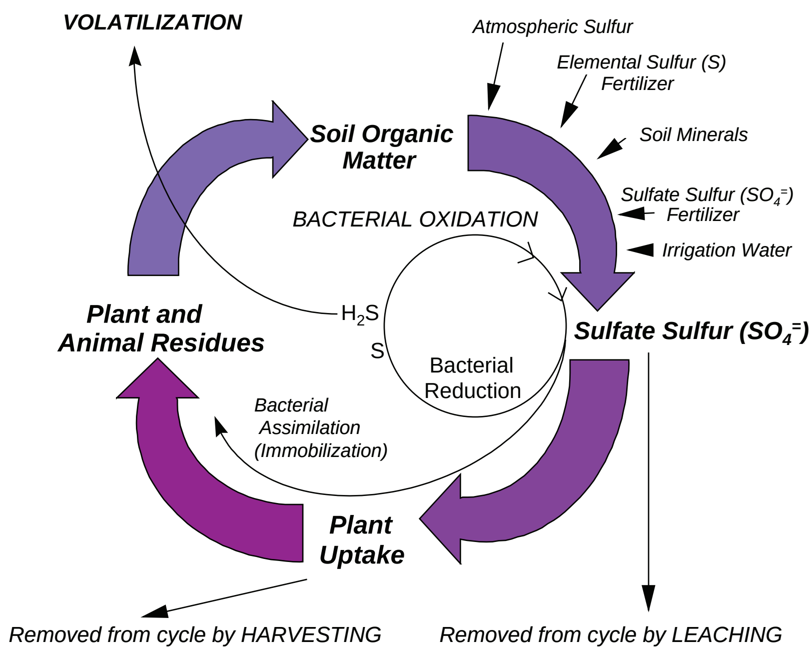
Historically, commercial fertilizers supplied considerable sulfur in addition to nitrogen, phosphorus, and potassium. This sulfur was primarily an impurity from the manufacturing process. As an example, the old standard phosphate fertilizer 0-20-0 contained 12% sulfur. It has been replaced by 0-45-0, 18-46-0 or 11-52-0, which normally contain less than 1% sulfur.

The Sulfur Cycle in Soil

Organic matter is the major reservoir of sulfur in most soils. Sulfur in organic matter, manure, or crop residues must change to sulfate-sulfur before plants can utilize it (Figure 5-5). Sulfur can be removed from soils through several avenues including plant uptake, leaching loss, or volatilization. Sulfate-sulfur is an anion similar to nitrate-nitrogen so it can move downward through soil with water. In waterlogged soils, sulfate can be reduced to hydrogen sulfide (rotten egg gas) and return to the atmosphere. This condition in Nebraska is rare and loss of sulfur in this manner is minor.

FIGURE 5-5

The sulfur cycle in the soil and sources of sulfur fertilizer.



Crop Sulfur Requirements and Determining Sulfur Fertilizer Needs

A 200 bushel per acre corn crop will remove about 15 pounds of sulfur per acre in the grain. Alfalfa will remove about 6 pounds for each ton produced. A 60 bushel soybean crop will remove about 9 pounds of sulfur per acre. Winter wheat yielding 60 bushels per acre will remove about 5 pounds of sulfur per acre. The sulfur requirements of most crops are low enough that most of the crop's needs can be met by the soil and other inputs listed previously. In most non-sandy Nebraska soils, the subsoil also contains substantial amounts of sulfur (usually sulfate). Because subsoil sulfur is not usually determined in subsurface soil samples, sulfur needs may be overestimated by a typical tillage depth sample (0 to 8 inches). The producer must determine the contribution of sulfur from both topsoil and subsoil to accurately estimate sulfur needs.

Sulfur deficiencies generally occur only in sandy soils. Research, however, has shown that applying sulfur to sandy soils will not always increase yield. Research has shown that the organic matter content of the soil also must be considered. The amount of sulfate-sulfur determined by a soil test is appropriate for sandy soils only. Fine-textured soils may test low in sulfate-sulfur but they may not show an increase in crop yield when sulfur fertilizer is applied. Producers must know the organic matter content of their soil and the sulfur content of their irrigation water in addition to the soil sulfate level to determine sulfur fertilizer needs.

Sources of Sulfur Fertilizer

Many different fertilizers supply sulfur for crop production. Ammonium sulfate is sold as a nitrogen source and contains 24% sulfur. Zinc sulfate, a commonly used zinc (Zn) source, contains 14% sulfur. Ammonium thiosulfate (12-0-0) is a liquid nitrogen fertilizer that contains 26% sulfur. Sulfur also is available as powdered, granular, or prilled gypsum that contains 17% sulfate-sulfur. Potassium-magnesium sulfate products contains 22% to 23% sulfur. Except for ammonium thiosulfate, all of these products are dry materials. The phosphate fertilizer 0-20-0 contains 12% sulfur and 16-20-0 contains about 15% sulfur, although these products are no longer produced in quantity due to low phosphorus analysis.

Sulfur can be used in its elemental form. Finely ground material (flour of sulfur) is most effective, but it is difficult to apply. This finely ground powder is commonly combined with clay or organic binding agents and formed into flakes or granules which improve handling characteristics. Prilled elemental sulfur formed without clay or a binding agent is not an effective source of sulfur as it breaks down very slowly. When fertilizers containing elemental sulfur are added to soils, the elemental sulfur must change to sulfate-sulfur through microbial activity in the soil. Prilled products (molten S dropped on a cooling table which produces a split-pea size particle) are dense and do not break down as easily as the powdered sulfur in flakes that contain a mix or clay or organic binding agents. Even with flaked sulfur products, the release of sulfur may be delayed. This change occurs rapidly when soil temperatures are warm, but it occurs slowly when soil temperatures are cool in early spring. A mixture of a 50-50 mix of sulfate and elemental forms can overcome the problem.

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6 Micronutrients

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Plants require seven micronutrients for plant growth: boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn). Iron and zinc deficiencies are common in Nebraska. Boron deficiency is very rare, but it can occur in Nebraska. Deficiencies of the other four micronutrients are not documented in the state.

Boron

University of Nebraska scientists have identified boron deficiencies on only two occasions in Nebraska. One case involved sugar beets growing on very sandy soil in north central Nebraska and the other occurred in alfalfa seed production in central Nebraska on sandy soil under severe drought stress. A producer should use boron with caution because the difference between an adequate level for one crop and a toxic level for another crop can be quite narrow. In fact, the optimum level for sugar beets may depress oat yields.

FIGURES 6-1 AND 6-2

Boron deficiencies in corn (top) and sunflower (bottom). Photographs courtesy of John Mortvedt, Colorado State University.

In alfalfa, boron deficiency is most likely exhibited during drought stress. Plant tops become yellow and plants are dwarfed. After yellowing, leaf margins and the undersides of younger leaves acquire a purplish to rose-pink color. Lower leaves remain green. (*Compendium of Alfalfa Diseases*, 1990).

For sugar beets, the first symptom of boron deficiency is a white, netted chapping of the upper leaf surfaces and wilted tops. Younger leaves are affected sooner than older leaves. Other symptoms include leaf blade crinkling and petiole darkening and cracking (Ulrich, et al., 1993).

The soil test commonly used for boron is the hot water extractable test. Soils containing less than 0.25 parts per million (ppm) boron are deficient. When boron deficiency occurs, the producer should apply fertilizer to supply 1 pound of boron per acre, avoiding contact with seed. The producer should take special precaution on irrigated crops because most of Nebraska's groundwater and surface water contains enough boron to supply crop needs. *If a boron soil test is low, the producer also should test the boron level of irrigation water before applying boron fertilizer*.

Iron

Most Nebraska soils contain adequate amounts of iron for optimal crop performance. In some soils, however, conditions restrict a plant's use of iron. As a result, iron chlorosis occurs. Iron chlorosis is commonly, but not always, associated with high lime (calcareous) soils. Iron chlorosis can occur on soils that have excess salts and high or excess sodium or that are poorly drained. It may occur even on soils testing high in iron. Soil test iron is considered to be very low when DTPA-Fe is less than 2.5 ppm, and marginal when DTPA-Fe is between 2.5 and 4.5 ppm. Values above 4.5 ppm indicate low probability of iron deficiency. Some crops grown in Nebraska are quite tolerant to low levels of iron, while others, such as soybean, sorghum, and field beans are not (Table 6-1).

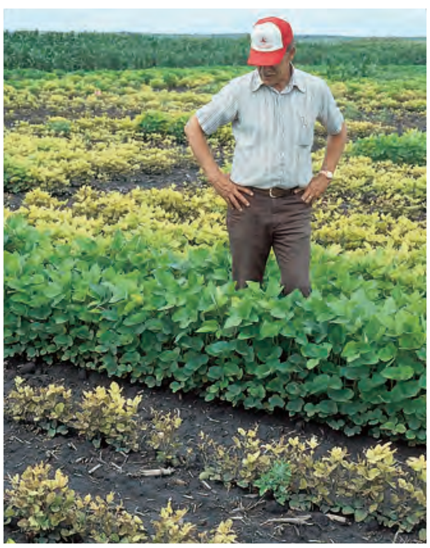
Table 6-1

Crop sensitivity to low levels of available iron in soil.

Sensitive	Moderately Tolerant	Tolerant
Field beans	Corn	Barley
Forage sorghum	Alfalfa	Grasses
Grain sorghum	Clover	Millet
Soybeans	Sweet corn	Potatoes
Sudan grass		Oats
		Rye
		Wheat
		Sugar beets

Figures 6-3 and 6-4

Iron chlorosis in soybean (top). Dr. Richard Wiese evaluates different soybean varieties and their susceptibilities to iron chlorosis (bottom).



Iron is relatively immobile in plant tissue, and chlorosis conditions are more likely on younger tissue. Iron chlorosis causes the interveinal areas of young leaves to become pale green to yellow or white (Figures 6-3 and 6-4). The interveinal striping on corn (Figure 6-5) and sorghum leaves (Figure 6-6) occurs along the full length of the leaf.

Correcting iron chlorosis is difficult. Manure application is effective when iron chlorosis is due to low soil iron availability, but it may not be effective when soil iron availability is adequate and metabolic use of plant iron is restricted. Mapping of chlorotic areas is recommended for site-specific application of fertilizer iron. Broadcast application of non-chelated iron is generally ineffective as iron rapidly becomes unavailable.

Soybean chlorosis can be managed by planting tolerant varieties, planting at a density of 12 viable seeds per foot, applying iron-chelate fertilizers with the seed, and using a foliar treatment. If chlorosis is a problem, do not plant soybean in narrow rows as it is important to have a high plant density within rows. Applying chelated iron (FeEDDHA), mixed in 5 to 8 gallons of water per acre, directly with the seed is often an effective fertilizer treatment for soybean. Seed dressing with iron EDDHA at 0.2 pound per acre iron has been as effective as applying 50 pounds per acre iron as iron sulfate. Soybean yield response to foliar application of iron fertilizer has been inconsistent and generally less effective than applying chelated iron with the seed.

For corn, research suggests that applying iron sulfate ($FeSO_4 \cdot 7H_2O$) in the seed furrow at rates of 50 to 100 pounds of product per acre prevents chlorosis. Iron sulfate (50 or 100 pounds per acre depending on chlorosis severity) applied in the seed row was less expensive but of similar effectiveness when compared to chelated iron, especially on non-tolerant hybrids. Corn hybrid selection is important for iron chlorosis management. Avoid over-irrigating high sodium and calcareous soils.

FIGURES 6-5 AND 6-6

Iron chlorosis in corn (left) and sorghum (right).

For dry beans, research shows that 1 to 1.5 pounds of FeEDDHA can increase yields in chlorotic areas. The material can be seed applied in 5 to 7 gallons of water with the seed or banded (due to mobility) or can be included in 10-34-0 and banded beside the seed. The FeEDDHA is usually dissolved in 3 to 4 gallons of water, which is then added to the 10-34-0 to facilitate mixing.

Foliar applications of iron can be used for corn, sorghum, soybeans, and dry beans, and have been more effective on hybrids/varieties relatively tolerant of iron chlorosis. By the time most iron chlorosis occurs and is treated with foliar application, significant growth reduction and loss of yield potential have already occurred. To avoid serious yield reductions, make the first foliar application of iron chelate (1 pound of FeEDDHA in 20 gallons of water) or a 1.0% to 1.5% solution of ferrous sulfate as soon as chlorosis appears. Because so little plant area is covered when the plants are small, repeated spraying every 7 to 14 days is necessary. Spray in early morning or early evening to avoid leaf burning. Additional information on is available in UNL Extension NebGuide G1830, *Micronutrient Management in Nebraska* and EC117, *Fertilizer Suggestions for Corn*.

Zinc

Most Nebraska soils have adequate zinc, but deficiencies can occur. In general, zinc may be needed for sensitive crops where:

- the soil is calcareous (pH greater than 7.3 because of excess free lime);
- the topsoil has been removed by erosion;
- land has been leveled or terraced; or
- soils are very sandy with low organic matter content.

Zinc deficiency is most likely to occur under cool, wet conditions in the spring when root growth is slow. In some cases, applying high rates of phosphorus without zinc on calcareous soils with a low or moderately low zinc level can induce zinc deficiency and reduce corn yields.

A soil test is the best guide for determining the need for a zinc fertilizer. In Nebraska, soil test zinc levels, using DTPA extraction, of 0.8 ppm or greater are adequate. Soils testing 0.4 to 0.8 ppm DTPA-Zn are medium and require zinc application for some crops. Zinc application is needed for several crops when DTPA-Zn is less than 0.4 ppm. (For more information see UNL Extension NebGuides addressing fertilizer use for individual crops.)

Corn is sensitive to low soil zinc levels (Table 6-2). If corn does not exhibit a need for added zinc, other crops are not likely to need zinc fertilizer. Zinc is relatively immobile in plants. Zinc deficiency symptoms appear first on newer leaves with interveinal striping beginning at the base of the leaf and extending to the tip, often appearing as broad, whitish bands on either side of the midrib (Figure 6-7). The midrib, leaf margin, and leaf tip remain green. Plants tend to be stunted due to a shortening of the internodes.

Table 6-2

Crop sensitivity to low levels of available zinc in soil.

Sensitive	Moderately Tolerant	Tolerant
Corn	Grain sorghum	Alfalfa
Field beans	Clover	Barley
Sweet corn	Potatoes	Oats
	Forage sorghum	Millet
	Soybeans	Rye
	Sugar beets	Wheat
	Sudan grass	Grasses

FIGURE 6-7

Zinc deficiency in corn.

Pinto beans exhibit a general stunting of the young plants. Leaves show a general yellowing of the upper foliage with a browning or bronzing of the older or lower leaves. The leaves of zinc-deficient beans typically have a crinkled appearance. A general downward curl of the leaves also will occur and pod set will be poor. Confirm visual observations with soil tests and/or plant analyses.

Zinc fertilizer products can be grouped as:

- Inorganics (dry or liquid)
- Soluble (chlorides, sulfates, nitrates, Zn-NH3 complexes)
- Insoluble (oxides, carbonates, silicates, oxysulfates)
- Synthetic chelates (dry or liquid)
- Strong versus weak chelation (EDTA versus other)
- Natural organic complexes
- Lignosulfonates from paper industry, sucrates from sugar industry

Zinc sources should be compared on the basis of solubility, cost per pound of zinc, ease of application, and residual effects.

Soluble sources of zinc will provide the most consistent correction, especially on higher pH soils. Insoluble sources are best used on soils with pH less than 6.5. Proper placement depends on the mobility of the zinc products. The zinc chelates move with soil water and the chelate delays zinc tie-up with soil minerals. The insoluble inorganic zinc carriers are not mobile, and must be broadcast as small, finely divided particles and thoroughly incorporated so the plant roots will come in contact with the zinc fertilizer. Organic complex zinc carriers and some inorganic carriers are soluble but not very mobile in the soil and need to be placed in the root zone to ensure root-zinc contact. All sources of zinc have been shown to be equally effective where the zinc carrier is dissolved or suspended in a fluid fertilizer. Manure is an excellent source of zinc.

Plant nutrients supplied in fertilizer are usually applied at rates sufficient to meet the requirements of the current crop. With zinc, however, it may be more practical to raise the zinc level of the soil, thus assuring an adequate supply for several years. On low zinc non-calcareous soils, 5 pounds of zinc per acre can be applied as granular zinc sulfate; this rate can be increased to 10 pounds per acre on calcareous soils. If soil pH is less than 7.4, finely ground zinc oxide is also a good choice when it's uniformly applied and incorporated into the soil.

Zinc sulfate or zinc oxide is effective when applied in a band with nitrogen and/or phosphorus fertilizer as a starter. Band application of fluid fertilizer containing a compatible zinc source provides good zinc distribution for root accessibility. A zinc-ammonium complex is often used in starter fertilizer solutions. If a producer uses a dry bulk blend (a zinc source blended with other dry fertilizers), segregation of the materials is minimized when the fertilizers are of similar particle size. Dry fertilizer blends that incorporate all nutrients in each prill also lead to better crop response due to improved fertilizer distribution.

A primary consideration with zinc materials is the cost per pound of nutrient. Research shows that mobile (chelated) forms are more plant-available than inorganic sources. The effectiveness of chelates depends on the application method, however. For broadcast zinc sources, one-third as much chelated zinc can be applied compared with a soluble inorganic source. For row-applied zinc, half as much chelated zinc can be used as compared with a soluble inorganic source. Claims of greater effectiveness of 10 to 1 or 5 to 1 for chelated versus inorganic sources of zinc are not supported by research. If soil test zinc is above 0.8 ppm and application is to build or maintain a high level of availability, use a soluble (> 40 to 50% water solubility) inorganic form.

Chlorine, Copper, Manganese, and Molybdenum

No data exist to support the use of these four micronutrients as fertilizer in Nebraska.

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7
pH and Liming

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Soil pH is the single most important diagnostic chemical measurement of soil. pH is an indication of H^+ ion concentration. Although soil pH is rarely low or high enough for H^+ ions to *directly* damage plants, soil pH can *indirectly* influence crop growth by affecting other important processes in soils. For example, soil pH values below 5 to 5.5 warn that soluble levels of certain metals, particularly aluminum (Al) and manganese (Mn) may be high enough to cause plant toxicity. Conversely, pH values above 7 often are associated with very low solubility of micronutrients such as zinc (Zn) and iron (Fe). Even more extreme pH values signify the presence of particular minerals or ions in soil. For example, pH values above 8.5 imply a presence of soluble or exchangeable sodium in the soil, whereas pH values below 3 usually indicate the presence of metal sulfides in the soil.

What is pH?

pH is a measure of a solution's acidity or alkalinity determined by measuring the H^+ ion concentration of a solution with a pH electrode. The more acid a solution, the more H^+ ions present. Water (H_2O), for example, is a molecule composed of hydrogen (H) and oxygen (O). In nature, a very small percentage of water will dissociate or break apart and form hydrogen ions (H^+) and hydroxyl ions (OH^-).

Equation 7-1

Dissociation of water to hydrogen and hydroxyl ions.

$$H_2O \leftrightarrow H^+ + OH^-$$

When the hydrogen and hydroxyl ions are equal, the pH of the solution is neutral. Pure water that is free of any minerals or carbon dioxide (CO_2) has a hydrogen ion concentration of 0.0000001 moles per liter. (Moles per liter is a unit of concentration and in this example equal to about 2.64 x 10^{-8} grams per gallon.) Since routine use of this decimal fraction would be cumbersome, the pH scale was devised so that the relative acidity or alkalinity of a solution could be expressed in whole numbers. Why, for example, does pure water have a pH of 7? pH is defined as "the negative logarithm of the hydrogen ion activity or concentration" and the equation is written:

Equation 7-2

pH.

$$pH = -log\ [H+]$$

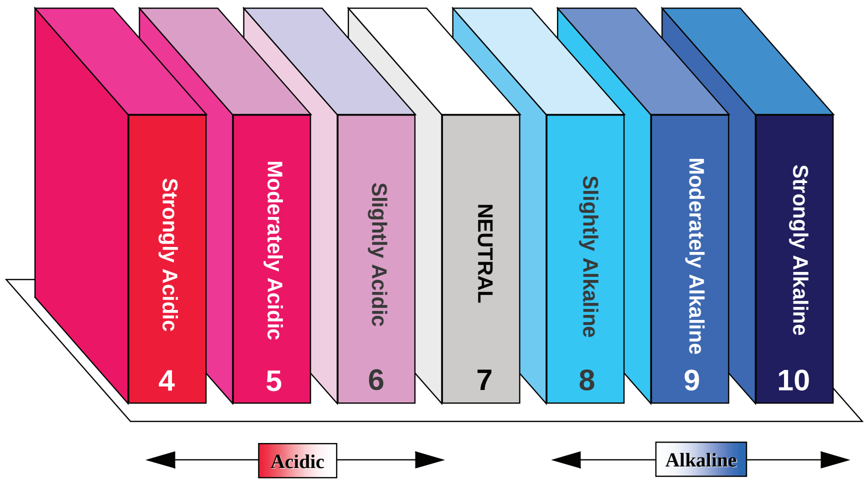
Pure water has a H^+ concentration of 0.0000001 moles per liter. By definition, then, pure water has a pH of 7 based on the calculation: -log (0.0000001) = 7.

Acidity and Alkalinity

Acid solutions have a pH below 7. The lower the pH, the stronger the acid. Similarly, alkaline solutions have a pH above 7. Since pH is logarithmic scale, a solution at pH 4 (H^+ concentration: 0.0001 moles per liter) is 10 times more acidic than a solution at a pH of 5 (0.00001 moles H^+ per liter) and 100 times more acidic than a solution at a pH of 6 (0.000001 moles H^+ per liter). pH values can vary significantly among solutions. Using some familiar examples, a 1% ammonia solution has a pH of 11.7; a 1% sodium bicarbonate (baking soda) solution has a pH of 8.5; fresh eggs have a pH of 7.6 to 8; cow milk has a pH of 6.3 to 6.6; vinegar has a pH of 2.4 to 3.4; and lemons have a pH of 2.2 to 2.4. Soil pH values typically range from a low of 4 to a high of 10. Based on pH, soils can be classified as strongly alkaline to strongly acidic (Figure 7-1).

FIGURE 7-1

Soil pH range.



Why pH is Important

Soil pH, often called the master variable, can affect three important processes in soils. Soil pH affects the availability of most essential nutrients, microorganism activity, and soil cation exchange capacity (CEC).

The availability of some plant nutrients (elements) is directly affected by pH because pH affects the solubility of the compounds which contain plant elements. Most plant nutrients have a pH range that is optimal for their availability (Figure 7-2). Some plant nutrients can actually become too available at certain pH levels and become toxic to plants. Iron, manganese, and aluminum (not a plant nutrient) increase in plant availability with decreasing pH. Aluminum toxicity can become particularly problematic when soil pH decreases below 5. Phosphorus (P) and boron (B) are usually unavailable in calcareous soils (high pH soils) resulting from reactions with calcium (Ca). They are also generally unavailable in very acid soils. Copper (Cu) and zinc have reduced availability in both highly acid and alkaline soils. Plant nutrient availability directly affects crop production. The most favorable soil pH for

FIGURE 7-2

Optimal pH levels for plant nutrient availability. Source: Fundamentals of Soil Science, 6th Edition by Henry D. Foth. John Wiley and Sons, Publisher. 1978.

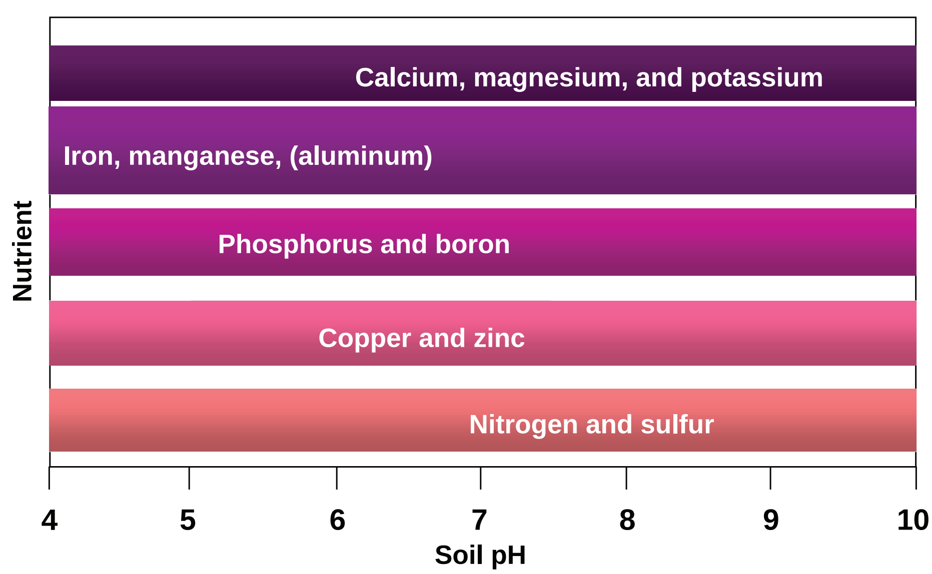
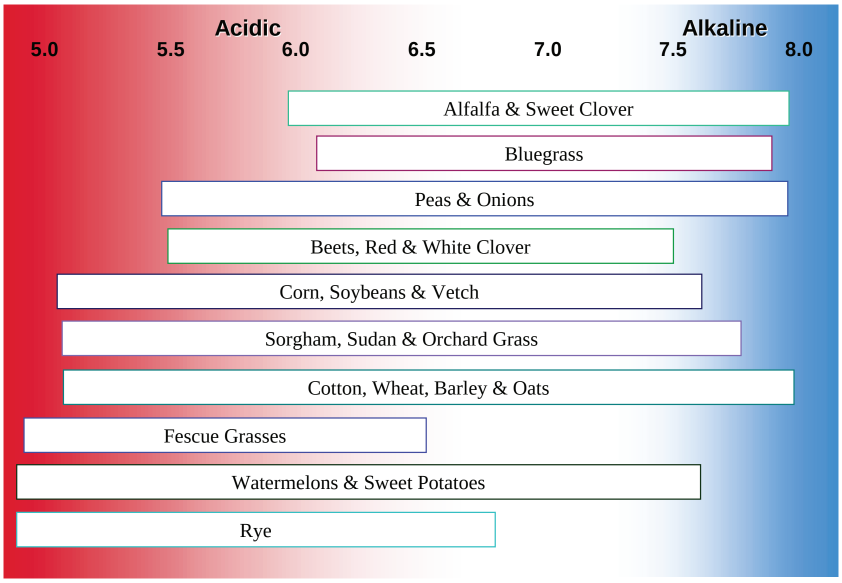


Figure 7-3

Optimal soil pH levels for various crops.

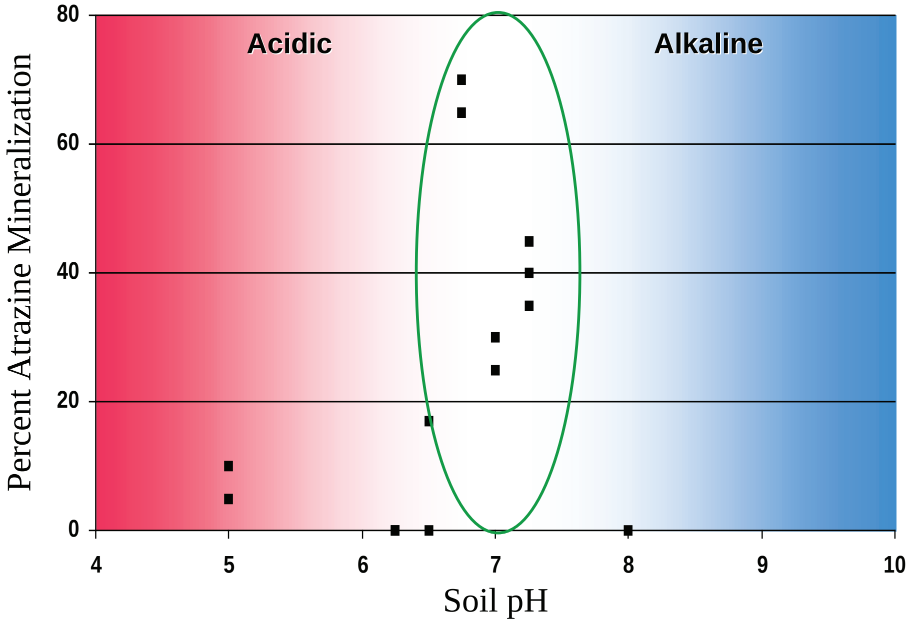


general crop production is 6 to 7. Alfalfa grows best in the pH range from 6.5 to 7.5, but many crops do well around pH 6 (Figure 7-3).

pH may indirectly affect other elements. Nitrogen (N) and sulfur (S), for example, are associated mainly with soil organic matter. Organic matter must decompose before nitrogen and sulfur become available to plants. Because microorganisms, which are influenced by pH, affect decomposition, the rate of soil organic matter decomposition is pH-dependent. pH can also affect the rate of chemical and biological degradation of pesticides. Atrazine is used extensively in Nebraska and its relative rate of decomposition is influenced by pH. Research at the University of Nebraska has shown that the maximum rate of atrazine mineralization—complete degradation into carbon dioxide and water (H_2O)—occurs when the soil pH is near neutral (Figure 7-4).

Figure 7-4

Influence of pH on atrazine mineralization; the highest mineralization was at pH 7.



Soil colloids are negatively charged. This negative charge attracts positively charged ions (cations) from the soil solution, minimizing leaching. The soil's ability to attract and hold cations is its cation exchange capacity. This process is important because many plant nutrients, including potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), ammonium (NH_4^+), zinc (Zn^{2+}), and iron (Fe^{3+}) are cations held to soil by the CEC. Soils differ in their capacity to hold cations. All soils have some permanent negative charge, which constitutes part of their CEC. The remainder of a soil's CEC is largely derived from soil organic matter, but this negative charge is pH-dependent and it generally increases with increasing pH. Therefore, increasing pH can increase a soil's CEC.

Factors Influencing pH

Some of the more important factors influencing soil pH are parent material, precipitation, native vegetation, crop type, acid-forming fertilizers and organic crop material, and fossil fuel burning.

Parent material

Rocks from which parent material originally formed vary from acidic to alkaline in reaction. Soils formed from sandstone or shale are more acidic than soils formed from limestone.

Precipitation

As annual precipitation increases, calcium and magnesium leaching also increases. This results in soil pH reductions on surface horizons. For example, most soils in Nebraska were formed from calcareous parent material; however, increased precipitation in the eastern part of the state has removed the calcium carbonate ($CaCO_3$) layer from the surface and resulted in lower soil pH. Soils in western Nebraska still have a calcareous surface layer.

Native vegetation

Soils formed under prairie grasses tend to be less acidic than soils formed under forests. Residue from coniferous trees is more acidic than residue from deciduous trees. Further, roots of growing plants produce carbon dioxide and small amounts of organic acids, which with time, increase soil acidity.

Cropping history

Legumes remove more calcium and magnesium than some grasses such as corn or sorghum. The removal of basic cations decreases OH^- ions and increases H^+ ions, thus lowering pH.

Acid forming fertilizers and organic material

Manure, crop residue and soil organic matter are potential sources of H^+ ions, which lower pH. Nitrogen sources such as anhydrous ammonia, ammonia nitrate, and urea require about 1.8 pounds of $CaCO_3$ per pound of nitrogen to neutralize the H^+ formed when nitrogen is converted to nitrate. Some phosphate fertilizers also have acidic properties. Carbon dioxide formed from mineralization of organic materials can form carbonic acid, which has an acidifying effect.

Fossil fuel burning

Due to the presence of carbon dioxide gas in the atmosphere, the pH of rainwater is generally 5.6. However, emissions from fossil fuel burning can release nitric oxide (NO) and sulfur dioxide (SO_2). These gases can react with oxygen and water to form acids which lower the pH of rain water (acid rain). Acid rain generally is not a problem in Nebraska, but it has created problems near heavily industrialized areas.

Active and Reserve Acidity

Measuring soil pH involves measuring the H^+ ion concentration in the soil-water suspension. This is a measurement of H^+ ions *in solution*. It is *not* a measure of the total H^+ ions of the soil. These two sources of acidity are important and are termed active and reserve acidity. The acidity of the soil solution is *active* and the acidity absorbed on the soil colloids is *reserve* (or potential). Reserve acidity can be hundreds to several thousand times greater than active acidity. Because these two forms are in equilibrium or balance with one another (Figure 7-5), one must neutralize a large portion of the reserve acidity to reduce the active acidity.

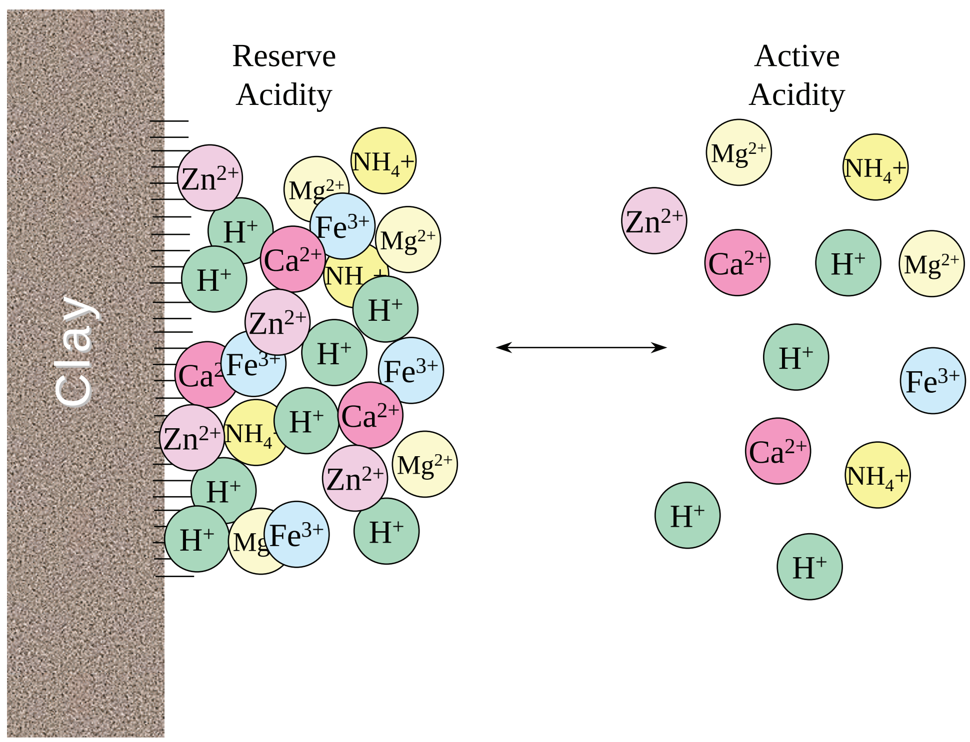


FIGURE 7-5

Active and reserve acidity; two sources of acidity in equilibrium.

Sources of reserve acidity

Several sources of reserve acidity exist. Some of the more common sources include:

EQUATIONS 7-3 AND 7-4

Sources of reserve acidity.

$$R^{*}\text{-}H \leftrightarrow R^{-} + H^{+}$$

(*R denotes a carbon containing molecule)

- Organic acids present in soils that release H^+ by dissociation (breaking up):
- Aluminum organic complexes that release acidity by reactions with water (hydrolysis):

$$\begin{matrix} R \\ & > Al^{3+} + H_2O \rightarrow & > AlOH^2 + H^+ \\ R \end{matrix}$$

In this example, note that it is the reaction of aluminum (Al^{3+}) with water that releases H^+ ions.

- Exchangeable H^+ and Al^{3+}, released as acidity by cation exchange and hydrolysis:

EQUATION 7-5

Source of reserve acidity.

$$K^+ + H^+\text{-CLAY} \rightarrow K^+\text{-CLAY} + H^+$$
$$K^+ + Al^3\text{-CLAY} \rightarrow AlOH^{2+} + K^+\text{-CLAY} + H^+$$

One way to determine the amount of reserve acidity present in soil is to measure the soil pH with a buffer. A buffer is a solution that is resistant to changes in pH. Consequently, soils that produce the greatest change in the buffer's pH are soils with the largest pools (sources) of reserve acidity. Soils differ in their amount of reserve acidity. Soils may have similar measurable pH values (active acidity) but differ dramatically in amounts of reserve acidity. An example of this is given in Table 7-1. In general, soils that have a higher CEC and clay content will have a larger pool of reserve activity and consequently require more lime to change the active acidity to the desired range (Table 7-1).

TABLE 7-1.

Influence of cation exchange capacity on soil pH (active acidity), buffer pH (reserve acidity), and lime requirement for three soil textural classes.

Soil Texture	CEC	Soil pH	Buffer pH	Lime Requirement
	meq/100g			*tons per acre*
Loamy sand	6	5.6	6.8	1
Silt loam	14	5.5	6.6	2
Silty clay loam	24	5.6	6.2	4

Soil pH is typically determined by mixing one part soil with one or two parts water, and measuring the pH of the solution with a pH electrode. Generally, when the soil pH is below 6.3, one conducts a buffer test to determine the lime required to raise the pH to 6.5. Two buffers commonly used in soil testing are the Woodruff and SMP buffers. The SMP buffer test was developed by three soil scientists (Shoemaker, McLean, and Pratt) at The Ohio State University. This test is widely used in most commercial Midwest laboratories and it determines total soil acidity (active and reserve). The pH of the SMP buffer solution is 7.5. When the SMP buffer is added to soils, the original pH of the SMP buffer will decrease. Because the amount of acid required to lower the SMP buffer to any given pH is known, the total acidity of the soil can be determined. The lime requirement can then be obtained from tables that relate depression of buffer pH to tons of limestone required.

For non-sandy soils, the Woodruff and SMP buffers yield about the same lime requirement. The SMP buffer, however, is not as sensitive for sandy soils having a lime requirement of less than 3,000 pounds per acre. To avoid over-liming sandy soils, the producer may want to request the Woodruff buffer test on sandy textured soils.

Buffer reactions of soils with acids

Soils resist changes in pH whether acidity or alkalinity is added. Numerous mechanisms are potentially involved in a soil's ability to buffer pH. Two of the most important mechanisms are carbonate mineral buffering and exchangeable base cation buffering.

Carbonate mineral buffering

Free carbonate minerals in soil such as calcium or magnesium carbonate can neutralize natural or introduced acidity. Soils containing free calcium and magnesium carbonates are calcareous and they usually have a pH above 7. Most soils in Nebraska were formed from calcareous parent material. When acid is introduced into these soils, bicarbonate salts generally result:

EQUATION 7-6

Carbonate mineral buffering.

$$H^+ + CaCO_3 \rightarrow HCO_3^- + Ca^{2+}$$

This reaction, combined with bicarbonate (HCO_3^-) leaching from soil horizons, slowly depletes the carbonate buffering capacity of soil and ultimately lowers soil pH. As indicated earlier, this phenomenon has occurred over centuries in Nebraska and its extent is related to the amount of annual precipitation occurring across the state. Due to higher rainfall and greater leaching, soils in eastern Nebraska have lost the carbonate layer that was once at the soil surface. Therefore, soils in eastern Nebraska generally have a lower surface pH than soils in western Nebraska.

Exchangeable base cation buffering

Soils in the intermediate pH range (5.5 to 7.0) do not contain free carbonate but they can still buffer pH because added acid cations (H^+ and Al^{3+}) exchange with base cations from clay or humus exchange sites:

EQUATION 7-7

Exchangeable base cation buffering.

$$2H^+ + Ca^{2+}\text{-}CLAY \rightarrow 2H^+\text{-}CLAY + Ca^{2+}$$

The capacity of this mechanism to buffer depends on the quantity of exchangeable base cations in the soil. In comparing soils with the same pH, the soil with the highest organic matter and layer silicate clay content should possess the greatest base cation buffering capacity. Importantly, the exchangeable base cation buffering mechanism does not actually neutralize the acidity but merely stores it in the soil's reserve acidity pool (see the previous section on *Sources of Reserve Acidity*). Consequently, the cost of buffering against acid inputs is the depletion of exchangeable base cations.

Soil Liming

With time, some soils eventually lose their ability to buffer against acid inputs, and soil pH values begin to decrease. When this occurs, liming soils may be necessary. Ground limestone is the only material required to increase soil pH. Limestone is available in pellet form, liquid form or in bulk ag form. Liquid and pelletized lime may be ground finer and potentially neutralize or react quicker with soil than bulk ag lime. However, even though finer-ground lime may react quicker than coarsely ground lime, within nine months to one year after application, both the coarse and fine textured lime will usually yield the same change on pH. Research data from Nebraska, Kansas, and Iowa indicate that liming soils with pH values below 5.8 is economical but producers will not realize a return in investment in one or two years; they must prorate investment return over at least eight years.

How liming influences soil acidity

Lime can neutralize various forms of soil acidity. For example:

EQUATIONS 7-8, 7-9, AND 7-10

Effects of liming on soil acidity.

- Lime reacts with H^+ ions in solution to neutralize them:

$$CaCO_3 + H^+ \rightarrow HCO_3 + Ca^{2+}$$

- Lime reacts with carboxylic acid groups (COOH) in organic matter:

$$2(\text{Organic matter-COOH}) + CaCO_3 \rightarrow \begin{matrix}\text{organic matter-COO}^-] \\ \text{organic matter-COO}^-]\end{matrix} > Ca^{2+} + H_2O + CO_2$$

- Or lime reacts with exchangeable Al^{3+} or H^+ on clays:

$$2Al^{3+}\text{-CLAY} + 3CaCO_3 \rightarrow 2Al\,(OH)_3 + 3\,Ca^{2+}\text{-CLAY} + 3H_2O + 3CO_2$$

Lime or $CaCO_3$ is not very soluble in water. The rate at which lime goes into solution depends on the surface area of the applied lime and degree of incorporation into the soil. Research has shown little if any advantage to grinding lime below 50 to 60 mesh.

Resources

1. Mamo, M., C. Wortmann, and C. Shapiro. 2009. Lime Use for Soil Acidity Management, NebGuide G1504, Updated. University of Nebraska–Lincoln Extension, Lincoln, NE.
2. Wortmann, C., M. Mamo, and C. Shapiro. 2009. Management Strategies to Reduce the Rate of Soil Acidification, NebGuide G03-1505. University of Nebraska–Lincoln Extension, Lincoln, NE.

8 Manure and Organic Residual Management

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Utilizing organic residuals, which include various materials such as sludges, manures, plant materials, compost and industrial byproducts, can be an important part of managing nutrients in a cropping system. With care and planning, the producer can successfully incorporate organic materials into a soil management program. The producer must consider how to estimate nutrient values of organic materials and how to effectively apply the materials. In addition, efforts need to be made to create a uniform manure through mixing and careful and consistent handling. Manure applicators need to be calibrated so they spread the material uniformly at a known rate. Resources at the end of this chapter provide more in-depth information.

Estimating Nutrient Values

Unlike fertilizer, organic materials are not uniform, and in many storage situations they often are not completely mixed. Manure consists of many nutrients and it will not contain the exact ratio of nutrients needed for every field and every crop. The producer must decide the mix of nutrients that will be applied as manure and which nutrients will be supplemented with other sources. Taking a representative sample is sometimes a challenge; however, total reliance on "book" values is not recommended.

■ *Nitrogen*

Nitrogen (N) is the nutrient in organic material that is most easily lost during handling, storage, and application. Table 8-1 shows average values for nitrogen losses from various animal waste handling and storage methods. The best way to accurately estimate the nutrient content of manure is to sample it shortly before application after the losses listed in Table 8-1 have occurred. With a regular sampling system, the producer can establish trends that lead to more precise planning.

TABLE 8-1.

Nitrogen losses from animal manure as affected by handling and storage method.

Manure Handling and Storage Method	Percent Nitrogen Loss[a]
Solid systems	
Daily scrap and haul	15-35
Manure pack	20-40
Open lot	40-60
Deep pit (poultry)	15-35
Liquid systems	
Anaerobic deep pit	15-30
Above ground storage	15-30
Earthen storage pit	20-40
Lagoon	70-80

[a]Based on composition of manure applied to the land vs. composition of freshly eliminated manure; adjusted for dilution effects of the various systems.

Not all applied manure nitrogen becomes available for crop use and the total amount does not become available all at once. This complicates how much nitrogen credit can be given to applied manure. How much is available depends on how it is applied, its percent organic matter and ammonium-nitrogen, and environmental conditions after application. From a managerial point of view, the producer cannot predict nitrogen availability with 100% confidence. If manure is left on the surface for a week or more, without significant rain (0.5 inches), one should assume all ammonium-nitrogen has been lost to the atmosphere. The producer can then estimate that a portion of the remaining nitrogen (in the organic component) will be available for crop use that year. This process is called mineralization.

Through mineralization, **40% of the organic nitrogen applied** in manure, compost and municipal biosolids is expected to be available to the first crop following application. Exceptions are 45% availability for layer manure and 15% availability for composted feedlot manure for the first crop. If manure is applied in late summer or fall and the first crop is winter wheat or another winter crop, 70% of these availabiliity factors should be used for that crop. For the second, third and fourth crop following application, the availability of applied organic N is 20, 10 and 5%, respectively. To detect potential nitrogen deficiencies if mineralization of manure is less than expected, in-season nitrogen status detection is recommended. This can be accomplished by presidedress nitrate soil testing, leaf sampling, or canopy reflectance measurements.

FIGURE 8-1

Waste lagoon.

Because manure contains other nutrients, the application rate is not simply the amount of manure needed to fulfill the nitrogen recommendation. In many cases, supplying all of a crop's nitrogen requirements with manure will cause over-application of phosphorus (P). Before choosing an application rate, the producer should calculate the quantity of other nutrients applied at that rate. The goal of an efficient manure management plan is to combine organic materials and fertilizers so that the combined materials provide all the nutrients needed by the crop without excess.

Phosphorus

Soil tests help producers determine the amount of phosphorus a crop needs. Loss of phosphorus is minor when waste material is incorporated, but manure application on erosion-prone frozen ground may result in phosphorus movement from the field. Generally, it takes less manure to fulfill a crop's phosphorus requirements than it takes to fulfill its nitrogen requirements. When manure is applied to fulfill the crop's phosphorus requirement, the producer receives the highest fertilizer value from the manure. Applying manure at this rate may be more costly since more acres are covered with the same quantity of manure. The increased area treated, however, requires additional time and extra wear on equipment.

Application Considerations

Knife applications that put manure below the soil surface (Figure 8-2) conserve the most nutrients and reduce odors. Table 8-2 shows percent crop available nitrogen associated with application methods. Application uniformity is a major concern, particularly with solid systems, because even under the best of circumstances, application will not be uniform (Figure 8-3).

A case could be made for applying periodic rates that supply two or three years' worth of phosphorus since this would alleviate some spreading problems. However, if the field is prone to erosion or if the resulting nitrogen rate and soil type would make leaching likely, the producer should not employ such a method. Incorporating the material immediately decreases the runoff hazard, but it may also increase the potential for nitrogen leaching because more nitrogen is in the soil and if on sloped ground, erosion rates might decrease.

The Nebraska P-Index is a tool developed to estimate the risk of phosphorus runoff based on location and management. It is available for download and requires Microsoft Excel to run. (*http://water.unl.edu/manure/software*)

Table 8-2

Proportions of inorganic nitrogen in various manures mineralized during the first cropping season after application (fraction of ammonia N available this year).

Sidedress Application			
Injected		*0.95*	
Sprinkler Irrigated		*>0.4″ applied 0.8*	
		≤ 0.4″ applied 0.4	
Preplant Application and Not Incorporated			
Surface applied in spring or fall		*0.00*	
Preplant Application and Incorporated			
		Temperature at Time of Spreading	
Manure Form	*Solid*	*Liquid > 50°F*	*Liquid ≤ 50°F*
Immediately	0.95	0.95	0.95
One day later	0.50	0.70	0.70
Two days later	0.25	0.45	0.55
Three days later	0.15	0.25	0.45
Seven+ days later	0.00	0.00	0.40

Recommendations

Soil sampling, organic material sampling, field choice, and record keeping all improve the use of manure-like materials as fertilizers. Combining fertilizers and organic materials allows the producer to credit for known nutrients while minimizing the effect of environmental conditions and equipment limitations.

FIGURES 8-2 AND 8-3.

Slurry application and dry application of manure.

Resources

1. For a listing of all Nebraska related manure management publications go to: *http://go.unl.edu/manurepubs*.
2. For Nebraska regulations (Title 130), applications and forms, and guidance documents, search the Nebraska Department of Environmental Quality website, *http://www.ndeq.state.ne.us/*.
3. Natural Resources Conservation Service (NRCS) Nebraska related resources can be found at *http://www.nrcs.usda.gov/wps/portal/nrcs/main/ne/technical/ecoscience/manure/*.

9 Soil Testing and Nutrient Recommendations

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For over 50 years, soil testing has been a recommended means of predicting the kind and amount of fertilizers needed. Yet, many farmers still do not use this relatively simple tool to increase fertilizer profitability. Producers still apply fertilizer where none is required or at higher rates than required to optimize yields. Others apply inadequate rates or use ineffective application methods. While soil test recommendations for nutrient requirements and optimum rates needed for maximum profit are not always totally correct, they are superior to no soil testing program at all.

Expectations for a soil test's ability to predict nutrient needs are often very high. When predictions seem to fail, some producers lack confidence in them and, therefore, choose to forego using soil testing as a tool. Soil testing can detect soil nutrient levels prior to planting quite well; however, soil testing cannot predict future factors that may influence crop yields which sometimes greatly affect crop response to fertilizers. Soil testing is a practical and common-sense means of using reliable chemical analyses to assess nutrient levels in soils in order to make decisions to improve fertilizer use. Note that words such as "exact," "precise," or "accurate" are not in this definition. A principal word, however, is "assess" which means to evaluate, to estimate, or to set a fixed value. The key to soil testing and fertilizer recommendations is to correlate and calibrate a soil test's numerical value with field nutrient response. Without this information, soil testing and the resulting fertilizer recommendations have no meaning. The producer must understand the limitations and capabilities of soil tests in order to develop a fertilizer management strategy.

Soil Sampling

The producer must base fertilizer decisions on the probability of yield response to fertilizer. Soil tests indicate relative nutrient availability at the time of sampling. If a soil test is low, the probability is high that a yield response to fertilizer application will occur if the crop matures to produce a harvestable yield. While the probability for yield increase may be high, it does not guarantee crop response. Similarly, when the soil test is high, the probability of yield response to fertilizer application is low, but that does not guarantee no response to fertilizer.

The components of a successful soil testing/fertilizer recommendation system include laboratory analyses, good soil samples, correlation/calibration information, and interpretation.

The top eight inches of soil in an acre weighs over 2 million pounds. The soil sample from a field may weigh about 2 pounds. When a soil sample is analyzed in the laboratory, the sample weighs less than 1 ounce. Because the soil sample must accurately represent an entire field or area sampled, soil sampling is the weakest link in the chain of developing a fertilizer management program. For more information refer to University of Nebraska–Lincoln Extension NebGuide G1740, *Guidelines for Soil Sampling*.

The effect of soil variability on sampling

Producers and agronomists have always been aware that soils vary from farm to farm, from field to field, and even within a given field. It is easy to detect noticeable visual differences in soils such as color, slope, erosion, salinity, or drainage. Detecting differences in soil chemical properties such as pH, phosphorus (P), or potassium (K) status is much more difficult.

Soil testing has historically focused on determining the *average soil test value* for a field or area. Soil sampling plans are designed to determine an adequate number of samples to provide a reliable estimate of the mean, the most efficient sampling plan, and some measure of spatial variability. The best sampling plans are ones which give the lowest sampling error at a given cost or the lowest cost at a given sampling error. While past research has shown that grid sampling almost always increases precision compared to random sampling, most producers have sampled to determine field averages as a matter of cost and convenience.

Site specific management (SSM) and variable rate application (VRA) have changed the way we think about soil sampling compared to the way it's been done for the past 50 years. The difficulty with soil testing today is that quantifying a soil test parameter's variability requires soil sampling at an intensity which allows the variability to be mapped spatially with some degree of confidence. This is nothing new, agronomists 50 years ago concluded that field variation was much greater than laboratory variation, that each soil property has a unique variation in a specific field, and that the specific soil property having the greatest variation cannot be anticipated.

Fertilizer application over the past 50 years has increased field variation in soil nutrients and pH. Most current soil sampling guidelines call for sampling to the depth of tillage, normally 6 to 8 inches. To determine residual nitrogen levels it is recommended samples be collected to a depth of at least 2 feet. However, fertilizer application methods (band vs. broadcast, manure application, differential crop removal) and changing tillage practices have increased heterogeneity and complicated both sampling and interpretation processes. Additional research is needed to determine improved future sampling techniques to deal with nutrient and pH stratification.

The following statements summarize the requirements for proper soil sampling, depending on the producer's objectives:

1. For conventional sampling (compositing cores), the person sampling should take several individual cores for compositing into a single sample for analysis, and take samples from all areas that he determines are different (often called directed sampling).
2. If the farmer is willing to invest more in soil testing, he should grid sample once on a two-acre basis to determine base maps of soil fertility, then sample at a reduced intensity every four to five years.

Sampling methods

Depending on soil variability, current guidelines recommend sampling areas no larger than 40 acres per sample with a minimum of 20 to 25 cores (Ferguson , et al., 2007). A directed random sampling pattern is favored by most agronomists (Figure 9-1). For no-till or minimum tillage, the producer should take samples at a shallower sampling depth of 2 to 4 inches in addition to a sampling depth of 8 to 10 inches to monitor surface pH and the buildup or stratification of immobile nutrients.

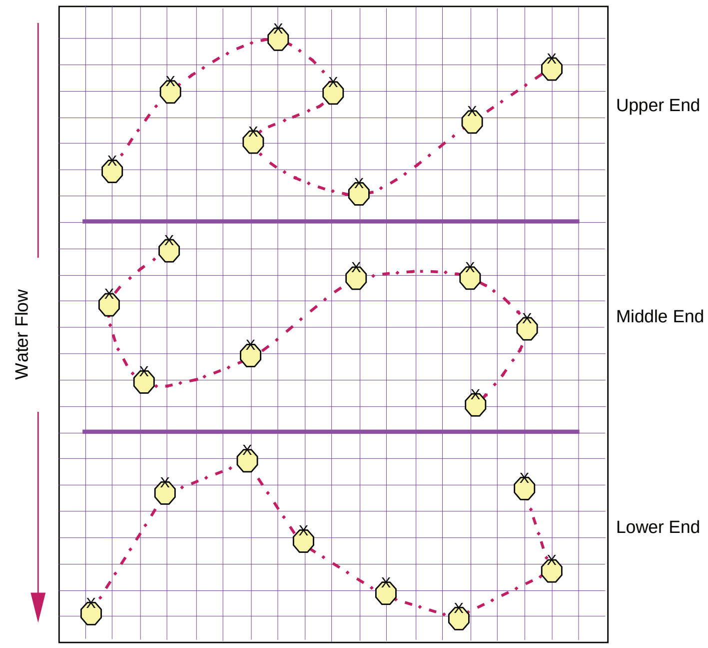


FIGURE 9-1

Dividing and sampling a 60-acre, furrow-irrigated field.

Sampling for site specific management

Because of the intensity required for site specific management soil sampling, producers must first look at sampling frequency. In the past many producers sampled fields yearly, often because it was offered as a service by local agrichemical dealers or by consultants. Annual sampling isn't really beneficial because most soil test values (immobile nutrients, pH) do not change rapidly. Instead, the original process was to collect a good sample, get the results and recommendations, follow the recommendation for four to five years, and then sample again (Table 9-1). In Nebraska, annual sampling is necessary only for residual nitrate determination.

Table 9-1

Relationship between changes in soil properties and frequency of sampling.

Soil Test Property	Frequency of Sampling
CEC/OM	15 years
pH	5 to 10 years
P, K, Zn	5 years
NO_3, SO_4	1 year

Detailed sampling provides significantly more information about soil properties than field average sampling. Because most soil properties (physical or chemical) do not change rapidly, the producer should base soil sampling frequency on the expected change in the parameter measured, and should base site-specific management sampling strategy on an anticipated change in properties.

Intensive sampling, whether it is a two-acre grid or directed sampling based on yield maps, remotely sensed images, or other spatial resources, provides much more information than a whole field average sample. The additional information can improve management and possibly reduce input costs by applying nutrients/amendments where they are really needed. This additional information comes with greatly increased sampling and analysis costs, however. The producer may initially sample intensively to establish base fertility maps of fields, then reduce sampling based on the initial map at one-third to one-fourth the initial intensity to develop a cost-effective site-specific soil testing plan. Sampling costs for these plans will still cost more than field average sampling, but this method will provide greatly improved information for making management decisions. For more information about spatial sampling techniques, refer to University of Nebraska–Lincoln Extension Circulars *Soil Sampling for Precision Agriculture* (EC154) and *Site-Specific Nitrogen Management of Irrigated Corn* (EC163).

Drying the soil sample

For best results, the person taking soil samples should air-dry them before they go to the laboratory for analysis. In drying soils, the sampler should not apply any heat, but should spread the soil out on clean paper and protect the soil from *any* contamination (such as fertilizer, dust).

Chemical Analysis

Today's soil test laboratory analyses are the result of many years of research and field verification. This process has developed chemical procedures that are reliable, reproducible, and suitably accurate. Generally, a chemical procedure applied to a given soil should yield reported values within +10%, depending on the test. For example, a reported phosphorus value of 20 ppm may actually be between 17 and 23 ppm, a reported pH value of 6.5 is often between 6.35 and 6.65, and a zinc value reported as 3.0 ppm is somewhere between 2.5 and 3.5.

Not all essential plant nutrients are needed in a fertilizer management program as the soil or irrigation water may supply sufficient amounts. Copper, boron, sulfur, or chlorine analysis of all soils would not always provide information useful in deciding what fertilizer nutrients are needed. Therefore, it is reasonable not to test for all nutrients on all samples when a particular nutrient is well supplied by the soil or water. This can save on analytical costs.

No matter how good a chemical test, a soil test value is meaningless unless the producer can relate it to the nutrient status of the soil in order to apply a corrective soil amendment or fertilizer treatment. A single numerical value reported by a soil test (say 11 ppm for phosphorus) has no meaning unless information is gathered to evaluate (1) whether crops will attain maximum growth and/or yield at that assessed phosphorus level, (2) whether crop growth or yield will be greater when the nutrient phosphorus is added to the soil, and (3) the amount of phosphorus needed for the crop to attain better growth or yield in different soils at different test levels.

Correlation and Calibration

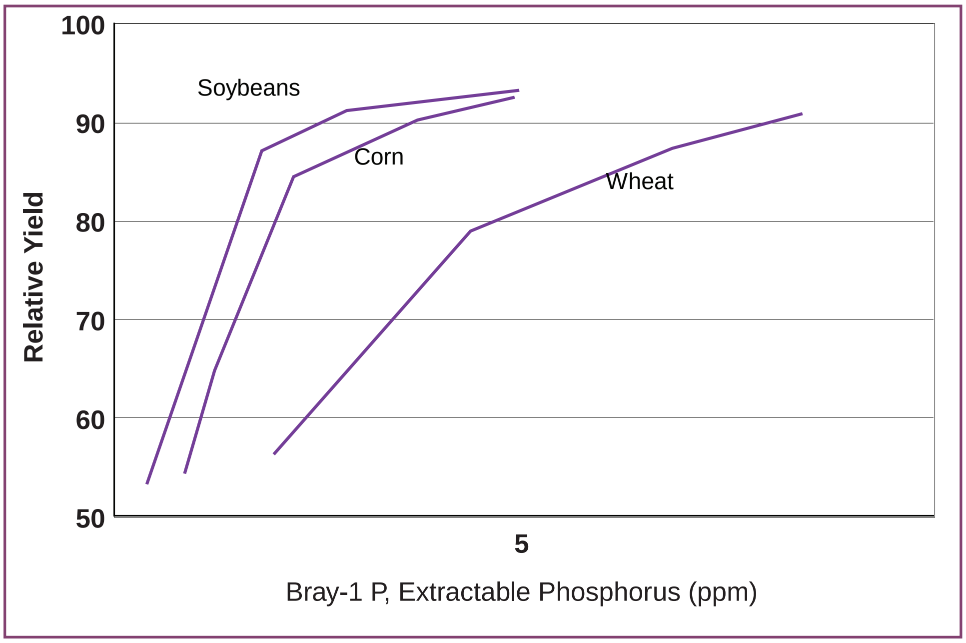
A combination of *correlation* and *calibration* research is necessary to gather information needed to answer these questions. Correlation is a relationship between the amount of nutrient extracted from soil by a laboratory test and nutrient uptake by plants in the greenhouse or field, and/or crop yield. If such a relationship cannot be established, the analytical procedure has little or no usefulness. Sometimes the relationship can be established for only one nutrient and one crop and on a particular group of soils. This is a limitation that the producer must know and recognize, and the soil test should only be used for those limited conditions.

A useful correlation has been established between the Bray-1 P test and percent of maximum yields for soybean, corn, and wheat grown under Nebraska soil and climate conditions. This correlation helps determine when soil test phosphorus is adequate for maximum yields—when no response from additional fertilizer is expected.

Different crops vary in their response to the amount of phosphorus in the soil (Figure 9-2). Yields of both corn and soybean change rapidly with small differences in soil test phosphorus. Winter wheat requires higher levels of soil phosphorus to attain maximum yields. Because of crop differences, soil test correlation research must be conducted with a large number of crops.

FIGURE 9-2

Different crop responses from different soil Bray-1 P levels.



Calibration establishes the relationship between a given soil test value and the yield response from an addition of the fertilizer nutrient to the soil. Table 9-2 shows the response of alfalfa hay produced from several rates of applied phosphorus on a soil with a Bray-1 P value of 8 ppm. Additional field experiments were repeated where soil phosphorus levels ranged from 2 to 30 ppm. From the yield results, one can determine the amount of fertilizer phosphorus needed over a range of phosphorus test levels for many soils where alfalfa is grown.

Table 9-2

Alfalfa yield response to applied phosphorus on a soil with a low Bray-1 P value.

P_2O_5 Applied	Alfalfa Hay Yield
pounds per acre	*pounds per acre*
0	1600
20	2400
40	3000
60	3600
80	3800
100	3600

After field correlation-calibration experiments have been completed, the producer can place soil levels of phosphorus into categories related to their probability of yield response. These categories give quick insight to fertilizer decisions. Their general meaning is given in Table 9-3 in terms of the probability of a yield increase due to phosphorus fertilizer application.

Table 9-3

Probability of a yield increase due to phosphorus fertilizer application.

Assessed Soil P Level	Nutrient Index Level	Meaning of Index Level for Small Grains
0 to 5	Very low	Applying P to a crop will be beneficial over 95% of the time.
6 to 15	Low	Applying P to a crop will be beneficial between 75% and 95% of the time, depending on crop and growing conditions.
16 to 24	Medium	Applying P to a crop has about a 50-50 chance of being beneficial in growth or yield.
>25	High	Applying P to a crop will be beneficial less than 10% of the time.

The increase in yield expected from different rates of a given nutrient will change as the soil test index changes (Figure 9-3).

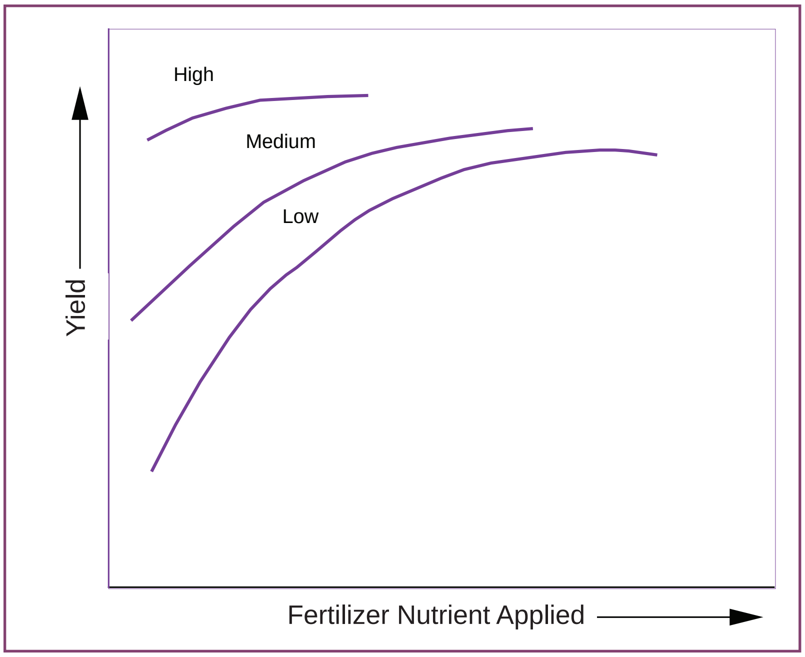


FIGURE 9-3

Crop response to applied fertilizer phosphorus at different soil test phosphorus levels.

This explanation illustrates much of the basic science behind using correlation calibration to develop fertilizer recommendations. Additional research and statistical methods can be used to develop continuous response functions or algorithms for fertilizer recommendations. These equations lend themselves better to variable rate application and will be the next generation of fertilizer recommendations. Additionally with computer generated recommendations, the producer can combine additional factors such as soil pH, placement methods, and even selling price of the crop into multivariate equations for predictions. These are not as easy to illustrate, but they perform the same function as looking up a value in a table. They allow the producer to specify more options than he was able to do in the past to improve fertilizer management and profitability.

Resources

1. Ferguson, R.B. and G.W. Hergert. 2009. Soil Sampling for Precision Agriculture, Extension Circular EC154. University of Nebraska–Lincoln Extension, Lincoln, NE.
2. Ferguson, R.B., G.W. Hergert, C.A. Shapiro, and C.S. Wortmann. 2007. Guidelines for Soil Sampling, NebGuide G1740. University of Nebraska–Lincoln Extension, Lincoln, NE.
3. Ferguson, R.B., A. Dobermann, and J. Schepers. 2007. Site-specific Nitrogen Management for Irrigated Corn, Extension Circular EC163. University of Nebraska–Lincoln Extension, Lincoln, NE.

Part II

Agronomic Crops

Nutrient Management for Agronomic Crops in Nebraska

10 Corn

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Farmers in Nebraska grow more corn than any other row crop. In 2010, Nebraska farmers produced 1.469 billion bushels of corn, which ranked Nebraska third in the nation in corn production. The average Nebraska corn yield in 2010 was 166 bushels per acre; Nebraska producers harvested an average of 186 bushels per acre from irrigated fields and 138 bushels per acre from non-irrigated fields. Nebraska producers harvested approximately 8.9 million acres of corn in 2010 — approximately 6.2 million irrigated acres and 2.7 million dryland acres. The five Nebraska counties having the largest corn harvest in 2010 were Phelps, Kearney, Hamilton, Brown, and York.

In 2010 Nebraska corn producers applied a per-acre average of 140 pounds of nitrogen (N), 41 pounds of phosphate (P_2O_5), and 26 pounds of potassium (K_2O) fertilizers. This compares to average 1996 rates of 140 pounds of nitrogen, 34 pounds of phosphate, and 22 pounds of potassium oxide per acre. This shows that fertilizer rates have remained relatively constant over the previous 14 years, suggesting that Nebraska farmers have become increasingly efficient in how they use fertilizers, with the average yield in 1996 at 143 bushels per acre compared to 166 bushels per acre in 2010 using the same amounts of fertilizers.

Nitrogen and phosphorus (P) are the primary nutrients corn needs for optimum yield in Nebraska. Soil potassium (K) levels low enough to expect yield increases from potassium fertilization are relatively rare in the state. Other nutrients which may be limiting in soil and require fertilization for corn are sulfur (S), zinc (Zn), and occasionally iron (Fe).

Nitrogen

The producer should determine the amount of nitrogen fertilizer necessary for corn after accurately accounting for sources of nitrogen already available to the crop, such as mineralization from soil organic matter, residual soil nitrate, organic resources, previous legume crops, and irrigation water. The University of Nebraska (UNL) web-based nitrogen recommendation tool for corn incorporates credit for organic matter and residual soil nitrate. One should credit other sources of nitrogen to derive the recommended fertilizer nitrogen rate.

The UNL N recommendations for corn grain are available through a web-based digital tool on the following link: https://cropwatch.unl.edu/nitrogen-tool (refer to UNL Extension publication EC117, Fertilizer Suggestions for Corn, for more information). The following equation provides N recommendations for silage corn, where OM stands for organic matter content (%), NO_3-N is the average nitrate-nitrogen concentration (ppm) in the root zone at 0-2 to 0-4 feed, and EY stands for expected yield in tons per acre.

EQUATION 10-1

University of Nebraska nitrogen rate equation for corn grain.

EQUATION 10-2

University of Nebraska nitrogen rate equation for silage.

$$\text{Corn Silage N Rate (lb/acre)} = 35 + (7.5 \times EY) - (8 \times NO_3 - N \text{ ppm}) - (0.85 \times EY \times OM) - \text{other credits}$$

The producer should base the expected yield on the previous five years' yields, minus any atypical yields (significantly influenced by hail, drought, wind damage, etc.), plus 5%. Table 10-1 provides nitrogen recommendations at three organic matter levels, with various soil residual nitrate and expected yield levels, once credits from other sources have been allowed.

The producer should base residual soil nitrate values on soil samples collected to a depth of at least 2 feet, and preferably 3 to 4 feet. The deeper the sample, the more accurate the estimate of soil residual nitrate-nitrogen credit. One should collect soil samples for residual nitrate-nitrogen according to procedures in Chapter 9 and in UNL Extension publications NebGuide G1740, *Guidelines for Soil Sampling,* and/or EC163, *Site-Specific Nitrogen Management of Irrigated Corn*.

Nitrogen credits

The farmer should estimate sources of nitrogen credit as carefully as possible in order to avoid over or under fertilization of the crop. The legume credits in Table 10-2 are conservative—typically the evident nitrogen credit to legumes will be greater than those shown. One cannot determine legume credits from a soil test because the credits reflect nitrogen that will be mineralized (or not immobilized) due to high nitrogen content legume residues in the following crop year. The producer can more accurately determine credits from irrigation water and organic resources by analyzing representative samples. The farmer should base irrigation water credits (Table 10-3) on a nitrate analysis of the irrigation water the preceding year. These irrigation water credits are also conservative, in that they do not reflect the normal total amount of irrigation water applied during the season, but only that irrigation water amount from which nitrogen is effectively used. Table 10-4 provides generalized, conservative nitrogen credits from a variety of organic resources (refer to NebGuide G1335, *Determining Crop-Available Nutrients from Manure*). Whenever possible, the producer should have organic resources analyzed to more accurately determine the nitrogen credit. Additional information and guidance on nitrogen credits is available in EC117, *Fertilizer Suggestions for Corn*, and EC168, *Slide Rule for Calculating Nitrogen Rates*.

Table 10-1

Nitrogen fertilizer recommendations for corn based on expected yield with adjustments for soil nitrate-nitrogen and soil organic matter.

Nitrogen Soil Test		**Expected Yield (Bu/Acre)**									
	Relative Level	**60**	**80**	**100**	**120**	**140**	**160**	**180**	**200**	**220**	**240**
ppm		*pounds of N to apply per acre*									
		3% soil organic matter									
3	Low	60	75	90	105	120	135	150	165	185	200
6	Low	35	50	65	80	95	110	125	145	160	175
9	Medium	0	25	40	55	70	90	105	120	135	150
12	Medium		0	15	35	50	65	80	95	110	125
15	High			0	0	25	40	55	70	85	100
18	High					0	15	30	45	65	80
21	High						0	0	25	40	55
24	Very high								0	15	30
27	Very high									0	0
		2% soil organic matter									
3	Low	65	85	105	120	140	160	175	195	215	230
6	Low	40	60	80	95	115	135	155	170	190	210
9	Medium	20	35	55	75	90	110	130	145	165	185
12	Medium	0	15	30	50	70	85	105	125	140	160
15	High		0	0	25	45	60	80	100	115	135
18	High				0	20	40	55	75	95	110
21	High					0	15	35	50	70	90
24	Very high						0	0	25	45	65
27	Very high								0	20	40
		1% soil organic matter									
3	Low	75	95	115	140	160	180	200	225	245	265
6	Low	50	70	95	115	135	155	180	200	220	240
9	Medium	25	50	70	90	110	135	155	175	195	215
12	Medium	0	25	45	65	85	110	130	150	170	195
15	High		0	20	40	65	85	105	125	150	170
18	High			0	20	40	60	80	105	125	145
21	High				0	15	35	60	80	100	120
24	Very high					0	15	35	55	75	95
27	Very high						0	0	30	50	75
33	Very high									0	25
36	Very high										0

Without a soil test for nitrate-N, assume 3 ppm; without a soil test for organic matter, assume 2%

Table 10-2

Estimated apparent nitrogen contributions from legumes.

Legume Crop	Nitrogen Fertilizer Reduction	
	Medium/Fine Textured Soils	*Sandy Soils*
	pounds per acre	
Soybean	45	45
Alfalfa (70 to 100% stand, > 4 plants/ft^2)	150	100
Alfalfa (30 to 69% stand, 1.5 to 4 plants/ft^2)	120	70
Alfalfa (0 to 29% stand, < 1.5 plants/ft^2)	90	40
Sweet and red clover	80% of credit allowed for alfalfa	

Credits for legumes are based on the University of Wisconsin recommendations.

Table 10-3

Nitrogen contributions from irrigation water.

Area of State	Net Irrigation	Irrigation Water Nitrate-N (ppm)						
		10	15	20	25	30	35	40
	inches	*pounds per acre*						
East	6	14	20	27	34	41	48	54
Central	9	20	30	41	51	61	71	82
West	12	27	41	54	68	81	95	108
Panhandle	15	34	51	68	85	102	118	135

Table 10-4

Estimated nitrogen contributions from manures and other waste materials for the first crop after application.

Dry Materials	Pounds of N/Ton	Liquid Materials	Pounds of N/1000 Gallons
Beef feedlot manure	4 - 5	Swine, liquid pit	10 - 15
Dairy manure	3	Swine, lagoon	2 - 5
Sheep manure	5	Beef, liquid pit	10 - 12
Poultry manure	12 - 17	Beef, lagoon	1 - 2
Composted beef feedlot manure	10 - 14	Dairy, liquid pit	7 - 8
Sewage sludge	2 - 3	Dairy, lagoon	1 - 2
Horse manure	3	Cheese whey	1 - 2

Phosphorus

Research at the University of Nebraska and other Midwestern universities has shown that significant yield increases due to phosphorus fertilization of corn are unlikely above a Bray-1 P soil test of 20 ppm. Table 10-5 reflects these findings. However, recent research investigating the spatial variability of nutrients in fields has shown that soil phosphorus levels are highly variable. Often phosphorus levels and distribution patterns in fields are influenced substantially by livestock manures. High concentrations of phosphorus are found near current or abandoned livestock confinement areas. These high levels can persist for many years after livestock are gone. In many cases, producers currently farming the land are unaware of past livestock confinement areas. If random soil sampling to determine average fertility levels includes samples collected where manures have been stockpiled or heavily applied, the phosphorus test from a composite soil sample will be higher than the rest of the field, and may result in the producer under-fertilizing a significant portion of the field. If the farmer is aware of past livestock confinement areas, or if he suspects their presence, he should exclude those areas from composite sampling and sample them separately.

The producer should base phosphorus fertilizer needs for corn on phosphorus soil test levels and the method of fertilizer phosphorus application as shown in Table 10-5. The efficiency with which corn uses phosphorus is generally low, the crop often takes up only 10% to 20% of the applied phosphorus fertilizer. The producer can improve plant-phosphorus use efficiency by reducing soil-fertilizer contact, and by concentrating phosphorus near plant roots by banding phosphorus fertilizer, either in preplant bands or at planting (starter). The increased efficiency of banded phosphorus fertilizer is reflected in lower recommended rates for band application as shown in Table 10-5.

Table 10-5

Phosphorus fertilizer recommendations for corn.

Phosphorus Soil Test		**Relative Level**	**P_2O_5 to Apply**	
*Bray-1 P**	*Olsen P**		*Broadcast*	*Band***
ppm			*pounds per acre*	
0 - 5	0 - 3	Very low	80	40
6 - 15	4 - 10	Low	40	20
16 - 24	11 - 16	Medium	0	†
25 - 30	17 - 20	High	0	†
> 30	> 20	Very high	0	0

*Phosphorus tests: Bray-1 P for acid and neutral soils; Olsen P for calcareous soils (pH 7.3 or greater).
**Applied in a band preplant or beside the row at planting.
†Applying 10 to 20 pounds per acre P_2O_5 with 5 to 10 pounds per acre N in a band at planting may increase early growth on these soils. See NebGuide G361, Using Starter Fertilizers for Corn, Grain Sorghum and Soybeans.

Potassium

Most soils in Nebraska contain adequate amounts of potassium for maximum corn yields. For those soils low in potassium, the producer should apply potassium fertilizer according to the guidelines in Table 10-6.

TABLE 10-6

Potassium fertilizer recommendations for corn.

Potassium Soil Test*	Relative Level	K_2O to Apply		
		Broadcast		*Band***
		pounds per acre		
0 - 40	Very low	120	+	20
41 - 74	Low	80	+	10
75 - 124	Medium	40	or	10
125 - 150	High	0		0
> 150	Very high	0		0

* Potassium test: exchangeable K.
** Banded beside the seed row, but not with the seed.

Sulfur

Nebraska corn crops generally only need sulfur on low organic matter, sandy soils. Guidelines for sulfur fertilizer needs for corn are given in Table 10-7. Most irrigation water, except in the very sandy area of north central Nebraska, contains enough sulfur to supply the sulfur requirement of corn. In these regions, therefore, applying fertilizer containing sulfur in a band at planting time on sandy soils is an effective method and the most efficient method to supply corn's early sulfur needs.

TABLE 10-7

Sulfur fertilizer recommendations for corn on sandy soils.

Sulfur Soil Test, SO_4-S‡	Annual Sulfur Application Rate	
ppm	*pounds per acre*	
	Soil Organic Matter ≤1%	*Soil Organic Matter >1%*
	Irrigation water with < 6 ppm SO_4-S	
< 6	10 row* or 20 broadcast	5 row*
6 - 8	5 row* or 10 broadcast	0
	Irrigation water with > 6 ppm SO_4-S	
< 6	5 row* or 10 broadcast	0
6 - 8	5 row* or 10 broadcast	0
> 8	0	0

‡Sulfur test is $Ca(H_2PO_4)_2$ extraction.
*Applied in a band next to row, but not with seed.

Zinc

The producer can best determine zinc fertilizer requirements with a soil test for zinc. Table 10-8 gives the recommended rates of zinc to apply according to the soil zinc level and excess lime content of the soil. Recommended broadcast rates are for raising soil zinc content to a level that is adequate for several years. Row treatment rates are for annual application.

Table 10-8

Zinc fertilizer recommendations for corn.

DTPA-Zn	Relative Level	Zn to Apply	
		Calcareous Soils	*Noncalcareous Soils*
ppm		*pounds per acre*	
0 - 0.4	Low	2 row or 10 broadcast	2 row or 5 broadcast
0.41 - 0.8	Medium	1 row or 5 broadcast	1 row or 3 broadcast
> 0.8	High	0	0

Iron

Symptoms of iron chlorosis, consisting of yellow striping on corn leaves, may occur when soils are highly calcareous or saline-sodic with pH levels above 7.8. Because of the nature of such soils, correcting an iron deficiency is difficult.

In such a case, the producer should select corn hybrids that have tolerance to these soil conditions. Corn hybrids vary greatly in tolerance to chlorosis. This genetic tolerance to chlorosis may be adequate. If not, the producer may have to apply iron materials to the soil.

Current research has shown that the most effective treatment for correcting high pH chlorosis in corn is an at-planting seed-row application of 50 to 100 pounds of ferrous sulfate heptahydrate ($FeSO4 \cdot 7H2O$) per acre. This is an economical treatment, but it does require dry fertilizer application equipment on the planter.

Another way to combat iron chlorosis is for the producer to apply a stable dry iron chelate (FeEDDHA), dissolved in water, with the seed. This method may be preferable if the producer has liquid fertilizer application equipment. Research has shown that at least 2.5 to 4 pounds of FeEDDHA per acre is necessary. Chlorosis correction from FeEDDHA has not equaled that of $FeSO4 \cdot 7H2O$ in research at North Platte and the chelate is expensive. The FeEDDHA works well for correcting soybean chlorosis on high pH soils, but not on corn because of iron uptake chemistry differences between grasses and legumes.

The producer can use foliar sprays using ferrous sulfate or FeEDDHA, but they are not always effective in producing significant yield responses. Failure to correct chlorosis with foliar treatment is often due to late application. The farmer must treat as soon as chlorosis first becomes visible and he must usually treat several times. The producer should repeat such treatment every 7 to 10 days until newly emerged leaves remain green and he must spray directly over the row in order for the treatment to be effective. A standard application is 20 gallons per acre of a 1% solution.

To develop a 1% solution of iron sulfate, the producer should add 8 pounds of FeSO4 or 15 pounds of FeSO4•7H2O to 100 gallons of water. Using an iron sulfate concentration greater than 1.5% usually results in excessive leaf burning.

Rather than using iron sulfate, the producer may opt to use an iron chelate; he should carefully follow the directions on the product container. Adding a commercial wetting agent or a cup of mild detergent to each 100 gallons will improve plant coverage. The addition of 25 pounds of feed grade urea or 5 gallons of 28-0-0 UAN fertilizer per 100 gallons of spray solution also enhances iron uptake.

Nutrient Removal and Sufficiency Ranges

Table 10-9 illustrates nutrient uptake of the nutrients most often applied as fertilizers in Nebraska for a typical yield of corn. Because of the nutrient supply in organic matter and clay minerals, most Nebraska soils can adequately meet crop requirements of potassium and sulfur for many years without supplemental fertilization. The sufficiency ranges for nutrients shown in Table 10-9 reflect nutrient levels in plants capable of optimum yield. Levels of nutrients in plant tissue can be influenced by hybrid and climate. Nutrient levels below those shown are likely to result in a yield limiting deficiency, and may be reflected in the appearance of the crop. Nutrient levels significantly above those shown may reflect over-fertilization and luxury uptake, but yield limiting toxicities of these nutrients are unlikely.

Table 10-9

Corn nutrient requirements (150 bushels per acre grain yield, 9000 pounds per acre stover yield).

Nutrient	Removed in Grain	Remaining in Stover	Total Uptake
	pounds per acre		
N	135	100	235
P_2O_5	64	36	100
K_2O	42	144	186
S	14	11	25
Zn	0.15	0.3	0.45

Nutrient	Sufficiency Ranges: Whole Plant, 3 to 4 Leaf Stage	Sufficiency Ranges: Ear Leaf at Silk
	percent	
N	3.5 - 5.0	2.7 - 3.5
P	0.4 - 0.8	0.2 - 0.4
K	3.5 - 5.0	1.7 - 2.5
S	0.2 - 0.3	0.1 - 0.2
Zn (ppm)	20 - 50	20 - 70

Source:
1. Franzen, D. and J. Gerwing, 1997. Effectiveness of Using Low Rates of Plant Nutrients. North Central Regional Publication 341. University of Nebraska, Lincoln, NE.
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Resources

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11
Winter Wheat

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Profitable winter wheat production often requires nitrogen (N) and phosphorus (P) fertilization in Nebraska, when there is adequate moisture. Other nutrients may be needed for some fields, but most Nebraska soils supply adequate nutrients other than nitrogen and phosphorus. Nebraska bases nitrogen recommendations for dryland winter wheat on soil organic matter, soil nitrate, plus wheat and fertilizer prices. Recommendations are assumed adequate for yields of 70 to 75 bushels per acre.

Winter wheat acreage in Nebraska has declined the past few years; however, irrigated winter wheat acreage has tripled since 1987 (Figures 11-1 and 11-2). The current acreage of irrigated wheat (~90,000 acres) is significant, although still small compared to all wheat (~600,000 acres). Irrigated wheat acreage has increased as water supplies have declined and producers look for crops that require less water but still produce a profit.

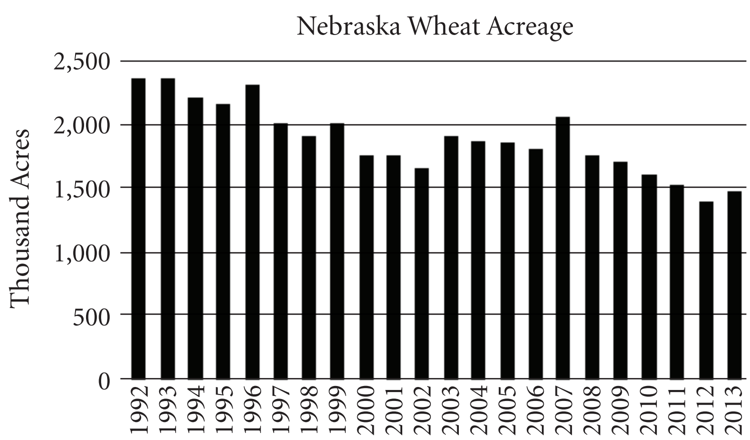

Figure 11-1.

Total winter wheat acreage in Nebraska.

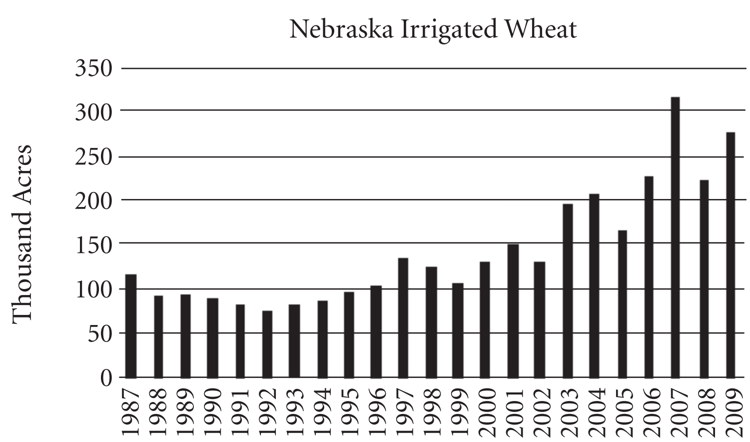

Figure 11-2.

Irrigated winter wheat acreage in Nebraska.

Soil Testing

Soil testing, the foundation of nutrient management in winter wheat, characterizes soil nutrient availability. Recommended fertilizers can then be applied to ensure optimal nutrition for the crop. Information on proper soil sampling is provided in NebGuide G1740, *Guidelines for Soil Sampling* (*http://www.ianrpubs.unl.edu/sendIt/g1740.pdf*). Soil samples from the surface (0 to 8 inches) or tillage layer should be analyzed for organic matter, pH, and other nutrients including nitrate-nitrogen.

Nitrogen

N rate recommendations

Most winter wheat grown in Nebraska requires nitrogen fertilization for profitable production. This is true for virtually all soils in Nebraska where wheat is commonly grown, unless there is a large carryover of nitrate-nitrogen. Residual soil nitrate can be measured effectively with a soil test of the root zone. While the depth of the root zone for wheat is often 5 to 6 feet or more, most available nitrogen affecting yield is in the top 3 or 4 feet of soil. Sampling less than 3 feet for residual nitrate can reduce the accuracy of the nitrogen fertilizer recommendation. Adjusting nitrogen recommendations from samples less than 2 feet deep is not recommended.

The optimum fertilizer nitrogen rate for winter wheat (with a maximum rate of 100 pounds of nitrogen per acre for dryland, and 150 pounds of nitrogen per acre irrigated) can be calculated with the following equation.

$$\text{Nitrogen Rate (lbs/acre)} = ((\text{N Price} / \text{Wheat Price}) + (NO_3\text{-N}/68.7) - 0.235)*\text{-}725$$

Where **N Price** is dollars per pound of fertilizer nitrogen; **Wheat Price** is in dollars per bushel of wheat; **NO_3-N** is the average parts per million (ppm) nitrate-nitrogen in the top 3 or 4 feet.

If a soil sample is not taken, an average soil nitrate-nitrogen level of 5 ppm of nitrate-nitrogen can be used.

While high yields for most crops require higher nitrogen application rates, research results for dryland winter wheat in Nebraska don't consistently show any effect of yield level on the nitrogen required for maximizing profits from fertilizer nitrogen. Recommended N rates are adequate for dryland yields across the state unless producers expect yields above 75 bushels per acre above which an additional 20 pounds of nitrogen per acre should be applied.

When to apply nitrogen

Nitrogen applications have a high probability of increasing yield when soil nitrogen availability is low in relation to yield potential, but nitrogen fertilizer application can cause yield depression, mainly under dry conditions. Yield depressions have occurred more often with fall applications than with spring topdressing applications. Fall applications tend to stimulate increased vegetative growth that depletes soil water and may increase susceptibility to disease. Yield depressions associated with fall application of nitrogen are uncommon and should not be used as a basis for not applying nitrogen to wheat.

Figure 11-3.

Row application of 10-34-0 at wheat planting in the Nebraska Panhandle.

If yield depression is a concern, especially in western Nebraska, spring topdressing is recommended. Spring topdressing allows the producer to evaluate yield potential based on plant stands and soil moisture. Some fall-applied nitrogen (10 to 20 pounds per acre) should be applied to promote growth for cover and competition with weeds. Topdressing the remaining nitrogen has a significant advantage over applying all nitrogen in the fall because it helps the producer avoid investing in a wheat crop that may have low yield potential. Nitrogen application should be completed prior to jointing. With nitrogen applications made after jointing, yield response is decreased, but grain protein content generally shows an increase compared to non-fertilized wheat. Yield decreases from nitrogen application also can occur on soils high in available nitrogen. When available nitrogen is too high, lodging often results, especially with high soil moisture in the spring. This emphasizes the importance of soil tests to determine soil nitrogen availability.

Sources of nitrogen for wheat

All common nitrogen fertilizer sources are similarly effective, including urea (46-0-0), urea-ammonium nitrate (32-0-0 or 28-0-0), and anhydrous ammonia (82-0-0), when properly applied. Nitrogen sources vary in their susceptibility to volatilization or gaseous loss as ammonia to the atmosphere. Incorporation of fertilizer (mechanical, rainfall, or irrigation) soon after application should provide equal effectiveness of sources.

Anhydrous ammonia is the most economical source of nitrogen, especially under normal tillage. However, if applied with standard knife applicators, the increased power requirements will add to application costs. This makes the lower ammonia price less advantageous compared to other nitrogen sources.

Newer ammonia applicators with coulters allow narrower knife spacing (15 inches) and also operate at shallower depths, greatly reducing power requirements. Depending on local pricing, ammonia application rates must be more than 40 pounds of nitrogen per acre to be more economical than other nitrogen sources. In western fallow areas, ammonia is generally a good source if it is applied early in the fallow period to avoid soil drying prior to seeding.

FIGURE 11-4.

Harvesting irrigated winter wheat.

Fertilizing for grain protein

Nebraska wheat has traditionally been high in protein content and quality, desirable characteristics for the baking industry. Nitrogen availability directly affects grain protein. With high soil nitrogen, grain protein is often 13% or higher, depending on yield levels. If soil nitrogen is low, grain protein tends to decrease as grain yield increases. Since grain protein reflects soil nitrogen availability, it can reflect when wheat yield will increase with applied nitrogen. A grain protein level of 12% to 13%, with an average yield, indicates adequate nitrogen. If grain protein is in the 10% to 11% range, however, yield response to nitrogen is very probable. University of Nebraska–Lincoln (UNL) nitrogen fertilizer recommendations for wheat will generally produce grain protein above 12%. If higher grain protein is your goal, about 20 pounds per acre additional nitrogen will need to be topdressed in the spring for each 1% increase in grain protein desired, up to a maximum of 40 pounds of nitrogen per acre.

Nitrogen fertilizing following high yields

For most wheat grown in wheat-fallow or wheat-summer crop-fallow systems, producers have sufficient time for straw decomposition before the next wheat crop, if favorable soil moisture and temperature conditions exist. Continuous wheat cropping is another consideration. This is not a recommended practice because of disease and insect concerns, but it is done in some areas. A producer planting wheat following above-average grain yields may need increased nitrogen fertilizer due to increased nitrogen removal by the previous crop, and because the increased straw requires additional nitrogen for decomposition.

Straw yields increase about 0.35 ton for each 10-bushel-per-acre increase in grain yields for semidwarf varieties and 0.45 ton for taller varieties. Straw only contains about 10 pounds of nitrogen per ton. Wheat following grain yields of 70 bushels per acre or more may require an additional 20 pounds of nitrogen per acre for proper straw decomposition to avoid nitrogen deficiency from nitrogen immobilization. This nitrogen deficiency usually does not express itself until the next spring during the wheat's rapid growth. If these conditions exist, additional nitrogen can be applied when straw is tilled before planting; or the additional nitrogen could be added during rapid vegetative growth early the following spring.

Figure 11-5.

Small plot nitrogen response to wheat in millet stubble at Sidney, NE in May.

Phosphorus Recommendations

Wheat responds to applied phosphorus (P) more than other major Nebraska grain crops. Soil test levels of phosphorus must be higher for wheat than for corn, grain sorghum, or soybean. Research indicates that phosphorus mainly increases tillering in the fall, which increases the number of heads and grain yield. To a lesser extent, phosphorus increases seed size and kernel number in the head. Because of the effect of phosphorus on wheat rooting, winterkill is often associated with low soil phosphorus. Phosphorus deficiencies also result in delayed maturity, which is clearly visible on eroded and high pH soils with low availability of soil phosphorus. Areas of green wheat among mature wheat also are good indicators of phosphorus deficiency.

Optimum phosphorus rate for row or dual placement

The UNL equation for phosphorus is based on soil test value, phosphorus application method, yield goal, phosphorus fertilizer price, and wheat price. Calculate the optimum fertilizer phosphorus rate for winter wheat, the following equations or by using Worksheets 1 or 2 and Tables II through VI in EC143. An Excel® spreadsheet found at *http://soilfertility.unl.edu* can also be used.

Bray-1 P Test:

P_2O_5 rate (lb/acre) = (-9.98 - 2.38 x LN(Bray-1P) + 4.39 x LN YG)/(P Price/Wheat Price)

Olsen P Test:

P_2O_5 rate (lb/acre) = (-9.98 - 2.38 x LN(OlsenP*1.5) + 4.39 x LN YG)/(P Price/Wheat Price)

Optimum phosphorus rate for broadcast application

Bray-1 P Test:

P_2O_5 rate (lb/acre) = (17.13 - 3.21 x LN (Bray-1P) + 2.89 x LN YG - 9.81 x LN pH)/(P Price/Wheat Price)

Olsen P Test:

$P2O_5$ rate (lb/acre) = (17.13 - 3.21 x LN (OlsenP*1.5) + 2.89 x LN YG - 9.81 x LN pH)/(P Price/Wheat Price)

In the equation, LN is the natural logarithm, Bray-1P is the soil phosphorus test (ppm), YG stands for yield goal in bushels per acre, pH is soil pH, P Price is dollars per pound of P_2O_5, and Wheat Price is in dollars per bushel of wheat

Several soil extractants are now used by commercial soil-testing laboratories to determine available phosphorus. Most research has been conducted by calibrating Bray-1 P with corn response.

The authors suggest using the following equations to convert results using other extractants to a “Bray-1 P equivalent” to make a phosphorus recommendation.

For Mehlich 2: Bray-1 P = 0.9 * Mehlich II

For Mehlich 3: Bray-1 P = 0.85 * Mehlich III

For Olsen P: Bray-1 P = 1.5 * Olsen P

Phosphorus application methods

Three basic methods of phosphorus application for wheat include applying it directly with the seed, broadcasting and incorporating prior to seeding, or dual placement, which is applying ammonium polyphosphate (10-34-0) together with anhydrous ammonia prior to seeding. With new air seeders, air distribution of fertilizer, and precision ammonia applicators available, producers can find many variations of these three application schemes. For example, a producer using different kinds of tillage and placement shovels, sweeps, or a no-till seeding system can place nitrogen and phosphorus fertilizers either under, or slightly to the side of, the seed row. Seed rows also may vary greatly in width, where the seed may be spread out over several inches under a sweep or seeded in a narrow slot.

These variations greatly influence fertilizer-seed contact, which may affect seed germination. The normal ammonium superphosphates (11-52-0, MAP or 18-46-0, DAP) generally have little effect on wheat stands because of their low salt index, the lower fertilizer concentration associated with narrow rows (7- to 10-inch vs. 14-inch), and the generally high rates of seeding used with modern wheat varieties. The seeding mechanism for applying phosphorus fertilizer with the seed (or in bands) is not critical unless the producer applies additional nitrogen at the same time. If you apply large amounts of nitrogen (over 15 to 30 pounds of nitrogen per acre, depending on row spacing), fertilizer nitrogen must be separated from the seed or stand losses may result. This is accomplished with some types of air seeders.

Experiments in Nebraska have shown that dual-placed phosphorus performs similarly to seed-applied phosphorus, so the recommendation is the same for both application methods. While dual-placed phosphorus often results in somewhat less uniform wheat growth than seed-applied phosphorus, harvest yields have been similar for the two application methods.

Greater wheat growth variability associated with dual-placed phosphorus results from delayed root contact due to the greater distance from the row that phosphorus is placed, compared to seed application. This mainly occurs on soils testing very low in phosphorus.

This difference in time of root-to-phosphorus contact normally does not affect yield when wheat is seeded at the optimum seeding date; however, if wheat is seeded late without time for adequate root growth, the seed application method is superior. Knife spacing for dual placement should be no greater than 15 inches. Wider spacing of nitrogen and phosphorus bands can result in variable plant height and may reduce yield. The normal ammonia application depth of 5 to 7 inches is also a good depth for phosphorus application. Double tubes on the shank for ammonia delivery and liquid fertilizer phosphorus are required.

Residual phosphorus

When fertilizer phosphorus is applied, only 10% to 30% is absorbed by the wheat. The remaining 70% to 90% of the applied phosphorus remains in the soil as residual phosphorus. This residual phosphorus begins slowly reverting to insoluble and less available P forms. Less than 25% to 30% of residual phosphorus is generally found in the following year's soil tests for phosphorus when the phosphorus is broadcasted and mixed with the soil. Studies have shown that residual phosphorus availability can increase significantly when it is knifed-in below tillage depth. Undisturbed bands may provide some phosphorus for several years, but the primary effect occurs during the year following application. Therefore, residual phosphorus from banding is most effective in continuous cropping systems and less effective in winter wheat-fallow systems because of the two-year period between phosphorus application and seeding of the next wheat crop.

Potassium Recommendations

Most Nebraska soils have enough potassium (K) for maximum wheat production. The plant must have adequate potassium nutrition to ensure efficient water use within the plant. Early symptoms of potassium deficiency include uniform chlorosis on older plant tissue. Leaves eventually become streaked with yellow or appear scorched, bronzed, or blighted along their edges.

Some experiments have shown apparent yield increases with potassium fertilization, but the increases have not been predictable and may have been the result of abnormal weather conditions, disease, or some indirect effect (chloride effect on foliar disease) other than a direct potassium response.

It is rare for potassium to be recommended for wheat grown on Nebraska soils because most soils in wheat growing areas contain more than 150 ppm potassium.

Other Nutrients

Zinc

When soil zinc (Zn) levels are less than 0.4 ppm (DTPA test), wheat may respond to zinc fertilization. Usually it is not economical to broadcast 10 or 15 pounds of zinc per acre from zinc sulfate to increase the soil test level unless producers are irrigating or producing other high-zinc requiring crops.

If the soil test is very low in zinc, row-applied 10-34-0 + 1% zinc is an excellent way to provide a small amount of zinc to correct potential deficiency. Zinc-ammonia complexes can be cold-mixed with 10-34-0 to provide Zinc and are often more economical than chelated Zinc sources. One-half to 1 pound of zinc per acre is usually sufficient.

Sulfur

Most fine-textured soils in Nebraska have adequate amounts of organic matter and/or residual sulfate sulfur (S) deeper in the soil for maximum wheat yield. The exception may be sandy soils, especially irrigated sandy soils. If sulfur is required on a sandy soil, a broadcast rate of 10 to 15 pounds of sulfur per acre should be sufficient. Irrigated wheat on sandy soils with low organic matter and low sulfate levels in the irrigation water may require up to 20 pounds of sulfur per acre. If 10-34-0 is row-applied at planting, ammonium thiosulfate (12-0-0-26S) should not be mixed with the phosphate. Thiosulfate can severely injure wheat seedlings and drastically reduce stands.

Chloride

Experiments conducted in western Nebraska on dryland winter wheat showed little response to chloride even though many soils contained low chloride based on guidelines developed from South Dakota research. At this time, the authors do not recommend chloride fertilization for winter wheat.

Soil pH Considerations

Increased precipitation captured from no-till and residue cover has improved crop yields and has also led to increased use of nitrogen fertilizer. As a result, many soils in western Nebraska above 18 inches of annual precipitation have shown significant decreases in pH during the past 25 years. The increased crop yields have led to higher export of bases (calcium, manganese, potassium), and acidification from ammonium-based nitrogen fertilizers has also contributed to pH decreases. The pH changes have been noted to at least a 1-foot depth. Subsoil pH has not yet been affected.

As pH continues to decrease, soil testing will be important to determine potential effects on crop growth and the need for liming. Traditional quarry lime sources in eastern Nebraska are a considerable distance from western Nebraska, however, precipitated calcium carbonate from sugar beet processing is readily available from plants at Ft. Morgan, CO, Scottsbluff, NE, and Torrington, WY. This material would provide a lower-cost liming option due to transportation costs and cost of the liming material, and may need to be considered as soil pH continues to decrease and if soils become acidic enough to produce high levels to aluminum that can be toxic to wheat. Fly ash from coal-fired power plants at Sutherland, Grand Island and Hastings, NE; Ft. Collins and Brush, CO; and Holcomb, KS may also provide a source of a low cost liming material that could be used.

Acknowledgment

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12
Grain and Silage Sorghum

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Nebraska ranks third nationally (behind Kansas and Texas) in grain sorghum production. Most of Nebraska's sorghum production is non-irrigated. The top five counties producing sorghum in 2007 were Furnas, Red Willow, Gage, Hitchcock, and Nuckolls.

Generally, sorghum is more tolerant of heat and moisture stress than corn, partially due to its more fibrous root system. This root system also contributes to sorghum's generally greater capacity for nutrient uptake at low soil nutrient levels than corn. However, lack of available water for grain sorghum can reduce yields and decrease yield response to fertilizer. When subsoil moisture is low in the spring, the probability of obtaining high yields of grain sorghum is lower, which necessitates the producer adjusting fertilizer rates downward by as much as 50%. During such periods of low subsoil moisture, the producer may wish to delay fertilizer application.

Expected Yield

The grower should carefully consider expected yield for either grain or forage sorghum, since nitrogen (N) fertilizer rates are significantly influenced by the choice of expected yield. As with corn, the producer should base expected yield on a five-year average and increase it by 5% after accounting for atypical years when adverse conditions such as hail and early frost influence yields.

Nitrogen

Nitrogen is generally the most limiting nutrient for optimum sorghum production in Nebraska. Like corn, expected yield and soil nutrient levels are important factors in determining nitrogen rates for sorghum production. Grain protein is an important consideration as well when applying nitrogen for grain sorghum. By applying adequate nitrogen fertilizer, a Nebraska producer may see as much benefit from improved grain protein as in higher yields.

Nitrogen fertilizer recommendations

Tables 12-1 and 12-2 give nitrogen recommendations for grain and silage sorghum respectively, based on expected yield, residual soil nitrate, and surface organic matter. As organic matter increases, the soil's ability to provide available nitrogen also increases, thus reducing nitrogen fertilizer recommendations on higher organic matter soils. The nitrogen rate for grain sorghum should be adjusted by the price of grain relative to the fertilizer price by multiplying the nitrogen rate by (P_GP_N x 0.11) where P_GP_N = the price of grain ($/bu) divided by the price of fertilizer N ($/lb).

TABLE 12-1

Nitrogen fertilizer recommendations for grain sorghum.

Nitrate	Expected Yield (Bushels per Acre)								
	40	**60**	**80**	**100**	**120**	**140**	**160**	**180**	**200**
ppm	*pounds of N to apply per acre*								
	3% soil organic matter								
2	25	50	70	90	115	135	160	180	200
4		20	40	65	85	110	130	150	175
6			10	35	55	80	100	120	145
8				5	30	50	70	95	115
10						20	45	65	90
12							15	35	60
14								10	30
16									
18									
	2% soil organic matter								
2	45	70	90	110	135	155	180	200	220
4	20	40	60	85	105	130	150	170	195
6		9	30	55	75	100	120	140	165
8			5	25	50	70	90	115	135
10					20	40	65	85	110
12						10	35	55	80
14							5	30	50
16									20
18									
	1% soil organic matter								
2	65	90	110	130	155	175	200	220	240
4	40	60	80	100	125	145	170	190	215
6	10	30	50	75	95	120	140	160	185
8		1	25	45	70	90	110	135	155
10				20	40	60	85	105	130
12					10	30	55	75	100
14						3	25	50	70
16								20	40
18									10

Table 12-2

Nitrogen fertilizer recommendations for silage sorghum.

Soil NO_3-N	Expected Yield (Tons per Acre)							
	4	**6**	**8**	**10**	**12**	**14**	**20**	**25**
ppm	*pounds of N to apply per acre*							
	3% soil organic matter							
2	30	45	60	75	90	105	150	190
4		15	30	45	60	75	120	160
6				20	35	50	95	130
8						20	65	100
10							35	75
12							10	45
14								15
16								
	2% soil organic matter							
2	50	55	80	95	110	125	170	210
4	20	35	50	65	80	95	140	180
6		10	25	40	55	70	115	150
8				10	25	40	85	120
10						10	55	95
12							25	65
14								35
16								10
	1% soil organic matter							
2	70	85	100	115	130	145	190	230
4	40	55	70	85	100	115	160	200
6	15	30	45	60	75	90	135	170
8			15	30	45	60	105	140
10					15	30	75	115
12							45	85
14							20	55
16								25

Table 12-3 presents nitrogen recommendations specifically for the grain sorghum following soybean in rotation. It is derived from research completed in 2004 which found that only yield goal and P_GP_N were predictive of the economically optimal nitrogen rate.

TABLE 12-3

Economically optimum nitrogen rate (EONR) for grain sorghum following soybean in rotation.

Yield goal (YG, bu/ac)	Grain price to nitrogen price ratio (P_GP_N), (\$/bu grain) / (\$/lb N) 2	4	6	8	10	12
70	0	10	25	45	50	60
90	0	15	35	60	75	85
110	0	20	45	80	95	110
130	0	30	75	95	115	135
150	0	40	85	110	135	160
170	10	55	95	120	155	185
190	10	50	100	130	170	200

EONR = (0.121 x EY x P_GP_N) – 0.164 x EY – (5.417 x P_GP_N)
If soil organic matter is less than 2%, increase nitrogen rate by 15 lb/ac. If the average nitrate-nitrogen concentration (ppm) in the root zone at 0-2 to 0-4 feet is greater than 6 ppm, decrease nitrogen rate by 8 lb/ac for each increase of 1 ppm in nitrate-N.

Nitrogen sources for sorghum

Although anhydrous ammonia and urea ammonium nitrate (UAN) solution are the most commonly used nitrogen fertilizers for sorghum, any nitrogen source will provide adequate fertilization with proper application. For fertilizers containing urea (urea and UAN solution), the farmer should incorporate them or apply them with a urease inhibitor to reduce the potential for ammonia volatilization.

Phosphorus

Phosphorus requirements for sorghum are very similar to those of corn and determined by soil test results. Sorghum seedlings normally are redder in color than corn, which may lead the grower to suspect a phosphorus deficiency early in the growing season.

Phosphorus fertilizer rate and source recommendations

Table 12-4 gives phosphorus fertilizer recommendations for sorghum based on soil phosphorus levels. Band application of phosphorus 1.5 inches below and to the side of the seed is the most effective application method for sorghum, often increasing early plant growth. Dry, diammonium phosphate (DAP, 18-46-0) or monammonium phosphate (MAP 11-52-0) and liquid ammonium polyphosphate (10-34-0) are the most common forms of phosphorus fertilizer for sorghum. All phosphorus fertilizers are equally effective if the producer applies them properly.

TABLE 12-4

Phosphorus fertilizer recommendations for sorghum.

Phosphorus Soil Test	**P_2O_5 to Apply**	
Bray-1 P	***Row***	***Broadcast***
ppm	*pounds per acre*	
0 - 5	40	80
6 - 15	20	40
16 - 25	0	0
> 25	0	0

Potassium

Potassium (K) is usually not limiting in Nebraska soils for sorghum production. Topsoil as well as subsoil and irrigation water generally contain adequate potassium. The producer growing sorghum on sandy and poorly drained, fine-textured soils, however, may see a benefit to applying fertilizer potassium. Table 12-5 shows potassium recommendations for sorghum based on soil potassium levels.

Table 12-5

Potassium fertilizer recommendations for sorghum.

Potassium Soil Test	**K_2O to Apply**
ppm	*pounds per acre*
0 - 40	80
41 - 75	60
75 - 125	40
>125	0

Iron

As with corn and soybean, iron (Fe) deficiencies in sorghum often occur on high pH soils in western Nebraska. Iron deficiency in sorghum most commonly occurs during cold springs and often disappears as soil temperature increases. If iron deficiency is a consistent problem in a field, the producer should probably avoid planting sorghum in that field.

■ *Iron deficiency symptoms and treatment*

Deficiency symptoms range from green and yellow striped leaves to a complete loss of green color, leaving the plant white. A foliar spray containing 2.5% ferrous sulfate may correct deficiency symptoms. The producer may need to apply the spray several times, making foliar treatment costly and often unprofitable.

Zinc

Zinc (Zn) deficiency is less common in grain sorghum than in corn. It generally occurs where topsoil is shallow or on high-lime soils and sandy soils low in organic matter. The producer can best determine zinc fertilizer requirements with a soil test for zinc.

Zinc fertilizer recommendations

Zinc recommendations for sorghum are given in Table 12-6. Broadcast rates of zinc are designed to meet zinc requirements for three to four years without the need for further soil testing. Inorganic forms of zinc, such as zinc oxide, zinc sulfate, or ammoniated zinc solutions are more cost-effective than zinc chelates.

Table 12-6

Zinc fertilizer recommendations for sorghum.

DTPA-Zn	Relative Level	Zinc Application Rate	
		Calcareous Soils	*Noncalcareous Soils*
ppm		*pounds per acre*	
0 - 0.4	Low	2 row or 10 broadcast	2 row or 5 broadcast
0.41 - 0.8	Medium	1 row or 5 broadcast	1 row or 3 broadcast
> 0.8	High	0	0

Rates are for inorganic forms of zinc such as zinc sulfate.

Sulfur

Sulfur (S) may be deficient for sorghum production on very sandy, low organic matter soils. Sulfur recommendations for sorghum are given in Table 12-7.

Table 12-7

Sulfur fertilizer recommendations for sorghum.

Sulfur Soil Test, SO_4-S‡	Annual Sulfur Application Rate	
ppm	*pounds per acre*	
	Soil Organic Matter ≤1%	*Soil Organic Matter >1%*
	Irrigation water with < 6 ppm SO_4-S	
< 6	10 row* or 20 broadcast	5 row*
6 - 8	5 row* or 10 broadcast	0
	Irrigation water with > 6 ppm SO_4-S	
< 6	5 row* or 10 broadcast	0
6 - 8	5 row* or 10 broadcast	0
> 8	0	0

‡Sulfur test is $Ca(H_2PO_4)_2$ extraction.
*Applied in a band next to row, but not with seed.

Starter Fertilizer and Row Cleaning for No-till

Application of starter fertilizer containing nitrogen and phosphorus, and maybe sulfur, often results in increased early growth, which can be important to weed suppression and earlier flowering under no-till conditions. However, trial results indicate little or no effect on grain yield and grain moisture content in eastern Nebraska.

Row cleaning, or removing crop residue from the planting row, in no-till situations also may be practiced to enhance early growth and nutrient uptake. As with starter fertilizer, this practice was found to increase early growth but did not affect grain yield in research conducted in southeast Nebraska.

Lime

Agricultural soils tend to acidify with time, primarily due to nitrogen application. Where grain sorghum is grown continuously or with other cereal crops, lime application is advised when the soil pH is 5.5 or less for the 0 to 8 inch depth as well as the 8 to 16 inch depth. In central and western Nebraska, the surface soil may be acid but the sub-soil may be calcareous; lime application at pH of 5.5 is not likely to be profitable in these situations. Where grain sorghum is produced in rotation with soybean, liming is advised when the soil pH is 5.8 or less. Surface application of lime without incorporation for no-till fields is effective but will require more time to correct the acidity of the deeper soil.

Nutrient Removal and Sufficiency Ranges

Table 12-8 illustrates nutrient uptake of the nutrients most often applied as fertilizers in Nebraska for a typical yield of sorghum. Because of the nutrient supply in organic matter and clay minerals, most Nebraska soils can adequately meet crop requirements of potassium and sulfur for many years without supplemental fertilization. The critical values for nutrients shown in Table 12-8 reflect nutrient levels in plants capable of optimum yield. Levels of nutrients in plant tissue can be influenced by hybrid and climate. Nutrient levels below those shown are likely to result in a yield limiting deficiency, and may be reflected in the appearance of the crop. Nutrient levels significantly above those shown may reflect over-fertilization and luxury uptake, but yield limiting toxicities of these nutrients are unlikely.

Table 12-8

Sorghum nutrient requirements and sufficiency ranges.

Nutrient	Removed in Grain	Remaining in Stover	Total Uptake
	pounds per acre		
N	80	106	187
P_2O_5	44	31	75
K_2O	25	156	181
S	6	—	6
Zn	0.05	—	0.05

Nutrient	Sufficiency Ranges	
	Vegetative, Whole Plant Stage	Grain Fill — Leaves
	percent	
N	2.5 - 3.2	1.6 - 1.8
P	0.07 - 0.17	—
K	—	1.0 - 1.7
S	—	> 0.15

Source:
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13 Oats and Spring Grains

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Oats and spring grain production is limited in Nebraska, mostly because they are not as profitable as other row crops. In 2013 150,000 acres of oats were planted and 25,000 acres were harvested at an average yield of 65 bu/ac. The value of this production was just over $6.74 million. Nebraska producers primarily use these crops to diversify rotations, combat certain weed infestations, and complement many aspects of mixed livestock-crop farms. Traditionally, Nebraska producers have used small grains as companion crops for alfalfa establishment. As herbicide use has replaced such use, oat acreage has decreased. Nebraska harvest records were set in 1917 for oats and in 1942 for barley and rye.

Nitrogen

Nitrogen (N) recommendations for oats and other spring grains are based on expected yield, organic matter, and residual soil nitrate levels. In Nebraska, oats are the most popular spring grain. Because Nebraska oats are grown under dryland conditions, weather is the final determinant of yield potential. Table 13-1 gives nitrogen recommendations for oats. This table assumes 40-pound-per-acre nitrate levels in the root zone (approximately 3.7 parts per million (ppm) nitrate-nitrogen). When giving credit to animal manures and other amendments, the producer should remember that the nitrogen in these materials may become available after the time when oats need the nitrogen. Therefore, only a partial credit should be used. When growing oats as a companion crop with alfalfa, the producer should reduce nitrogen to favor alfalfa establishment. Excess nitrogen can cause lodging, which necessitates using the correct rate for the conditions in the field. Tables 13-2 and 13-3 give nitrogen recommendations for spring wheat and spring barley, respectively, over a range of expected yields and soil organic matter levels. Triticale recommendations are similar to spring wheat. The farmer should only use these tables within the organic matter range of 1% to 3%. Use the 3% recommendation for soils with over 3% organic matter.

TABLE 13-1, 13-2, AND 13-3

Nitrogen recommendations for oats (top), spring wheat (middle), and spring barley (bottom). (Assumes 40 lb nitrates, or 4 ppm soil nitrates.)

Expected Yield — Oats	**Soil Organic Matter (%)**		
	1	**2**	**3**
bushels per acre	*pounds of N to apply per acre*		
60	70	50	30
80	90	70	50
100	110	90	70

Expected Yield — Spring Wheat/Spring Triticale	**Soil Organic Matter (%)**		
	1	**2**	**3**
bushels per acre	*pounds of N to apply per acre*		
30	62	42	22
50	110	90	70
70	158	138	118

Expected Yield –Spring Barley	**Soil Organic Matter (%)**		
	1	**2**	**3**
bushels per acre	*pounds of N to apply per acre*		
40	50	30	10
60	80	60	40
80	110	90	70

Phosphorus

Table 13-4 contains recommendations for applying phosphorus (P) to spring grains. Recent research with winter wheat has shown that higher yields are possible with band application when compared to broadcast application.

TABLE 13-4

Phosphorus recommendations for oats and other spring small grains.

Relative Level	Soil Test Value		P_2O_5 Application Method	
	Bray-1 P/Mehlich III	Olsen-P	Broadcast	Band
	ppm		*pounds per acre*	
Very low	0 - 5	0 - 3	80	40
Low	6 - 15	4 - 10	60	30
Medium	16 -25	11 -17	40	20
High	> 25	> 17	0	0

Potassium

Spring grains have no special potassium (K) requirements. See Table 13-5 for specific recommendations.

TABLE 13-5

Potassium recommendations for oats and other spring small grains.

Potassium Soil Test Level	Soil Test Value	K_2O Broadcast Application Rate
	ppm	*pounds per acre*
Very low	0 - 39	120
Low	40 - 74	80
Medium	75 - 124	40
High	> 125	0

Sulfur

Sulfur (S) deficiencies usually do not occur in spring grains, mainly because producers generally do not grow the crops on irrigated sands where sulfur problems exist. In coarse soils, and in soils low in organic matter, experimenting with sulfur application to spring grains might show positive results.

Zinc

Usually, zinc (Zn) levels remaining from previously planted corn provide adequate zinc for small grains in soils where zinc levels are historically low.

Nutrient Removal from Spring Small Grains

Tables 13-6 and 13-7 illustrate removal of the nutrients most commonly applied as fertilizer to spring small grains in Nebraska. The producer should not necessarily use these tables as guidelines for fertilizer application. In Nebraska, significant amounts of these nutrients are provided from most soils though the process of mineralization, making the nutrients adequately available to supply most or all of the crop requirements for optimum yields. Table 13-8 reflects nutrient levels in plants capable of optimum yield. Nutrient levels below those shown are likely to result in a yield-limiting deficiency.

Table 13-6

Oat nutrient removal (100 bushels per acre grain yield, 5,000 pounds per acre stover yield).

Nutrient	Removed in Grain	Remaining in Stover	Total Uptake
	pounds per acre		
N[1]	77	30	107
P_2O_5[1]	28	16	44
K_2O[1]	19	93	102
S[1]	7	11	18
Zn[2]	0.36	0.36	0.72

Source:
[1]Murrell, T. Scott, 2005. Average Nutrient Removal Rates for Crops in the North Central Region. IPNI. *http://nanc.ipni.net/articles/NANC0005-EN* (Verified 04/27/2014.)
[2]Franzen, D. and J. Gerwing. 1997. Effectiveness of Using Low Rates of Plant Nutrients. North Central Regional Publication 341. University of Nebraska, Lincoln, Nebr.

Table 13-7

Barley nutrient removal (100 bushels per acre grain yield, 5,000 pounds per acre stover yield).

Nutrient	Removed in Grain	Remaining in Stover	Total Uptake
	pounds per acre		
N[1]	99	32	131
P_2O_5[1]	40	13	53
K_2O[1]	32	98	130
S[1]	9	8	17
Zn[2]	0.12	0.10	0.22

Source:
[1]Murrell, T. Scott, 2005. Average Nutrient Removal Rates for Crops in the North Central Region. IPNI. *http://nanc.ipni.net/articles/NANC0005-EN* (Verified 04/27/2014.)
[2]Franzen, D. and J. Gerwing. 1997. Effectiveness of Using Low Rates of Plant Nutrients. North Central Regional Publication 341. University of Nebraska, Lincoln, Nebr. *http://www.ksre.ksu.edu/bookstore/pubs/NCR341.pdf* (verified 4/29/2014)

Table 13-8

Sufficiency ranges for sampling whole plants of spring small grains at boot stage.

Nutrient	Percent
N	3.00 - 4.00
P	0.23 - 0.40
K	1.60 - 3.20
S	0.30 - 2.50
Zn (ppm)	10.0 - 60.0

Source:
Hergert, G. 1982. Plant Analysis: Uses and Interpretation. *In* Soil As A Plant Sees It. Section 6. University of Nebraska, Lincoln, NE.

Resources

1. Moomaw, R., A.F. Dreier, and C.A. Shapiro 1992. Oat Production in Nebraska. NebGuide G79-430A. University of Nebraska, Cooperative Extension, Lincoln, Nebr. *http://digitalcommons.unl.edu/extensionhist/760/*.

14 Fertilizer Management for Alfalfa

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Alfalfa is an important crop in Nebraska. It is the only crop that has been planted on more than 1,000 acres in every county of the state. Nebraska consistently ranks as one of the top 10 alfalfa producing states in the country. Adequate soil fertility is necessary for alfalfa production on both dryland and irrigated soils of Nebraska.

Nutrient Needs

Nutrient removal from alfalfa production is high because most of the aboveground plant material is harvested and removed several times during the growing season (Table 14-1). Therefore, supplying adequate nutrients to the crop is important. As with other crops in Nebraska, we recommend a deficiency correction approach to alfalfa nutrient needs. This means crediting other sources of nutrients before applying specific nutrients.The nutrient application rate suggestions are based on research in Nebraska or neighboring states. In Nebraska nitrogen, phosphorus, potassium, sulfur, and boron have been shown in research to increase yields in some soils. Lime additions can benefit alfalfa on low pH soils.

Collecting soil and irrigation water samples is the first step in determining fertilizer and lime needs for alfalfa. Collect soil samples at any time of the year from a depth of 0 to 8 inches every three to five years to determine soil pH, soil buffer pH, and phosphorus and potassium needs. The best time to collect soil samples is at least six months prior to seeding a new crop to allow incorporation during tillage. The irrigation water may contain significant amounts of lime, potassium, and sulfur which can reduce the cost of the fertilizer program. Irrigation water normally needs to be analyzed every three to five years.

Table 14-1

Average nutrient removal by established alfalfa at harvest (based on moisture content common at harvest).

Nutrient	lb/ton
N	55.0
P (P_2O_5)	10.0
K (K_2O)	60.0
Ca	30.0
Mg	4.6
S	8.0
Zn	0.006
Cu	0.14
Mn	1.8
Fe	1.8
B	0.02

The fixation of nitrogen in alfalfa roots by the bacteria *Rhizobium meliloti* is optimized between a soil pH of 6.2 and 7.5. Use lime to establish new alfalfa stands and to ensure high yields the first two years after seeding if the pH of the topsoil is 6.2 or less. Soils with a history of reduced tillage might develop a stratified pH, with lower than average pH near the surface. For situations where the general soil pH is near 6.2 and there is a history of reduced tillage, a surface sample of 3 inch depth can be analyzed for pH. Many soils in Nebraska have adequate pH in the subsoil. Once alfalfa roots penetrate deep enough to reach soil materials with a high pH, there will be decreased to no growth response from applied lime. A soil buffer pH analysis from a soil sample can determine if lime is required and the rate of application. The eastern one-third of Nebraska has a higher chance for the need of lime due to lower soil pH. However, sandy soils in north central and western Nebraska can be acidic and require lime applications. If one just samples the surface 3 inches and gets a lime recommendation, this recommendation should be cut in half since the volume of soil that needs pH change is about one-half of normal.

Lime

Lime needs to be incorporated into the soil for maximum benefit for a newly seeded alfalfa crop. Lime applied to the soil surface and not incorporated will only change the soil pH at the soil surface and have minimal benefits to the new alfalfa stand. Incorporation is not needed on no-till land if the lime is applied two or more years before sowing. Soil pH will gradually increase during the first 6 to 18 months after lime application. Therefore, it is best to lime a year before seeding alfalfa to allow the lime to react in the soil. If lime cannot be applied and incorporated in time to increase the pH, an application of 30 to 40 pounds of nitrogen may prevent early nitrogen deficiency of alfalfa seedlings.

For information about lime materials, quality, and application refer to University of Nebraska–Lincoln Extension NebGuides *Management Strategies to Reduce the Rate of Soil Acidification* (G1503), and *Lime Use for Soil Acidity Management* (G1504).

Nitrogen Recommendations

On established alfalfa stands, nitrogen fertilization is not required because *Rhizobium meliloti* bacteria convert nitrogen gas from the air into a plant-usable form of nitrogen. To ensure establishment of these bacteria in the alfalfa roots, alfalfa seed needs to be inoculated with the bacteria prior to planting. Most alfalfa seed currently sold is pre-inoculated with the appropriate bacteria. For instructions on how to inoculate seed that was not pre-inoculated or seed that has aged beyond the expected lifespan of the bacteria in the pre-inoculation, follow instructions on purchased inoculum packages. Newly seeded alfalfa can benefit from 10 to 15 pounds of nitrogen fertilizer per acre to get it started on many soils, especially sandy or low organic matter sites and with early spring plantings into cold soil. Many farmers and ranchers report that the application of some nitrogen with the drill will increase the probability of obtaining a good stand. Residual nitrogen in the soil may be high enough to supply adequate nitrogen to newly seeded stands. Past fertilizer and cropping history and/or a soil analysis for nitrate in the surface 8 inches will help determine if sufficient nitrogen is available in the soil. If inoculation is unsuccessful, top-dressing nitrogen will be necessary.

Excessive nitrogen will reduce the effectiveness of the nodules. When this occurs, the alfalfa uses fertilizer nitrogen for growth and development.

Phosphorus

Phosphorus applications will be needed to achieve top yields on many soils in Nebraska. Suggested rates based on soil analysis are listed in Table 14-2. Obtain a soil test to determine phosphorus level because phosphorus levels that are sufficient for other crops, such as corn, are not adequate for optimal alfalfa growth.

Table 14-2

Phosphorus fertilizer recommendations for alfalfa in Nebraska based on Bray-1 or Olsen phosphorus tests.

Phosphorus Soil Test			Irrigated	Non-irrigated	
Bray-1 or Mehlich-3	Olsen	Relative Level	Annually	Annually	Every Two Years
(ppm)				*(lb P_2O_5/acre)*	
2-5					
0-5	0-3	Very Low	60	40	80
6-15	4-7	Low	40	30	60
16-25	8-14	Medium	30	20	40
> 25	> 14	High	0	0	0

When establishing alfalfa apply two or three years' worth of phosphorus, preferably before tillage, in order to incorporate the phosphorus. Yearly applications of phosphorus are suggested for irrigated alfalfa and dryland alfalfa with a pH greater than 7.0. On calcareous soils in northeast Nebraska (Crofton and Nora soil types), application ahead of seeding followed by topdressing every two years was found to be the most profitable. Knifing phosphorus in bands before planting may be especially effective on higher pH soils since less soil-phosphorus contact reduces phosphorus fixation.

Alfalfa responds better to incorporated applications than to topdressed applications. When phosphorus is incorporated in the soil, roots can find phosphorus in a greater volume of soil. Under drought conditions, surface phosphorus may not be available; therefore, adequate phosphorus deeper in the soil is an important risk management strategy, especially in rainfed production areas. Therefore, when establishing alfalfa, incorporate phosphorus prior to planting and apply phosphorus to the surface in established stands. Phosphorus should be applied early in the spring or in the fall after the last cuttings to get maximum benefit from broadcast applications. Some common forms of phosphorus fertilizer include: triple super phosphate (0-46-0), diammonium phosphate (18-46-0), and monoammonium phosphate (11-52-0).

Potassium

Alfalfa requires large amounts of potassium. Most soils, especially non-sandy soils, in Nebraska have sufficient native potassium levels for alfalfa production and do not require potassium fertilizer additions. However, potassium may be needed for alfalfa production on some course-textured, sandy soils. These soils are usually irrigated. Suggested rates based on soil analysis are listed in Table 14-3. As with phosphorus use, annual broadcast applications are recommended for irrigated alfalfa while large applications sufficient for two to three years applied at seeding are suggested for non-irrigated production. For irrigated alfalfa, the amount of potassium applied in the irrigation water can be subtracted from the application rates. Apply potassium fertilizers after final harvest to prevent damage to the crowns of growing plants and increase winter hardiness of the plants. There are no differences between sources of potassium fertilizers when applied at the same rate. Therefore, use the least expensive source. Potassium chloride (Potash) (0-0-60) is common and usually the least expensive source of potassium.

TABLE 14-3

Potassium fertilizer recommendations for alfalfa in Nebraska based on soil potassium test.

Potassium Soil Test *(ppm)*	**Potassium to Apply** *(lb K_2O/acre)*
0-40	120
41-74	80
75-125	40
126-150	0
> 150	0

Sulfur

As with other Nebraska crops, alfalfa often needs sulfur on sandy, low organic matter soils under irrigated and non-irrigated conditions. In eastern and central Nebraska, a need for sulfur is most likely when the soil is sandy and the organic matter content is less than 1%. In western Nebraska, a response to sulfur will most likely occur on sandy soils with an organic matter content of less than 0.6%. Sulfur may increase protein content in alfalfa but may not increase yield.

When needed, annual applications of 30 to 40 pounds of sulfur per acre is suggested for irrigated alfalfa. The use of 100 pounds of sulfur per acre once every three years should provide adequate amounts of this nutrient for dryland alfalfa. Research has shown that fertilizers containing elemental sulfur are as effective for alfalfa production as those containing sulfate-sulfur. Test the irrigation water for sulfur and subtract the amount applied from the total sulfur application rate. Sulfur fertilizer materials include gypsum (16% sulfur), ammonium sulfate (24% sulfur), ammonium thiosulfate (26% sulfur), potassium-magnesium sulfate (22% sulfur), and agricultural sulfur (96% sulfur). Do not apply ammonium thiosulfate with the seed. It can be mixed with a fertilizer solution such as 10-34-0 but must not be placed with the seed. It can seriously affect germination.

Micronutrients

Except for boron (B), micronutrient deficiencies have not been found in alfalfa in Nebraska. Boron deficiencies are rare. Before applying boron, first take soil and/or tissue samples and observe the crop. Most soil testing labs and extension specialists consider soils testing under 0.5 ppm deficient in boron. When boron is deficient in alfalfa the upper leaves turn bronze to yellow without wilting and leaves are cupped or curled. Top leaves often appear bunched due to shortened internodes. Lower leaves remain a healthy green. Symptoms are similar to potato leafhopper yellowing and drought stress, so be certain it is boron deficiency before making an application. It is easy to overapply boron, and it may become toxic to the alfalfa and subsequent crops. If a boron deficiency is indicated, apply 1 pound of boron per acre. Boron fertilizer is often mixed and applied with other fertilizers because of the small amount needed. Do not apply boron near the seed. Test the irrigation water for boron content before applying it to irrigated alfalfa.

Things to Consider When Applying Fertilizer for Establishment

Fertilizer required for alfalfa production can be broadcast and incorporated before establishment, applied with a drill at planting time, or applied by a combination of these two methods. When low rates of nutrients are needed, the application of fertilizer with the drill when seeding would be appropriate.

Fertilizer containing high levels of nitrogen and potassium should not be placed in direct contact with the seed. These nutrients create a salt effect that may reduce germination and stand. Fertilizers containing only phosphorus should not cause problems when placed in direct contact with the seed. The sum of nitrogen and potassium applied with the drill should be limited to less than 20 pounds per acre. If soil is drier than normal, limit application rates to half this amount. If not all the required fertilizer can be placed with the seed, broadcast the balance and incorporate prior to seeding.

Iron Chlorosis

On high pH calcareous soils, new seedlings of alfalfa may be light green or yellow (iron chlorosis) due to a deficiency in iron. This condition is most common in early spring. The iron chlorosis will usually disappear as temperatures rise and growing conditions improve.

Manure Application to Alfalfa

Producers can apply animal manures to alfalfa as a nutrient source, and alfalfa can serve as an accumulator crop for nitrogen in situations where producers have limited land resources available for manure nitrogen applications. These situations are common around large animal feeding operations. Research conducted at Concord, NE, has shown that alfalfa fertilized with swine effluent can remove twice as much nitrogen as corn on a per acre basis. Based on Table 14-1, an irrigated alfalfa crop that produces 6 to 9 tons per acre will remove 330 to 495 pounds of nitrogen per acre. A corn crop that yields 200 bushels per acre will remove approximately 240 pounds of nitrogen in harvested grain per acre. Alfalfa also can recover nitrogen in soil to a depth of 12 feet due to its extensive deep root system. To minimize the potential for nitrate leaching, manure application to alfalfa should be limited to 50% of predicted removal, and probably should not be applied all at once.

New Seeding

Manures with high salt and ammonia levels, such as liquid manure sources, can result in reduced germination of alfalfa. Therefore, avoid direct contact with manure and seed by mixing manures with soil at least six weeks before planting. Avoid applying manure after the field has been seeded. Nitrogen removal during the seeding year may be between 24% and 57% less than established stands and nitrogen rates need to be adjusted accordingly during the seeding year.

Established Stand

Top-dressing manure to established stands can increase the risk of injury due to salts and ammonia in the manure. Do not apply more than 3,000 to 5,000 gallons of liquid or 10 tons of solid manure per acre in a single application. New leaves are susceptible to burning. To minimize damage potential, apply the manure as soon as possible after harvest when little regrowth of leaves has occurred. It is important to uniformly apply the manures to avoid concentrating manure in areas of the field. Applications to older alfalfa stands or poor stands have less chance for injury compared to younger stands. Because production is less for old and poor stands, if salt and ammonia damage occurs, the risks of production losses are less than for productive younger stands. Added nitrogen from manure can stimulate grass growth. If this is a concern apply manure during peak alfalfa growth when alfalfa can compete with grass. Reduced application rates (50% of the calculated nitrogen removal rate) during individual applications can reduce chances for salt damage under these conditions.

Resource

1. Undersander, D., D. Cosgrove, E. Cullen, C. Grau, M. Rice, M. Renz, C. Sheaffer, G. Shewmaker, and M. Sulc. 2011. Alfalfa Management Guide. American Society of Agronomy. 68 pages. *https://www.agronomy.org/publications/alfalfa*

15 Dry Edible Beans

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Nebraska is one of the leading states in the nation in dry edible bean production, raising a total of 3.2 million hundred weight (cwt) in 2012. Nebraska ranked first in great northern bean production (1.09 million cwt) and second in pinto beans (1.83 million cwt) in 2012. Other varieties produced in Nebraska include navy, light red kidney and black turtle soup. Dry bean production is concentrated in the Nebraska Panhandle and the southwestern part of the state. The top five dry bean counties in 2012 were Scottsbluff, Box Butte, Sheridan, Morrill, and Chase. The total value of the dry edible bean crop in Nebraska was $123.9 million in 2012.

Nitrogen

Dry beans are a member of the legume family and are able to symbiotically fix nitrogen from the air. The nodules on the roots contain bacteria that fix nitrogen for plant use. Dry beans, however, are extremely inefficient nitrogen fixers and research shows that adding fertilizer nitrogen increases yields if the level of residual nitrate in the soil is low. Dry beans need 100 to 125 pounds of nitrogen per acre for top yields, in addition to nitrogen fixed by the plant. This additional nitrogen can be residual soil nitrogen, fertilizer nitrogen, nitrogen in irrigation water, nitrogen in manure, or a combination of these sources.

Inoculum containing the *Rhizobium* bacteria can be purchased and applied with the seed or to the soil in the seed furrow. If there is no history of dry bean production on the field, inoculation of the beans at planting time is essential. If dry beans recently were grown on the land and the beans were well-nodulated, inoculation is unnecessary. Nitrogen rates based on residual nitrate-nitrogen are shown in Table 15-1.

Table 15-1

Nitrogen fertilizer suggestions for irrigated dry bean (2,500-3,000 lb/ac) yield.

lb NO_3-N in 30 inches	ppm NO_3-N in 30 inches	Fertilizer N - lb/acre
0-20	0-2.2	100
21-40	2.3-4.4	80
41-60	4.5-6.7	60
61-80	6.8-8.9	40
81-100	9.0-11.1	20
> 100	> 11.1	0

Nitrogen rates can be reduced if the irrigation water has a high nitrate level. The pounds of nitrogen applied per acre foot of irrigation water is calculated by multiplying the parts per million nitrate-nitrogen in the irrigation water times the factor 2.72.

The use of nitrogen fertilizer for dry beans does have some limitations. Excessive nitrogen rates can delay maturity. The same effect is seen when planting dry beans in a newly plowed alfalfa field. Planting dates and/or varieties should be adjusted to compensate for the delayed maturity. Nitrogen fertilizer also will increase the amount of foliage produced. This can be a serious problem in fields with histories of white mold. The incidence of white mold damage, when present, can be increased as much as 30% with nitrogen fertilization.

Phosphorus

Dry beans respond to phosphorus fertilizer when soil test levels are low. Banding phosphorus is more efficient than broadcasting; consequently, the application rate for banded phosphorus is one half the broadcast rate. Banding improves phosphorus availability in cool, wet, or compacted soils. Phosphorus fertilizers have relatively low salt indices, but contact between the fertilizer band and the seed should be avoided.Different soil extractants are now being used by commercial soil testing laboratories to determine available phosphorus. Most research has been conducted on calibrating Bray 1 phosphorus with yield response. The following equations can be used to convert other extractants results to a "Bray 1 phosphorus equivalent."

For Mehlich 2: Bray-1 = 0.9 * Mehlich 2

For Mehlich 3: Bray-1 = 0.85 * Mehlich 3

For Olsen P: Bray-1 = 1.5 * Olsen P

Because most soils in the dry bean growing regions of the state are higher pH or are calcareous, the Olsen P test is often used by growers. Phosphorus recommendations are given as an equation to more accurately accommodate computer controlled and GPS guided variable rate applications. This equation provides values similar to older tabular (stair step) values, is comparable to other High Plain (CO, WY, MT) dry bean phosphorus recommendations, and gives a better approximation of fertilizer needs over a wide range of soil test levels.

The following equation for phosphorus recommendations is suggested for dry beans:

P rate (pounds per acre) = 7*(10 - Olsen P test value).

A summary of average fertilizer recommendations for phosphorus are shown in Table 15-2.

TABLE 15-2

Phosphorus recommendations for dry beans.

Phosphorus soil test method and critical levels			**lb P_2O_5/acre**	
Olsen-P	*Bray P-1*	*Mehlich 3*	*Banded P*	*Broadcast P*
3	4.5	5	30	60
6	9.0	11	20	40
9	13.5	16	10	20

Potassium

In western Nebraska, where dry beans traditionally are grown, soils are very high in potassium (K). Dry beans have not shown a response to potassium fertilization on soils testing over 125 ppm potassium. Potassium recommendations are shown in Table 15-3.

TABLE 15-3

Potassium fertilizer recommendations for dry edible beans.

Calibration Range	Soil Test Value	K_2O Broadcast Application Rate
	ppm	*pounds per acre*
Very low	0 - 40	60
Low	41 - 74	40
Medium	75 - 124	20
High	> 124	0

Zinc

Zinc (Zn) is the most common micronutrient deficiency of dry beans in Nebraska. Zinc deficiency can occur when the topsoil has been removed by leveling or erosion. Soils low in organic matter, compacted soils, sandy soils and/or soils with a pH greater than 7.3 may exhibit zinc deficiency. It also can be a problem when beans follow sugar beets.

As with phosphorus, banding is more efficient than broadcasting and half as much zinc is recommended for banding. Zinc does not revert to insoluble forms as rapidly as other micronutrients, so broadcast application provides residual effects for several years. Soluble sources of zinc (zinc sulfates, zinc chelates, or zinc-ammonia complexes) are preferable to zinc oxide-based materials or other low water-solubility zinc fertilizers.

Zinc recommendations are shown in Table 15-4.

TABLE 15-4

Zinc fertilizer recommendations for dry edible beans.

DTPA Soil Test Zn – ppm	pH less than 7.5		pH more than 7.5	
	# Banded Zn	*# Broadcast*	*# Banded Zn*	*# Broadcast*
0-0.5	3	6	5	10
0.51-1.0	2	4	4	8
1.01-1.5	1	2	2	4
> 1.5	0	0	0	0

Iron

Dry beans are sensitive to iron deficiency chlorosis (IDC). IDC can occur on soils with pH values greater than 7.5 that contain free calcium carbonate and have low organic matter. In addition, cool wet springs increase the probability of iron chlorosis. As these soils warm or lose moisture, IDC symptoms often disappear without any iron treatment. If chlorosis persists, yield losses can occur.

Soil application of inorganic iron sources is generally not effective. Recently, renewed interest in FeEDDHA (ortho-ortho formulation) chelate for IDC correction has shown promise. Research near Scottsbluff, NE, has shown the potential for economical yield increases with low rates of banded o-o FeEDDHA. The material can be either seed-applied alone in a water solution to avoid salt damage or can be mixed with nitrogen-phosphorus liquid fertilizers and banded beside the seed. The research shows that for severely chlorotic areas, 1.0 to 1.5 pounds of o-o FeEDDHA is required. On areas with more moderate IDC, 0.75 to 1.0 pound of the chelate is sufficient. Yield increases for these rates can range from 250 to 450 pounds of seed per acre when IDC is severe. If there is no IDC expressed, yields will not be increased.

One of the most effective ways to economically correct IDC is to map fields with aerial photography in combination with yield maps to define the different areas or zones of IDC severity in fields. These areas always present, however, the degree of IDC severity changes with yearly weather conditions. The creation of IDC severity zones allows variable rate application of different iron chelate rates based on potential IDC. Responses to foliar solutions of iron sulfate have increased yields but have not been adopted as common practice. Deficiencies can be corrected by spraying the crop with a 1 to 1.5% ferrous (iron) sulfate solution at the rate of 20 to 25 gallons per acre. Another option is to use 1 pound of o-o FeEDDHA per 20 to 25 gallons of water. Foliar sprays may reduce IDC but the treatment is usually applied late enough that full yield potential is not realized. Multiple sprays also may be required. Aerial application may not provide sufficient foliage coverage because of gallonage limitations.

Figure 15-1

Iron chlorotic (yellow) dry bean next to a normal plant.

Other Micronutrients and Sulfur

Other nutrient deficiencies (boron, chlorine, copper, manganese, molybdenum) have not been observed in the High Plains dry bean growing region. Documented responses to sulfur applications are rare. The most likely need for sulfur would occur on sandy soils with low organic matter, and soils irrigated with water low in sulfate-sulfur (< 6 ppm SO_4-S). If sulfur is required, 10 pounds sulfur from a sulfate source is recommended.

Salinity

Dry beans are one of the most sensitive crops grown in Nebraska to soluble salts. A saline/alkali soil test should be run on soils suspected of having a salt problem. Salinity levels testing over 2 dS/m (mmhos/cm) normally cause some injury and reduce yields. Salt sensitivity of several crops is shown in Table 15-5.

TABLE 15-5

Soil salinity effects on dry edible beans.

Crop	**Relative yield decrease in yield – percent**			
	0	**10**	**25**	**50**
	dS/m salinity level causing yield reductions above			
Dry bean	1.0	1.5	2.3	3.6
Corn	1.7	2.5	3.8	5.9
Wheat	5.0	7.4	9.5	13.0
Sugar beet	7.7	8.7	11.0	15.0
Barley	8.0	10.0	13.0	18.0

The most common effect of salts is on the plant's ability to absorb water. The symptoms of salt injury on the bean plant are stunting, smaller, thicker, darker green leaves or, in some cases, burning around the leaf margins (Figure 15-2). The effects of salts can't be separated from water stress since salts contribute to moisture stress in the plant. The bean plant is most sensitive to salt effects during germination and early growth.

Most soils do not have high enough salinity to cause injury to beans, but under drought and high temperatures salts may accumulate near the soil surface and injure the developing seedling. The same conditions of high temperatures and low soil moisture also can affect preplant herbicide performance, which may lead to herbicide injury. The possibility exists for all these factors to interact and dramatically reduce bean yield. The best strategy to counteract the salt stress problem is to irrigate the crop early to leach salts out of the seed zone.

FIGURE 15-2

Salt damage to dry bean.
Photo courtesy of R.G. Wilson.

FIGURE 15-3

Dry beans showing no salt damage (foreground) and dry beans in an area with salinity above 2 dS/m.
Photo courtesy of R.G. Wilson.

Other Nutrients

The likelihood of obtaining a response in dry beans from applying fertilizers containing calcium, magnesium, manganese, copper, molybdenum, boron, or chlorine is extremely unlikely in Nebraska soils.

Resource

1. Hergert, G.W., and J. A. Schild. 2013. Fertilizer Management for Dry Edible Beans, NebGuide G1713. University of Nebraska–Lincoln Extension, Lincoln, NE.

16 Soybean

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Soybean production in Nebraska has steadily grown since the early 1960s. In 2011 (a record year for soybeans in Nebraska), approximately 5 million acres were harvested, production reached over 250 million bushels, and average yields were 61 and 47 bushel per acre for irrigated and dryland soybeans respectively. The total value of soybean production in Nebraska was $2.97 billion in 2011, ranking Nebraska fourth nationally.

Nitrogen

Nitrogen (N) requirements for soybean are typically met by a combination of soil-derived nitrogen, and nitrogen provided through the process of symbiotic fixation from *Rhizobia* bacteria in root nodules. The relative nitrogen supply from these two sources can vary widely depending on the soil nitrogen supply and conditions for nodule development. Nitrogen supplied from symbiotic fixation can range from 25% to 75% of the total nitrogen in the plant depending on these conditions (Varco, 1999). The least expensive means of supplying adequate nitrogen to soybean is to ensure adequate nodulation by inoculating the seed at planting. For fields in which soybean has not been previously grown, inoculation is essential. For such fields, a soil-applied inoculant may provide greater yield potential than a seed applied inoculant. For fields in which soybean has been previously grown, either a soil-applied or seed-applied inoculant is good insurance for providing adequate nitrogen for the crop.

Considerable research has been conducted in Nebraska evaluating soybean yield response to preplant nitrogen fertilizer. In this research, a yield increase has been observed about 50% of the time with nitrogen fertilization, but predicting a yield response to nitrogen has not been possible based on soil conditions. Most often, yield increases with preplant nitrogen fertilization have been noted when soil residual nitrate was very low, if the soil had low nitrogen mineralization capability, or if the soil pH was quite low, inhibiting effective nodulation. In such cases, supplemental nitrogen fertilization of 50 to 100 pounds of nitrogen per acre has been found to significantly increase yield potential.

Other research has suggested a potential for increasing yield of soybean by supplemental nitrogen fertilization during early reproductive stages (Wesley, et. al., 1998). Between the onset of flowering to pod fill, the peak nitrogen uptake of soybean can reach 4 pounds of nitrogen per acre per day (Hanway and Weber, 1971). Under high-yield potential conditions (particularly under irrigated conditions in Nebraska), nitrogen fertilization at the R3 growth stage may increase soybean yield. The producer growing soybean under pivot irrigation systems with high yield potential (greater than 50 bushels per acre), should consider applying 20 to 40 pounds of nitrogen per acre through the irrigation system at R3. Because it is difficult to accurately predict when producers may see a significant yield increase to this practice, the producer might consider this practice on an experimental basis. When possible, the farmer should leave sections of the field as unfertilized checks in order to evaluate the effectiveness of supplemental nitrogen fertilization.

Phosphorus

Soybean is more efficient at producing good yield at low soil phosphorus (P) levels than other major agronomic crops in Nebraska. Yield increases from phosphorus fertilization will probably not occur when the Bray-1 P test is greater than 12 parts per million (ppm). Subsoil levels of phosphorus usually are not an issue when making recommendations for phosphorus fertilization. However, subsoil phosphorus levels in many Nebraska soils may be somewhat higher than those found in much of the Midwest, explaining the lack of response to phosphorus fertilization for some soils.

Generally, no great advantage exists for using a starter-applied fertilizer with soybean. Nebraska producers plant soybean later than corn, when soil temperatures are higher and the growing point of soybean is above ground, versus below for corn, so soil temperature has less influence on soybean growth. With low soil-test phosphorus levels, band application of fertilizer is more efficient than broadcasting. The producer should space fertilizer bands 10 to 15 inches apart and 3 to 6 inches deep. If the producer applies phosphorus at planting, he should band at least 1 inch away from the seed. The producer should not place fertilizer with the seed due to the risk of seedling injury during germination. Phosphorus fertilizer recommendations for soybean are provided in Table 16-1.

Table 16-1

Phosphorus fertilizer recommendations for soybean.

Phosphorus Soil Test		Relative Level	P_2O_5 to Apply
Bray-1 P	*Olsen-P*		
ppm			*pounds per acre*
0 - 5	0 - 3	Very low	60
6 - 10	4 - 5	Low	20
11 - 15	6 - 7	Low	0
16 - 24	8 - 24	Medium	0
> 24	> 14	High	0

Potassium

Nebraska soils seldom need potassium (K) fertilizer for soybean production. For soils that are not high in exchangeable potassium, producers should apply potassium fertilizer in the amounts shown in Table 16-2. Broadcasting and incorporating potassium prior to planting is the most efficient method.

Table 16-2

Potassium fertilizer recommendations for soybean.

Potassium Soil Test*	Relative Level	K_2O to Apply
ppm		*pounds per acre*
0 - 40	Very low	60
41 - 74	Low	40
75 - 124	Medium	20
> 124	High	0

*Potassium test: Exchangeable K.

Sulfur

Soybean need for sulfur (S) fertilizer is very unlikely. Soybean is tolerant of low sulfur levels in the soil, so it is not likely to respond to sulfur fertilization.

Zinc

Soybean is more tolerant to low levels of zinc (Zn) in the soil than corn is, but zinc fertilizer may be beneficial when soil zinc levels are low. Table 16-3 shows the recommended zinc fertilizer rates for soybean in Nebraska.

TABLE 16-3

Zinc fertilizer recommendations for soybean.

DTPA-Zn	Relative Level	Zinc to Apply: *Calcareous soil*	Zinc to Apply: *Noncalcareous soil*
ppm		*pounds per acre*	
0 - 0.4	Low	1 row or 10 broadcast	1 row or 5 broadcast
0.4 - 0.8	Medium	0	0
> 0.8	High	0	0

Iron

Iron (Fe) chlorosis is common in calcareous soil and in certain soils in Nebraska's Platte, Elkhorn, and Republican River Valleys. The problem is difficult and it requires a specific management program, which includes selecting appropriate varieties, properly adjusting seeding density, applying materials with the seed, and using foliar sprays.

Variety selection

A producer should consult a seed dealer for current soybean varieties tolerant to chlorotic conditions.

Seeding density

Seed density has an influence on how well a soybean variety tolerates an alkaline soil—even with tolerant varieties. Chlorosis is more severe when plant density is low; therefore, a producer should apply a seeding rate of 12 viable seeds per foot, regardless of row spacing. This seeding density is excessive for most varieties grown in less alkaline soils, but the in-row density of typically drilled plants is not adequate for alkaline soil tolerance.

Applying materials with the seed

In those soils where variety selection and seeding density do not overcome chlorotic conditions, the producer should apply iron chelate (Fe-EDDHA). Applying Fe-EDDHA directly with the seed at planting is the most effective and consistent treatment. The amount needed depends on the degree of chlorosis, but the most common rate is between 1 and 4 pounds of product per acre. Fe-EDDHA is a dry powder that mixes easily with water. The producer should dissolve the powder in 20 to 25 gallons of water per acre and apply it directly with the seed, without the addition of any other fertilizer.

Foliar treatment

Soybean yield response following foliar application of iron-containing materials is often inconsistent. Frequently, chlorosis will be advanced beyond the stage where foliar iron application will help. High air temperature and wind erosion also reduce foliar application effectiveness. To fully correct the problem, two to three applications may be necessary using a 1% solution of ferrous sulfate (FeSO4). Two pounds of ferrous sulfate or 4 pounds of ferrous sulfate heptahydrate (FeSO4 • 7H2O) in 25 gallons of water makes a 1% solution. A greater-than-1% solution can lead to leaf burning.

The farmer can also use iron chelates for foliar application. Adding a commercial wetting agent or a cup of mild household detergent to 100 gallons of solution can improve plant coverage. Adding 5 pounds of urea fertilizer per 100 gallons of spray solution also may improve foliar spray performance.

The more severe the chlorosis, the harder it is to correct. Therefore, if a producer employs a foliar application, he should begin as soon as the first chlorosis symptoms appear and treat at a 7- to 10-day interval, until new growth shows normal color.

Nutrient Removal

Table 16-4 shows nutrient uptake for a typical soybean yield in Nebraska. Most or all of the nitrogen required by a soybean crop at this yield level will be supplied from the soil (as residual nitrogen and nitrogen derived from mineralized organic matter) and from symbiotic fixation from the atmosphere.

Table 16-4

Soybean nutrient uptake.

Nutrient	Removed in Seed	Remaining in Stover	Total Uptake
	pounds per acre		
N	188	127	315
P_2O_5	44	30	74
K_2O	66	576	142
S	5	15	20
Zn	0.05	0.3	0.35

Resources

1. Hanway, J.J., and C.R. Weber. 1971. N, P, and K Percentages in Soybean [Glycine max (L.)] Plants. Agron. J. 63:406-408.

2. Hergert, G.W., C.S. Wortmann, R.B. Ferguson, C.A. Shapiro, and T.M. Shaver. 2012. Using Starter Fertilizers for Corn, Grain Sorghum, and Soybeans, NebGuide G361. University of Nebraska–Lincoln Extension, Lincoln, NE.

3. Varco, J.J. 1999. Nutrition and Fertility Requirements. *In* L.G. Heatherly and H.F. Hodges (eds) Soybean Production in the Midsouth. CRC Press, Boca Raton, FL.

4. Wesley, T.L., R.E. Lamond, V.L. Martin, and S.R. Duncan. 1998. Effects of Late-Season Nitrogen Fertilizer on Irrigated Soybean Yield and Composition. J. Prod. Agric. 11:331-336.

17 Sugar Beet

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Sugar beet has been an important crop in western Nebraska for the last century. The intermountain area of Nebraska, Colorado, Wyoming, Montana, and Idaho produces about 20% of U.S. sucrose production from sugar beet. Nebraska averages 53,000 acres per year and contributes over $60 million to the regional economy. Yields have increased from 22 tons per acre in 2000 to over 35 tons per acre in 2014, due to new varieties with improved disease tolerance and the introduction of Roundup Ready® sugar beet.

Soil Sampling and Testing

Soil testing is the foundation of sugar beet nutrient management. The goal is to determine the amount of nutrients in the soil prior to planting, then develop a fertilizer program for optimal nutrition of the crop. A 0- to 8-inch sampling depth is used for the top depth, with deeper samples used to determine residual nitrate-nitrogen because of sugar beet's extensive taproot. Current guidelines recommend sampling to a 4-foot depth (Figure 17-1). Soil sampling schemes have also changed significantly with the advent of precision agriculture. Grid sampling and management zone sampling are options other than conventional sampling.

FIGURE 17-1

Sugar beet rooting photo taken near Scottsbluff in 1930 by Lyman Andrews for Great Western Sugar Company.

Nitrogen

Good nitrogen (N) management is critical for optimal sugar beet production. Applying too little nitrogen will result in a significant reduction in root yield, while excess nitrogen will increase leaf growth and impurities and decrease sucrose content (Figure 17-2). About 8 to 9 pounds of nitrogen are taken up in 1 ton of harvestable sugar beet (roots and tops). Nitrogen fertilizer recommendations are based on residual nitrate in the soil, soil organic matter, previous crop, amounts of manure applied in previous years, and amounts of nitrogen in irrigation water.

FIGURE 17-2

Nitrogen deficient (left) and nitrogen sufficient sugar beet in early August in western Nebraska.

Nebraska recently revised its algorithm and changed the soil nitrate-nitrogen test to a 4-foot basis. Fertilizer nitrogen recommendations can be calculated using the following equation:

Nitrogen need (lb N/acre) = (8 x EY) + (30 X OM) + RSN4ft + other credits

where:

EY = expected yield (tons/acre)

OM = organic matter percent

RSN4ft = residual soil nitrogen measured to a 4-foot depth (pounds of nitrogen per acre)

other credits = Nitrogen mineralization from organic, legume, or crop reside sources or nitrate-nitrogen in irrigation water.

Recommended nitrogen fertilizer rates are presented in Table 17-1

Table 17-1

Suggested nitrogen fertilizer rates for three yield levels at 1.5% soil organic matter.

NO_3-N in top 4 feet (lb)	**Sugar Beet Yield Goal**		
	24 tons	*28 tons*	*32 tons*
	------- *pounds of nitrogen per acre to apply* -------		
25	125	155	185
50	100	130	160
75	70	105	135
100	50	80	110
125	20	55	90

All nitrogen fertilizer sources {urea (4600), ureaammonium (2800 or 3200), ammonium sulfate (2100), and anhydrous ammonia (8200)} can be used for sugar beet production. Shallow incorporation of a high rate of spring preplant urea-nitrogen can have a detrimental effect on stand establishment. Spring application of 100 pounds of urea nitrogen per acre reduced stands by more than 6,000 plants per acre, compared to no nitrogen. Under gravity irrigation, it is advisable to apply nitrogen fertilizers and incorporate with plowing or disking before planting, or sidedress between the two- to six-true leaf growth stages. Another option is to apply nitrogen using strip-tillage application. Nitrogen application with sprinkler irrigation is also a very efficient method and has no effect on stand due to nitrogen dilution with irrigation water. One limitation of nitrogen application is that all nitrogen, whether sidedressed or applied through irrigation water, must be applied by July 15 to reduce potential quality concerns and reduced sucrose content.

Manure application is not recommended for sugar beet production. Use manure on other crops in the rotation, especially corn. Much of the nitrogen from manure is released in the latter part of the growing season and tends to retard sugar accumulation and increase impurities. Nitrogen credits for plowed down alfalfa are given in Table 17-2.

TABLE 17-2

Guide for adjusting nitrogen recommendations following a previous alfalfa crop.

Stand	Crop N credit (lb)
0-29%	50
30-69%	70
70-100%	100

Recent research with composted manure showed minimal detrimental effects on quality due to slower nitrogen mineralization compared to non-composted manure. The composted manure contained 15 to 20 pounds of nitrogen per ton and provided an apparent nitrogen release of about 10 pounds of nitrogen per ton during the growing season. About 12 tons of composted manure may be needed but would cost much more than an optimum rate of inorganic nitrogen. The additional phosphorus, sulfur, carbon, and micronutrients from manure could benefit sugar beet and following crops, but the economics must be considered. The highest rate of compost (16 tons per acre) did not significantly reduce stand, sugar, or tonnage, or increase impurities. If there ever is a major fertilizer shortage, composted manure could be substituted for mineral fertilizer and produce acceptable yields, quality, and sugar.

Phosphorus

Phosphorus is the second most limiting nutrient in sugar beet production. Leaves of plants deficient in phosphorus appear darker green than plants with adequate phosphorus. With inadequate phosphorus, plant growth will be stunted. Phosphorus deficiencies are usually associated with soils that are high in pH and low in organic matter (eroded knolls and areas of extensive and intensive land leveling). Soils that require phosphorus fertilization can be identified by soil testing. Commercial soil testing laboratories use different soil extractants than was used in the past to determine available phosphorus. Most research has been conducted on calibrating Bray 1 P or Olsen P (sodium bicarbonate) with yield response. The following equations can be used to convert other extractant results to a “Bray 1 P equivalent.”

For Mehlich 2: Bray-1 = 0.9 x Mehlich 2

For Mehlich 3: Bray-1 = 0.85 x Mehlich 3

For Olsen P: Bray-1 = 1.5 x Olsen P

Research indicates that yield increases are expected from phosphorus applications when soil test levels are below 15-18 ppm by the Bray 1 method or equivalent conversion of other tests. As average sugar beet yields continue to increase, there is a good probability of yield increase from P fertilization when soil tests are equal to 20 parts per million (ppm) Bray 1 P or below. Yield increases are unlikely if soil tests are greater than 20 ppm Bray 1 P. Use of starter phosphorus will help maintain soil phosphorus and other nutrients that may be applied in starter fertilizer.

Phosphorus recommendations for sugar beet are provided in Table 17-3 or can be calculated using the following equation:

P rate (pounds per acre) = 5 x (24 - Bray P1 test value) or

P rate (pounds per acre) = 7.5 x (16 - Olsen P test value)

Table 17-3

Phosphorus fertilizer recommendation based on soil test results.

ppm Bray 1-P	ppm Olsen P	P recommendation (lb/acre)
3	2	105
6	4	90
9	6	75
12	8	60
15	10	45
18	12	30

Starter Fertilizer and Pop-up Fertilizer

Band application at planting (starter fertilizer) is the most efficient placement method for phosphorus fertilizer. If the phosphorus fertilizer is band-applied, the phosphorus rate can be reduced by 50% compared with the phosphorus recommendations in Table 17-3.

Pop-up fertilizer placement (directly with the seed) is not recommended for sugar beet because seedling emergence may be slowed and stand reduced due to salt effects, especially in dry soil. Recent research at Scottsbluff did not show a yield enhancement regardless of soil test phosphorus level, and in two out of three years, there was significant stand loss at pop-up rates above 3 gallons per acre of 10-34-0. If pop-up rates are above 3 gallons per acre, dilute starter fertilizer in a solution that is half water and half fertilizer.

Monoammonium phosphate (MAP, 11-52-0), diammonium phosphate (DAP, 18-46-0), and ammonium polyphosphate (10-34-0) are equally effective per unit of phosphorus if properly applied. Choose fertilizer based on product and equipment availability and cost per unit of phosphorus.

Potassium

Most soils where sugar beet is grown in Nebraska have much higher potassium (K) soil test levels than needed for optimal sugar beet production. Potassium fertilizer recommendations are given in Table 17-4.

Table 17-4

Potassium fertilizer recommendations for sugar beet in Nebraska.

Potassium Soil Test	Relative Level	K_2O to Apply
ppm		*pounds per acre*
0 – 40	Very low	120
41 - 74	Low	80
75 - 124	Marginal	40
> 124	Adequate	0

Sulfur

The likelihood of obtaining a response to sulfur (S) fertilizers on sugar beet in Nebraska is quite small. The producer should test irrigation water for sulfate content and if it is above 6 ppm, no sulfur is required. If sugar beet is grown on sandy soils with less than 1% organic matter, and irrigation water levels of sulfate are less than 6 ppm, 10 pounds of sulfur per acre may increase yields.

Zinc

Producers should not expect a response to zinc (Zn) fertilizer in sugar beet unless the DTPA zinc soil test level is less than 0.5 ppm. Research results have shown that even below this level the likelihood of a zinc response is low. If the DTPA zinc soil test level is less than 0.5 ppm, apply 1 pound of zinc per acre in a band or 5 pounds of zinc per acre broadcast.

Other Nutrients

The likelihood of obtaining a response in sugar beet from applying fertilizers containing calcium, magnesium, iron, manganese, copper, molybdenum, boron, or chlorine is extremely unlikely in Nebraska soils.

■ *Nutrient removal*

Table 17-5 shows nutrient uptake for sugar beet. Because of the nutrient supply in organic matter and clay minerals, most Nebraska soils can adequately meet crop requirements of potassium, calcium, and magnesium for many years without supplemental fertilization.

Table 17-5

Nutrient removal per ton of sugar beet.

Nutrient	Removed by Beets	Remaining in Foliage	Total Uptake
	pounds per ton of beets		
N	3.5	5.5	9.0
P_2O_5	1.6	1.3	3.0
K_2O	6.0	8.3	14.3
Ca	1.3	2.5	3.8
Mg	0.7	1.3	2.0

Resource

1. Gary W. Hergert. 2013. Sugarbeet Nutrient Management. NebGuide G1459. University of Nebraska–Lincoln Extension, Lincoln, NE.

18 Sunflower

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Sunflower is a crop suited for both dryland and irrigated production in western Nebraska. In 2013, Nebraska producers harvested almost 35,000,000 pounds of sunflower seed from 38,500 acres for an average yield of 901 pounds per acre. In 2011 Nebraska ranked fifth in the nation in sunflower production.

Sunflower is a deep-rooted crop that responds to fertilizer applications most when soil nutrient levels are low. Profitable sunflower production requires adequate soil fertility based on soil tests. Nitrogen (N) is the most yield-limiting nutrient unless high residual nitrate levels exist. Phosphorus (P) is the next most limiting nutrient. Levels of available potassium (K), sulfur (S), and micronutrients generally are sufficient for sunflower production in most Nebraska soils.

The sunflower producer should establish a realistic expected yield to help determine crop nitrogen needs. The expected yield should be within 200 pounds of the average yield for the last three years. Dryland sunflower usually will yield between 1,000 and 1,500 pounds per acre whereas irrigated yields will range from 1,800 to 2,500 pounds per acre.

Nitrogen

The producer should base nitrogen rates for sunflower on the expected yields for each field. Sunflower usually requires some nitrogen fertilization unless there is substantial nitrate carry-over. Nitrogen recommendations based on expected yield and residual nitrate are given in Table 18-1. To improve the accuracy of nitrogen recommendations, the farmer should take subsoil samples from at least a three-foot depth and preferably to a four- or five-foot depth because sunflower will remove nitrate this deep. Nitrogen credits also should be deducted from the values in Table 18-1. Sources for credits include manure and previous legume crops as well as nitrate in irrigation water. Nitrogen fertilizer rate recommendations based on soil testing will be adequate for most soils with 1% to 1.5% organic matter. For soils having less than 1% organic matter, the producer should add 10 to 15 pounds per acre of nitrogen above recommended rates. For soils over 2% organic matter, 10 pounds of nitrogen per acre should be subtracted from the table values.

Table 18-1

Nitrogen fertilizer recommendations or sunflower.

Nitrate-N Soil Test	Dryland Expected Yield					Irrigated Expected Yield			
	pounds per acre								
	1000	*1200*	*1400*	*1600*	*1800*	*2000*	*2200*	*2400*	*2600*
	N to apply								
*ppm**	*pound per acre*								
0 - 1.0	30	40	50	60	70	80	90	100	110
1.0 - 2.0	15	25	35	45	55	65	75	85	95
2.1 - 3.0		10	20	30	40	50	60	70	80
3.1 - 4.0		0	0	15	25	35	45	55	65
4.1 - 5.0		0	0	0	0	20	30	40	50
5.1 - 6.0						0	15	25	35
> 6.0						0	0	10	20

*Average ppm NO_3-N in a 0- to 3-foot sample.

The sunflower grower can apply fertilizer nitrogen either preplant or sidedress. If some of the nitrogen is applied with starter fertilizer, the fertilizer band needs to be at least 2 inches away from the seed. Because sunflower seed is sensitive to fertilizer salts, direct seed application of fertilizers may cause damage. If seed application is the only method for applying a starter fertilizer, the producer should use no more than a total of 10 pounds of nitrogen and potassium. In dryland situations, applying nitrogen ahead of planting is the most efficient fertilizer method for nitrogen distribution into the root zone because of the limited leaching potential. Sidedress or split applications are the preferred methods for irrigated sunflower. Sunflower roots grow quickly in the soil between the rows so in order to avoid root pruning, the producer should sidedress early.

Phosphorus

Crop response to applied phosphorus is most likely on soils with low and medium levels of extractable phosphorus. When soil tests are below 15 parts per million (ppm) Bray-1 P or 10 ppm Olsen P, a producer can expect yield increases from phosphorus fertilizer application. Soil tests are recommended for sunflower. In many areas, sunflower that is in a winter wheat rotation will have adequate soil test phosphorus levels because soil test phosphorus levels are built to a higher level for the winter wheat. Phosphorus fertilizer recommendations based on the Bray-1 P and Olsen P tests are given in Table 18-2.

Placement of phosphorus fertilizers is important in sunflower production. Band application at planting is the most efficient placement method for phosphorus and recommended rates for row application are half that of broadcast (Table 18- 2). Broadcast application of phosphorus fertilizers also works well, but the farmer should thoroughly incorporate the fertilizer before planting. Different phosphorus sources (monammonium phosphate (MAP, 11-52-0); diammonium phosphate (DAP, 18-46-0); and ammonium polyphosphate (APP, 10-34-0)) are equally effective if properly applied. The producer should select a fertilizer carrier based on available equipment and cost per unit of phosphorus.

Table 18-2

Phosphorus fertilizer recommendations for sunflower.

Phosphorus Soil Test		P_2O_5 to Apply	
*Bray-1 P**	*Olsen-P**	*Broadcast*	*Row*
ppm		*pounds per acre*	
0 - 5	0 - 4	60	30
6 - 15	5 - 10	40	20
16 - 25	11 - 15	20	10
> 25	> 15	0	0

*Phosphorus tests: Bray-1 P for acid and neutral soils; Olsen-P for calcareous soils.

Potassium

Most Nebraska soils have large amounts of potassium and few crop responses to potassium fertilizers have been reported. Recommended potassium rates related to soil test values are given in Table 18-3. The main potassium fertilizer is potassium chloride (KCl) and the usual application method is broadcast with incorporation in the soil prior to planting.

Table 18-3

Potassium fertilizer recommendations for sunflower.

Potassium	Category	K_2O to Apply	
		Broadcast	*Row*
ppm		*pounds per acre*	
0 - 40	Very low	120	20
41 - 80	Low	80	10
81 - 120	Medium	40	10
121 - 150	High	0	0
> 150	Very high	0	0

Other Nutrients

Most Nebraska soils contain adequate levels of sulfur for sunflower production. Irrigation water for most surface and well water contains sufficient sulfate-sulfur for irrigated sunflower production. In most dryland situations sulfate-sulfur that resides deeper in the soil can supply adequate sulfur in addition to that which is mineralized from organic matter. No confirmed deficiencies of boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn) in sunflower are on record in Nebraska. If soil zinc levels are less than 0.4 parts per million DTPA extractable zinc, (including one pound of actual zinc in 10-34-0 or as a bulk blend dry mix with any dry phosphates), banding the fertilizer may be helpful. This amount of zinc would sufficiently correct any possible zinc deficiency that might exist at this very low soil test zinc level.

Nutrient Uptake

Table 18-4 illustrates nutrient uptake of the nutrients most often applied as fertilizers in Nebraska for a typical yield of sunflower. Because of the nutrient supply in organic matter and clay minerals, most Nebraska soils can adequately meet crop requirements of potassium, sulfur, zinc, calciumm and magnesium for many years without supplemental fertilization.

TABLE 18-4

Nutrient content removal in a sunflower crop producing 1,000 pounds of seed per acre.

Nutrient	**Removed by Seed**	**Removed by Stover**	**Total Uptake**
	pounds per acre		
N	30	18	48
P_2O_5	12	3	15
K_2O	8	28	36
S	2	4	6
Mg	2	5	7
Ca	1.2	18.5	19.7
Zn	0.05	0.04	0.09

Source:
High Plains Sunflower Production Handbook, Colorado State University, Kansas State University, University of Nebrska, University of Wyoming, USDA-Agricultural Research Divison.

Resources

1. Anderson, F.N. 1986. Fertilizing Sunflowers. NebGuide G86-827. University of Nebraska, Cooperative Extension, Lincoln, NE.

2. Schild, J., D. Baltensperger, D. Lyon, G. Hein, and E. Kerr. 1991. Sunflower Production in Nebraska. NebGuide G91-1026A University of Nebraska, Cooperative Extension, Lincoln, NE.

19
Proso Millet

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Proso millet is generally grown under dryland conditions, usually after winter wheat or after summer fallow. Millet planted following a wheat crop usually has a higher nitrogen (N) requirement than if it follows summer fallow because summer fallow provides additional nitrogen from decomposing wheat straw. Foxtail millets are grown for forage in parts of the Great Plains. Fertilizer guidelines for foxtail millets grown for forage are similar to those for proso following wheat.

Figure 19-1

Proso millet during summer.

Figure 19-2

Proso millet harvest using a stripper-header combine.

Nitrogen

Proso millet is planted in early summer which provides adequate time to apply and incorporate nitrogen before planting. Producers should base fertilizer choice on product availability, equipment availability and cost per unit of nitrogen. Soil temperatures and evaporation potential are higher with the late planting. Therefore, the producer should incorporate nitrogen, whether liquid or dry, to reduce the potential for nitrogen volatilization. As no-till acreage continues to increase, nitrogen sources may need to be treated with urease inhibitors to reduce potential nitrogen loss. Another option is placing some nitrogen with the seed. Soil testing for residual nitrate-nitrogen to 3 feet helps fine-tune nitrogen fertilizer recommendations. Table 19-1 shows nitrogen fertilizer rates to apply based on average soil nitrate content in the top 3 feet of soil. Because of weed competition and a limited root system, starter fertilizer has proven helpful when soil requires limited nitrogen or phosphorus (P) fertilization.

All nitrogen fertilizer sources are generally effective. When nitrogen fertilizers are placed with the seed at planting, row spacing must be considered. No more than 20 pounds nitrogen per acre should be used with 12 inch row spacing. At 7.5 inch spacing up to 30 pounds nitrogen per acre can be applied. Higher rates of nitrogen can be applied safely when placed at least 2 inches away from the seed. Anhydrous ammonia can be used, but it is not a typical source due to soil disruption, knife spacing and soil drying that might affect stand.

Table 19-1

Nitrogen recommendations for proso millet with a 3-foot soil sampling depth.

ppm NO_3-N	lb NO_3-N/acre	Previous Cropping	
		Fallow	Wheat
ppm		*pounds per acre*	
0 - 1.9	0 - 20	55	75
2.0 - 3.2	21 - 35	35	55
3.3 - 4.6	36 - 50	20	35
4.7 - 6.0	51 - 65	10	20
6.1 - 7.4	66 - 80	0	10
> 7.4	> 80	0	0

Phosphorus

In the western High Plains, proso millet is commonly grown on high pH or calcareous soils. The Olsen-P soil test is recommended for high pH soil, whereas the Bray P-1 soil test is suggested for neutral to acidic soil. The Mehlich 3 soil test is used by many commercial laboratories because it seems to works well across acidic to calcareous soils.

Phosphorus fertilizer application method affects plant response to phosphorus. Banded phosphorus fertilizer with the seed has been the more effective than broadcasting phosphorus. Phosphorus recommendations are given in Table 19-2.

Table 19-2

Phosphorus recommendations for proso millet.

Soil Test Value – ppm			lb P_2O_5 /acre to apply	
Bray P-1	Mehlich 3	Olsen P	Banded	Broadcast
< 10	< 12	< 6.7	40	80
10 - 15	13 - 18	6.8 - 10	20	40
16 - 20	19 - 24	10.1 - 13.3	10	20
> 20	> 24	> 13.3	0	0

Potassium

Most Nebraska soils where millet is grown have adequate levels of potassium (K) for maximum production. The exception may be some sandy soils under irrigation. Table 19-3 shows the amounts of potassium fertilizer needed in relation to soil tests for adequate fertility for growing millet.

Table 19-3

Potassium recommendations for proso millet.

Potassium Soil Test – ppm	Broadcast lb $K_2 0$/acre to apply
0 - 39	120
40 - 74	80
75 - 124	40
> 124	0

Other Nutrients

Proso millet rarely shows increases from sulfur or micronutrients. Zinc deficiency can be determined by soil testing. When the DPTA-Zn test is less than 0.5 ppm, zinc application is recommended. One-half to one pound of zinc per acre with 10-34-0 (seed-applied) is usually sufficient to prevent Zn deficiency.

Resources

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Acknowledgment

Thanks to Frank Anderson and Juan Rodriguez who provided much of the original research and to David Baltensperger, Jürg Blumenthal, and Greg Binford for earlier EC and NebGuide versions.

20
Grass Pastures and Hayland

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Grass pastures, hayland, and range cover over 45% of Nebraska's area. Of the 49.2 million acres in Nebraska, 23.4 million are in pasture or range. Of that, 2.6 million are pasture or crop land used for grazing. With the variety of grass species, and soil and terrain conditions, managing grass pastures and haylands requires viewing these resources as a system that includes the animals foraging on them. When fertilizing pastures, one must increase forage production through higher carrying capacity or the money spent on nutrients is wasted. Timing of nutrient application and grass maturity are critical to successful grassland management.

Nitrogen

Nitrogen (N) applications to dryland grass and pastures depend on soil moisture conditions and rainfall. If other factors are not limiting, grassland can use a large amount of nitrogen. Figure 20-1 shows Nebraska and the rainfall regions used for making the nitrogen recommendations listed in Table 20-1. Fertilizing the upland, native range in Zones III and IV generally is not economical, especially where soils are sandy. Therefore, the producer should apply the recommended rates of nitrogen only to sub-irrigated sites in these zones.

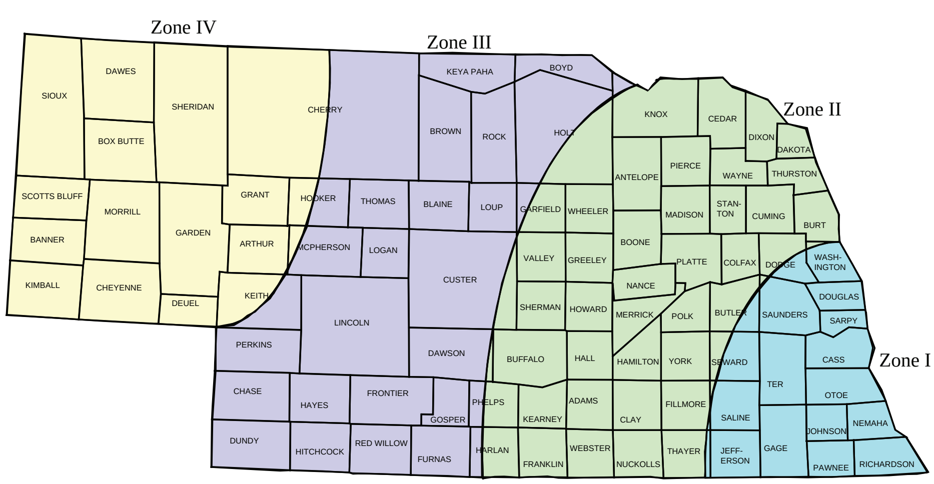


Figure 20-1

Nitrogen fertilizer zones for grass and haylands in Nebraska.

Table 20-1

Nitrogen recommendations for Nebraska pastures and haylands.

	Cool Season Grasses		Warm Season Grasses	
Zone	*Pasture*	*Hayland*	*Pasture*	*Hayland*
	Nitrogen to Apply* *pounds per acre*			
I	80 - 120	100 - 150	60 - 90	75 - 100
II	50 - 80	60 - 90	40 - 75	50 - 80
III	40 - 60	50 - 75	25 - 50	40 - 60
IV	20 - 40	30 - 60	20 - 40	30 - 50

*Use the higher rate when a full profile of subsoil moisture is present.

Irrigated pastures may contain legumes. If so, nitrogen applications may tend to increase grass stands at the expense of the legumes. On pastures, increased dry matter production is not economical unless grazing management takes advantage of the increased production. Table 20-2 shows nitrogen rates based on soil nitrate and stocking rate. Figure 20-2 shows when to apply fertilizer. On warm season grasses, early nitrogen application will stimulate weeds and cool season grasses, and decrease warm season grasses.

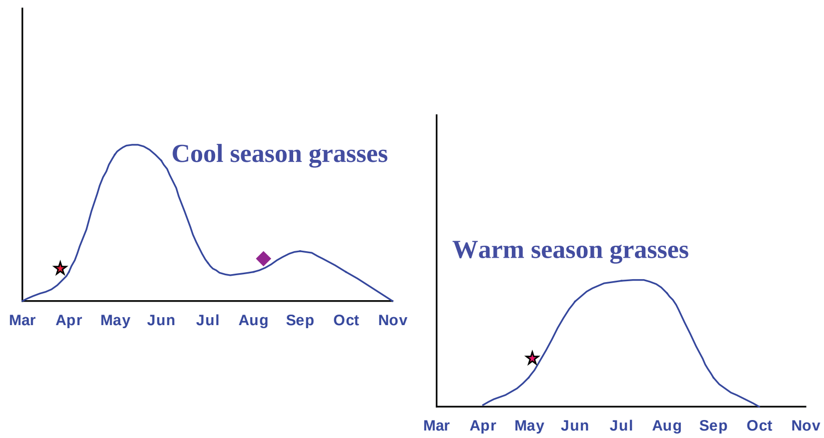
Table 20-2

Recommended nitrogen rates for Nebraska irrigated pastures based on soil residual nitrate-nitrogen levels.

	Fertilizer Nitrogen *pounds per acre*		
	0 - 50	**50 - 100**	**100 - 150**
Stocking Rate *yearlings per acre*	**Soil Residual Nitrate-N** *pounds per acre in soil to 6 feet*		
3	180	120	80
4	240	180	140
> 4	270	240	200

FIGURE 20-2

Fertilizer application timing for Nebraska grassland. The red stars indicate when to fertilize for each grass type. The purple diamond indicates when to fertilize for fall growth if moisture is sufficient.



Phosphorus

Due to increased production and the presence of legumes, phosphorus (P) recommendations vary (see Table 20-3). The producer should apply phosphorus with nitrogen before peak growth as shown in Figure 20-2.

TABLE 20-3

Phosphorus recommendations for dryland and irrigated grasslands.

Relative Index Value	**Soil Test Value**		**Dryland P_2O_5 to Apply**	**Irrigated P_2O_5 to Apply**	
	Bray-1 P	*Olsen-P*		*Grass*	*Grass-legume*
	ppm		*pounds per acre*		
Very low	0 - 5	0 - 3	40	60	90
Low	6 - 15	4 - 10	20	40	60
Medium	16 - 25	10 - 17	10	20	30
High	> 25	> 17	0	0	0

Potassium

Potassium (K) recommendations for pastures and hayland are given in Table 20-4. As with phosphorus, the increased potassium rates for an irrigated grass-legume mix is to keep the legume in a competitive environment with the grass. Research results in eastern Nebraska have shown that pastures generally do not respond to potassium fertilization.

Table 20-4

Potassium recommendations for irrigated pastures.

Soil Test Value	Relative Index Value	K_2O to Apply	
		Grass	*Grass-Legume*
ppm K		*pounds per acre*	
4 - 40	Very low	90	120
41 - 75	Low	60	80
76 - 124	Medium	30	40
125 - 150	High	0	0
> 150	Very high	0	0

Sulfur

Irrigated, sandy, low organic matter sites may need sulfur (S). The producer can apply sulfur at 30 to 40 pounds per year or at 100 pounds before seeding, and then once every three years.

Nutrient Removal

Table 20-5 illustrates typical crop nutrient removal values for the primary nutrients and sulfur for selected hay species in Nebraska. Values are expressed in pounds of nutrient removed per ton of hay yield. This table is not necessarily a guideline for fertilization. In Nebraska, significant amounts of these nutrients are provided for most soils through the process of mineralization, and are adequate to supply most or all of the crop requirement for optimum yield. Typical yields in

Nebraska are 1 to 1.5 tons per acre for prairie hay, and 1.5 to 2 tons per acre for brome, orchard grass, and crested wheatgrass.

Table 20-5

Approximate crop removal of primary and secondary nutrients for representative hay crops in Nebraska.

Crop	N	P_2O_5	K_2O	S
	pounds per ton			
Smooth brome hay, immature	48	15	56	4
Crested wheatgrass hay, mid-bloom	31	10	48	2
Orchardgrass hay, early bloom	42	10	48	5
Prairie hay, early bloom	28	9	26	2

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21 Popcorn

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Since the mid to late 1970s, Nebraska has become one of the leading popcorn producing states in the nation, often bringing in the highest popcorn yields. Increased popcorn production in Nebraska is due primarily to irrigation resulting in more consistent yields, which is critical when producing popcorn under contract.

In 2007, Nebraska producers raised 294.5 million pounds of popcorn equaling 34% of all popcorn grown in the United States. Nebraska ranked first in total harvested acres (59,728) and in total shelled production of popcorn in 2007.

Fertility requirements for popcorn are similar to field corn. Popcorn, however, has a less extensive root system compared to field corn, and is less efficient at utilizing nutrients in soil. Consequently, though yield levels for popcorn are less than field corn (on average about 50% of field corn yield), fertility requirements are similar. Popcorn also typically has poorer standing ability than field corn, and consequently is susceptible to lodging at high nitrogen (N) rates, particularly if potassium (K) levels are low. Popcorn seedlings are less vigorous than field corn, so the producer should probably use a starter fertilizer on popcorn.

Nitrogen and phosphorus (P) are the two most essential nutrients in both popcorn and field corn production. Soil potassium levels low enough to expect yield increases from potassium fertilization are relatively rare in Nebraska. Other nutrients that may be limiting in the soil and require fertilization for popcorn are sulfur (S), zinc (Zn), and occasionally iron (Fe).

Nitrogen

Like field corn, the amount of nitrogen necessary for popcorn is based on expected yield, soil organic matter, residual nitrate in the soil, previous crop in the field, the amount of manure and other organic wastes applied, and irrigation water nitrogen. The producer should credit all nitrogen sources and adjust the fertilizer rate accordingly. That rate should be about 15% lower than the recommended rate for field corn on the same field with the same expected yield. As previously expressed, excessively high nitrogen rates can cause lodging, especially when potassium levels are low.

Nitrogen fertilizer recommendations

Table 21-1 shows nitrogen fertilizer rate recommendations for various yield levels based on soil nitrate and organic matter levels. These rates apply for preplant or sidedress applications. The popcorn producer should not employ a fall nitrogen fertilization program.

Table 21-1

Nitrogen recommendations for popcorn.

Nitrogen Soil Test	**Expected Yield** *hundred weight per acre*								
	25	30	35	40	45	50	55	60	70
ppm	*pounds of N to apply per acre*								
	3% soil organic matter								
2	60	70	75	85	95	100	110	120	135
4	45	55	60	70	75	85	95	100	120
6	30	35	45	55	60	70	80	85	105
8	10	20	30	35	45	55	60	70	85
10		5	15	20	30	40	45	55	70
15							5	15	30
20									
	2% soil organic matter								
2	65	75	85	95	105	115	125	135	150
4	50	60	70	80	90	100	105	115	135
6	35	45	55	65	75	80	90	100	120
8	20	30	40	45	55	65	75	85	105
10	5	10	20	30	40	50	60	70	90
15						10	20	30	50
20									10
	1% soil organic matter								
2	75	85	95	105	115	125	135	150	170
4	55	70	80	90	100	110	120	130	155
6	40	50	60	75	85	95	105	115	140
8	25	35	45	55	70	80	90	100	120
10	10	20	30	40	50	65	75	85	105
15					10	25	35	45	65
20								5	25

Phosphorus

The grower should base phosphorus fertilizer needs for popcorn on Bray-1 P or Olsen P test levels. Table 21-2 gives phosphorus application rates based on soil phosphorus level and phosphorus fertilizer application method.

Table 21-2

Phosphorus fertilizer recommendations for popcorn.

Phosphorus Soil Test		Relative Level	P_2O_5 to Apply	
*Bray-1 P**	*Olsen-P**		*Broadcast*	*Band***
ppm			*pounds per acre*	
0 - 5	0 - 3	Very low	80	40
6 - 15	4 - 10	Low	40	20
16 - 24	11 - 16	Medium	0	†
25 - 30	17 - 20	High	0	†
> 30	> 20	Very high	0	0

* Phosphorus tests: Bray-1 P for acid and neutral soils; Olsen-P for calcareous soils (pH 7.2 or greater).

** Applied in a band preplant or beside the row at planting.

† Applying 10 to 20 pounds per acre P_2O_5 with 5 to 10 pounds per acre N in a band at planting may increase early growth on these soils. See NebGuide G631, Using Starter Fertilizers for Corn, Grain Sorghum and Soybeans.

Potassium

Most soils in Nebraska contain adequate amounts of potassium for maximum popcorn yields. For soils low in potassium, the producer should apply potassium fertilizers according to the guidelines in Table 21-3.

Table 21-3

Potassium fertilizer recommendations for popcorn.

Potassium Soil Test*	Relative Level	K_2O to Apply		
		Broadcast		*Band***
		pounds per acre		
0 - 40	Very low	120	+	20
41 - 74	Low	80	+	10
75 - 124	Medium	40	or	10
125 - 150	High	0		0
> 150	Very high	0		0

* Potassium test: exchangeable K.

** Banded beside the seed row, but not with the seed.

Sulfur

Sulfur deficiency in Nebraska generally only occurs on sandy, low organic matter soils; however, in popcorn it also may occur on medium to coarse textured soils. This is because popcorn seed germinates and seedlings grow more slowly than field corn. Also, the popcorn root system is less extensive than the field corn root system so high clay soils and poorly draining soils weaken roots, reduce yields, and increase lodging. Popcorn producers should test soil and irrigation water for sulfur content if there is a concern about sulfur availability to the crop.

Guidelines for sulfur fertilization are listed in Table 21-4. Most irrigation water, except in the very sandy area of north central Nebraska, contains enough sulfur to supply popcorn's requirements. Where sulfur may be low, as indicated by soil testing, applying fertilizer containing sulfur in a band at planting on sandy soil may be effective.

TABLE 21-4

Sulfur fertilizer recommendations for popcorn.

Sulfur Soil Test, SO_4-S‡	**Annual Sulfur Application Rate**	
ppm	*pounds per acre*	
	Soil Organic Matter ≤1%	*Soil Organic Matter >1%*
	Irrigation water with < 6 ppm SO_4-S	
< 6	10 row* or 20 broadcast	5 row*
6 - 8	5 row* or 10 broadcast	0
	Irrigation water with > 6 ppm SO_4-S	
< 6	5 row* or 10 broadcast	0
6 - 8	5 row* or 10 broadcast	0
> 8	0	0

‡Sulfur test is $Ca(H_2PO_4)_2$ extraction.
*Applied in a band next to row, but not with seed.

Zinc

Zinc is most likely to be limiting for popcorn production in low organic matter soils, and areas of fields that have been leveled for irrigation. Soil testing provides the best method for measuring zinc requirements in popcorn. Table 21-5 gives recommended rates of zinc to apply according to soil testing and excess lime content of the soil. Recommended broadcast rates are for raising soil zinc content to a level that is adequate for several years. Row treatment rates are for annual application.

TABLE 21-5

Zinc fertilizer recommendations for popcorn.

DTPA-Zn	**Relative Level**	**Zn to Apply**	
		Calcareous Soils	*Non-calcareous Soils*
ppm		*pounds per acre*	
0 - 0.40	Low	2 row or 10 broadcast	2 row or 5 broadcast
0.41 - 0.80	Medium	1 row or 5 broadcast	1 row or 3 broadcast
> 0.80	High	0	0

Resource

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22 Potato

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In 2008, Nebraska produced 8.3 million hundredweight of potato valued at over $82 million produced on 19,500 acres. Nebraska potato production is primarily in the Panhandle, the southwest corner, in south central and east central around Kearney and Columbus, and in north central between Ainsworth and O'Neill.

Nitrogen

Nitrogen (N) and, in some locations, phosphorus (P) are limiting nutrients for potato production in Nebraska. The amount of nitrogen fertilizer required for potato production varies with the intended markets, which include tablestock, chipstock, frystock and seedstock. The amount required as well as application timings also vary with the variety grown, requiring varietal-specific fertilizer management. Published variety profiles are available for many commonly grown potato. Most growers rely on varietal-specific petiole nitrate-nitrogen curves to guide them in nitrogen fertilization throughout the growing season.

The best way to determine soil nitrogen levels is through soil testing. The general fertilizer recommendations provided in Table 22-1 are based on residual soil nitrate-nitrogen levels. The producer should take soil samples from the 0- to 12-inch depth plus any additional depth of rooting for specific varieties. Leguminous crops (such as alfalfa) in the previous rotation, organic matter, and manure or other organic waste may affect the nitrogen fertilization rate for potato. Manure and other organic waste may carry potato pathogens such as common scab (*Streptomyces scabies*), which can lower marketable quality of potato.

When potato grows under deficient or excessive nitrogen, harvested tubers are smaller and have higher sugar levels and lower starch content than desired. Deficient or excessive nitrogen also affects tuber maturation. Additionally, without proper nitrogen fertilization, plants are more susceptible to diseases. Conversely, excessive nitrogen can delay tuberization and promote vine overgrowth.

Nitrogen level affects potato tuber yield (U.S. #1 grade), dry matter content and sugar content (Table 22-1). For tablestock, nitrogen fertilization recommendations are based on yield because dry matter content is not a concern. Dry matter content is critical, however, for potato chip production and less nitrogen is necessary for varieties going to this market. In French frying, tuber size is most important with yield and higher nitrogen rates are usually justified. Too much nitrogen can cause dry matter content to be too low. Longer season varieties usually need more nitrogen to maintain a longer vegetable growth period. Ammonium nitrate affects dry matter content more than ammonium sulfate.

Table 22-1

The effect of nitrogen on yield and process quality.

Nitrogen Rate	U.S. #1 Yield	% Dry Matter	Sugar Levels
pounds per acre		*effect*	
0 - 150	Increase	No change	Decrease
150 - 400	No change	Slight decrease	No change
> 400	Decrease	Decrease	Increase

Table 22-2 shows nitrogen fertilizer rate recommendations based on soil nitrate-nitrogen levels. Total nitrogen should be between 150 to 200 pounds per acre but may vary depending on the potato variety and the market. Typically, the potato grower should apply one-third of the required nitrogen at planting, one-third three weeks after tuber initiation, and the remainder through an irrigation system.

Table 22-2

Fertilizer nitrogen rates for potato.

Soil Test Level	Soil Nitrate-N	N to Apply
	pounds per acre	*pounds per acre*
Very Low	0 - 25	175
	26 - 50	150
	51 - 75	125
Medium	76 - 100	100
	101 - 125	75
High	126 - 150	50
	151 - 175	25
Very High	176 - 200	0
Excessive	> 200	0

Phosphorus

Because of the market desire for larger tubers, the producer may apply a greater amount of phosphorus fertilizer for tablestock and frystock than for chipstock and seedstock. Many soils in Nebraska's potato-growing regions release only small amounts of phosphorus for plant uptake during the growing season. Phosphorus-deficient plants produce smaller tubers having slightly lower dry matter content, and tend to be over-mature at harvest.

Phosphorus levels affect potato tuber yields (U.S. #1 grade), dry matter content and sugar content (Table 22-3). For tablestock, the grower should apply phosphorus fertilization to increase the proportion of tubers to the 10 to 11.5 ounce weight (70-80 count carton). For frystock, the producer should apply phosphorus fertilization to increase tuber length and the proportion of tubers to be greater than 10 to 16 ounces. Excessive phosphorus will not injure potato, and researchers have found no differences among superphosphate, diammonium phosphate or monoammonium phosphate.

Table 22-3

The effect of phosphorus (P_2O_5) on yield and process quality.

Phosphorus Rate	**U.S. #1 Yield**	**% Dry Matter**	**Sugar Levels**
pounds per acre		*effect*	
0 - 50	Increase	Slight increase	Decrease
> 50	No change	Slight increase	No change
0 - 100	Increases larger tuber size grades		

Table 22-4 provides broadcast phosphorus fertilizer recommendations for potato. As with other crops, soil tests provide the most accurate way to determine supplemental phosphorus fertilizer needs.

Table 22-4

Phosphorus (P_2O_5) fertilizer recommendations for potato.

Soil Test Level	**Bray-1 P Soil Test**	**Olsen P**	**P_2O_5 to Apply**
	ppm		*pounds per acre*
Very low	0 - 5	0 - 3	100
Low	6 - 15	4 - 10	80
Medium	16 - 25	11 - 17	40
High	> 25	> 17	0

Potassium

Most soils cropped to potato in Nebraska supply needed potassium. The intended market use of harvested tubers influences potassium application rates more than nitrogen or phosphorus application rates. Potassium promotes larger potato tubers by increasing water accumulation resulting in a lower dry matter content. Lower percent dry matter (specific gravity) can eliminate tubers from the chipping market. However, percent dry matter is less important for most frystock varieties for which tuber length and blockiness, (greater than 12 ounce) is premium. Also, for tablestock, dry matter content is unimportant. For these two markets, more potassium may be desired. For seedstock, the target is to keep tubers smaller (four to eight ounces) so less potassium is desired.

TABLE 22-5

The effect of potassium (K_2O) on yield and process quality.

Potassium Rate	U.S. #1 Yield	% Dry Matter	Sugar Levels
pounds per acre		*effect*	
0 - 80	Increase	Decrease	Decrease
> 80	Increase*	Decrease	No change

*Increases larger tuber sized grades.

Table 22-5 shows the effects of potassium levels on potato tuber yields (U.S. #1 grade), dry matter content, and sugar content. As with phosphorus fertilizers, the producer should apply potassium to increase tuber size grades. Potassium chloride fertilizer will produce a lower percent dry matter content than either potassium nitrate or potassium sulfate.

Table 22-6 shows recommended potassium fertilizer rates based on soil potassium test levels.

TABLE 22-6

Potassium (K_2O) fertilizer recommendations for potato.

Soil Test Level	Soil Test Value	K_2O to Apply*
	ppm	*pounds per acre*
Very low	0 - 40	120
Low	41 - 74	80
Medium	75 - 124	40
High	125 - 150	0
Very High	>150	0

*These amounts may be higher for tablestock and frystock markets, and lower for seedstock markets.

Sulfur

Irrigation water may provide some or all of the sulfur required for potato production on Nebraska soils. The producer should test irrigation water for sulfur content, especially in sandy, low organic soils where a sulfur deficiency is more probable. Table 22-7 gives sulfur fertilizer rates to avoid deficiency based on soil sulfur levels.

TABLE 22-7

Sulfur fertilizer recommendations for potato.

Soil Test Level	Sulfur to Broadcast
ppm SO_4-S	*pounds per acre*
0 - 5	25
6 - 8	15
> 8	0

Market pressures for sulfur application do not exist as they do with nitrogen, phosphorus and potassium fertilization. However, disease pressures may influence sulfur fertilization rates as some evidence has suggested that higher amounts of sulfur applied in the furrow can substantially decrease tuber infection by common scab and black scurf. Common scab is especially important in the tablestock and chipstock markets and somewhat important in the other two major markets. Black scurf is especially important in the tablestock and seedstock markets. The best form of sulfur to apply is ammonium sulfate placed in the furrow at planting. Table 22-8 gives the effect of ammonium sulfate on these two soilborne diseases.

Table 22-8

The effect of ammonium sulfate on common scab, black scurf, and yield when applied in-furrow at planting.

Ammonium Sulfate Rate	Common Scab	Black Scurf	U.S. #1 Yield
pounds per acre	*effect on percent tubers*		*effect*
0 - 210	Decrease	Slight decrease	Increase
> 210*	No change	No change	No change

*210 pounds of ammonoium sulfate gives 50 pounds of sulfur and 44 pounds of nitrogen.

Secondary and Micronutrients

Potato require small amounts of various micronutrients but Nebraska soils used for potato production are rarely deficient in these. Some zinc—up to five pounds per acre—is occasionally necessary. The grower may add boron (B) or magnesium (Mg) at one to three pounds per acre when interveinal leaf stripping is evident. Excessive B can cause toxic affects to potato.

TABLE 22-9

Zinc fertilizer recommendations for potato.

DTPA-Zn	**Zinc to Apply**	
	Calcareous Soil	*Noncalcareous Soil*
ppm	*pounds per acre*	
0 - 0.5	5	4
0.6 - 1.0	2	2
> 1.0	0	0

Resources

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