

Plant nutrition

From Wikipedia, the free encyclopedia

Plant nutrition is the study of the chemical elements and compounds that are necessary for plant growth, and also of their external supply and internal metabolism. In 1972, E. Epstein defined two criteria for an element to be essential for plant growth:

1. in its absence the plant is unable to complete a normal life cycle; or
2. that the element is part of some essential plant constituent or metabolite.

This is in accordance with Liebig's law of the minimum.^[1] There are 14 essential plant nutrients. Carbon and oxygen are absorbed from the air, while other nutrients including water are obtained from the soil. Plants must obtain the following mineral nutrients from the growing media.^[2]

There are three fundamental ways plants uptake nutrients through the root: 1.) simple diffusion, occurs when a nonpolar molecule, such as O₂, CO₂, and NH₃ that follow a concentration gradient, can passively move through the lipid bilayer membrane without the use of transport proteins. 2.) facilitated diffusion, is the rapid movement of solutes or ions following a concentration gradient, facilitated by transport proteins. 3.) Active transport, is the active transport of ions or molecules against a concentration gradient that requires an energy source, usually ATP, to pump the ions or molecules through the membrane.^[4]

- Nutrients are moved inside a plant to where they are most needed. For example, a plant will try to supply more nutrients to its younger leaves than its older ones. So when nutrients are mobile, the lack of nutrients is first visible on older leaves. However, not all nutrients are equally mobile. When a less mobile nutrient is lacking, the younger leaves suffer because the nutrient does not move up to them but stays lower in the older leaves. Nitrogen, phosphorus, and potassium are mobile nutrients, while the others have varying degrees of mobility. This phenomenon is helpful in determining what nutrients a plant may be lacking.

A symbiotic relationship may exist with 1.) Nitrogen-fixing bacteria, such as rhizobia, which are involved with nitrogen fixation, and 2.) mycorrhiza, which help to create a larger root surface area. Both of these mutualistic relationships enhance nutrient uptake.^[4]

Fertilizer

From Wikipedia, the free encyclopedia

Fertilizer (or **fertiliser**) is any organic or inorganic material of natural or synthetic origin (other than liming materials) that is added to soil to supply one or more plant nutrients essential to the growth of plants.^[1] Conservative estimates report 30 to 50% of crop yields are attributed to natural or synthetic commercial fertilizer.^[2] Global market value is likely to rise to more than US\$185 billion until 2019.^[3] The European fertilizer market will grow to earn revenues of approx. €15.3 billion in 2018.^[4]

Mined inorganic fertilizers have been used for many centuries, whereas chemically synthesized inorganic fertilizers were only widely developed during the industrial revolution. Increased understanding and use of fertilizers were important parts of the pre-industrial British Agricultural Revolution and the industrial Green Revolution of the 20th century.

Inorganic fertilizer use has also significantly supported global population growth — it has been estimated that almost half the people on the Earth are currently fed as a result of synthetic nitrogen fertilizer use.^[5]

Fertilizers typically provide, in varying proportions:

- six macronutrients: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S);
- eight micronutrients: boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), zinc (Zn) and nickel (Ni) (1987).

The macronutrients are consumed in larger quantities and are present in plant tissue in quantities from 0.15% to 6.0% on a dry matter (0% moisture) basis (DM). Micronutrients are consumed in smaller quantities and are present in plant tissue on the order of parts per million (ppm), ranging from 0.15 to 400 ppm DM, or less than 0.04% DM.^{[6][7]}

Only three other structural elements are required by all plants: carbon, hydrogen, and oxygen. These nutrients are supplied by water (through rainfall or irrigation) and carbon dioxide in the atmosphere.

Fundamentals of Soil Testing

The major emphasis in this lesson is soil testing and understanding the procedures needed to take a representative soil sample. You will understand the term variability, how it affects soil tests, and how a soil test is developed.

[This lesson is an excerpt of the Soils series, taken from the "Soils Home Study Course," published in 1999 by the University of Nebraska Cooperative Extension.]

What is a Soil Test?

Soil testing is a practical and common sense means of using reliable chemical analyses to assess soil nutrient levels and determine how fertilizer use can be improved. Note that there are no words like "exact," "precise," or "accurate" in this definition. A key word is "assess," which means "to evaluate," "to estimate," or "to set a fixed value."

From the definition, the purpose of soil testing is:

- to assess nutrient levels, and
- to guide decisions in fertilizer use.

Assessing Nutrient Levels

Differences in pH, nitrogen, phosphorus, potassium, zinc, soluble salts, cation exchange capacity, and organic matter content are determined by chemical analyses. **Soil sampling** is the first step to help estimate field levels of specific chemicals. There are two primary objectives when sampling soils to determine nutrient levels. These are:

1. Sample the soil to obtain the average nutrient level and the average pH for a given field.
2. Sample the soil to map the variability of chemical properties over a specific field.

How a field is sampled depends on which of these is the primary objective.

The second objective is becoming more popular with site-specific farming. Even subdividing a field into three or four subfields can be profitable. *Table 9.1* shows the soil test results of three samples collected from a single field. Each sample was obtained from 15 to 20 individual soil cores that were thoroughly mixed to make one sample. These three samples show a field average. If only two samples were taken, instead of three, the average nutrient level for phosphorus, potassium and zinc would be different. Without three samples, the low zinc level or the low phosphorus level in one area of the field may not be known. Therefore, how a field is sampled is important. The knowledge of the variability in a field is also important and is the basis for the concept of site-specific management.

Table 9.1. An example of average nutrient levels and nutrient variability from three samples within the same field.

Soil Test	Sample			Average
	A	B	C	
pH	6.8	7.4	7.2	—
Phosphorus ¹ (Bray)	9	3	15	9
Potassium ¹	320	280	400	333
Zinc ¹ (DTPA)	0.25	1.75	2	1.33
¹ P, K, and Zn are reported as parts per million				

A Good Soil Sample is Important

The laboratory conducts its analysis of the soil on an extremely small sample of the target field. It is critical to the legitimacy of the process to have a representative sample. The top six to eight inches of soil in an acre weigh about two million pounds. Yet, the amount of soil from a soil sample which is analyzed in any laboratory weighs less than an ounce. Most soil samples are composites from 20 or more acres. Therefore, the guidelines suggested for proper sampling must be followed to obtain useful results.

The soil sample submitted to the laboratory must be representative. It must accurately represent the field or area sampled. Sampling is the weakest link in the soil testing chain and the greatest source of error. You can't be too careful when collecting a soil sample. Consistency in sampling procedures must be followed so that the analytical results can be interpreted.

Soil Variability and Sampling

Soil variability is the reason sampling procedures are so important. Soils vary continuously within fields and between farms. Surface variation may be easily seen, but nutrient variability is usually not obvious.

Sampling Procedures for Field-Based Samples

A **soil sample** is a collection of individual cores from a known area. A **soil core** is a continuous length of soil taken with a soil probe to a specific depth. Soil samples are taken as a surface sample and sometimes a deep sample. All the soil from the length of the soil sample is saved. Individual soil cores are combined and mixed. Usually there is more soil in the collecting bucket than room in the sample bag or box. It is important that individual cores are mixed thoroughly before the sample box or bag is filled.

One statement summarizes the guiding principle for proper sampling: **Take lots of individual cores for compositing into a single sample, and take lots of samples.** Practical considerations must balance what is most applicable.

Soil Nutrients

Soil pH

Soil pH is defined and its implications for crop production are described in this lesson. How are soil pH and buffer pH determined? How are these assessments used in lime recommendations? The factors that influence pH variations in soils, the chemistry involved in changing the pH of a soil, and the benefits associated with liming acid soils will be discussed.

[This lesson is an excerpt of the Soils series, taken from the "Soils Home Study Course," published in 1999 by the University of Nebraska Cooperative Extension.]

What is pH? Defining pH

The definition of pH is: The negative logarithm of the hydrogen ion activity (concentration) in equivalents per liter [eq./l] or written as an equation:

$$\text{pH} = -\log[\text{H}_+] = \log 1/[\text{H}_+] \quad (3)$$

The mathematical expression, pH of 7, is much easier to say than “a hydrogen ion concentration of 0.0000001 gram equivalents per liter” as shown in *Equation 4*.

$$\text{pH} = 7.0 = -\log(.0000001 \text{ eq.H}_+/1) \quad (4)$$

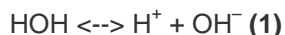
$$\text{pH} = 5.0 = -\log(.00001 \text{ eq.H}_+/1) \quad (5)$$

$$\text{pH} = 9.0 = -\log(.000000001 \text{ eq.H}_+/1) \quad (6)$$

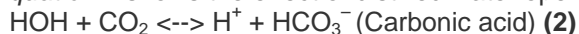
As shown in *Equation 5*, there is 100 times more hydrogen present for pH 5 than for pH 7 and similarly for pH 9, there is 100 times less hydrogen than for pH 7. The pH scale, by definition, ranges from 1 to 14. In perspective, the pH of lime juice is about 2, while [aqua ammonia](#) is about 12.

Acidity and **alkalinity** of an aqueous system (solution) are described (measured) by the term **pH**. pH is the negative logarithm of the hydrogen ion [H⁺] concentration. Hydrogen is a component of all acids. When hydrogen ionizes to form ions [H⁺], its concentration determines the acid properties of soil solutions.

Pure water, free of all minerals such as calcium, magnesium, etc., and free of carbon dioxide [CO₂], has a pH of 7.0, which is called neutral. Water [HOH] ionizes to form hydrogen ions [H⁺] and hydroxyl [OH⁻] ions according to the following equation:



If carbon dioxide is dissolved in water in the absence of other compounds or minerals, the water becomes slightly to moderately acid. *Equation 2* shows the effect of distilled water open to CO₂ in the atmosphere:



There is now more H⁺ than OH⁻; thus, the pH of distilled water that has absorbed CO₂ from the atmosphere may range from 4.0 to 7.0, depending on temperature and the amount of CO₂ in the atmosphere. The reaction in *Equation 2* is probably responsible for seasonal fluctuation of 0.2 to 0.5 units in soil pH.

Soil pH: The Nebraska Perspective

Active and Reserve Acidity

The relationship between active and reserve acidity is not constant across soils, and is influenced primarily by type and amount of [clay](#) and [organic matter](#) content of the soil. As the clay and organic matter content increase, the ratio of reserve to active acidity also increases. This relationship gives rise to the buffering capacity of the soil. The buffer capacity, or reserve, of a sandy soil is much less than that of a soil containing more clay such as a silt loam. Buffering, reserve, and active acidity are part of a complex system, which may be better explained by the following analogy.

Consider two full coffee urns, one with a 50-cup capacity and the other a 10-cup, both having the same size indicator tube and spigot. Coffee in the indicator tube represents the active acidity (measured by regular pH), and that in the urn represents the reserve acidity (measured by buffer pH). Let the large urn represent a clay soil high in organic matter, while the small urn represents a sandy soil. Both urns have equal amounts of coffee in the indicator tube; i.e., the same active hydrogen, so the same pH. Now, open the spigot and remove one cup of coffee from each urn. Removing one cup of coffee from each urn could be equated to adding small amounts of limestone to an acid soil. Opening the spigot will cause the level of coffee in the indicator tube to drop below the level in the urn, but will return to almost the original level (clay soil) when the spigot is closed. The momentary drop of coffee in the indicator tube represents the initial increase in pH when lime is added (affects the active hydrogen); but reserve hydrogen (similar to coffee in the urn) soon equalizes the effect from the lime, and the pH returns to essentially its original level, (clay soil, *Figure 2C*).

If the pH is 6.2 or lower, a [buffer pH](#) is run to measure the reserve acidity. The result of the buffer pH shows the amount of lime required to neutralize a major portion of the reserve acidity. The relative amounts of coffee in the two urns (*Figure 2C*) show why a sandy soil and a clay soil with the same pH result in different lime requirements. For example, removing one cup of coffee from each urn (like adding a small amount of limestone to an acid soil) reduced the total coffee (reserve acidity) by 10 percent in the small urn (sandy soil), but by only 2 percent of the large urn (clay soil). In a similar manner, one ton of agricultural limestone will make a greater change in the pH of a sandy soil than of a clay soil.

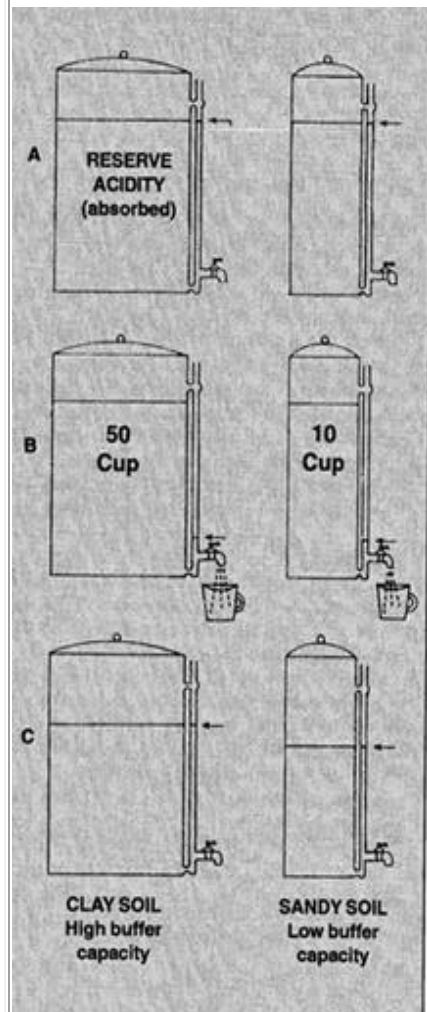


Figure 4.1

1. **Herbicide activity.** Soil pH markedly influences performance of [s-triazine herbicides](#). As soil pH increases, particularly [above 7.2](#), herbicides become more available to both weeds and crops, so it takes less herbicide to control weeds and also injure crops.

2. **Activity of soil bacteria.** Symbiotic [Rhizobium](#) bacteria associated with legume [nodulation](#) are reduced in acid soils.

3. **Availability of plant nutrients.** High pH soils usually have excess calcium carbonate which reduces the availability of [phosphorus](#) by forming less soluble calcium phosphate compounds. Availability of [micronutrients](#), like copper (Cu), manganese (Mn), zinc (Zn), iron (Fe) and boron (B), may be reduced, while calcium (Ca) and molybdenum (Mo) will be more available. Some plants may suffer lime-induced chlorosis (some soybean varieties and sorghum). At low pH values, iron, aluminum (Al) and manganese

become very soluble and may become toxic. For example, some acid sandy soils in Kansas have toxic levels of aluminum, especially those on which wheat is grown. Fortunately, aluminum toxicity on acid sandy soils in Nebraska has not been a problem. Phosphorus availability may be reduced on acid soils, while zinc is increased.

4. **Possible soil chemistry problems.** Low pH (< 6.3) indicates the need to run buffer pH to determine if lime is needed; high pH indicates excess carbonates which may be accompanied by saline or sodic conditions.

5. **Activity of soil microorganisms.** Usually, at lower pH values, the microorganisms that decompose organic material are less active, resulting in reduced release of plant nutrients, such as [nitrogen \(N\)](#), phosphorus (P), sulfur (S) and zinc (Zn). 6. **Plant growth.** Crops have a pH range where they grow best. These generalized ranges are shown in [Table 4.1](#).

7. **Reduced amounts of Ca and Mg.** At low pH values, less calcium and magnesium are held on the soil particles. Calcium deficiency has not been a problem in Nebraska soils, even at pH values below 5. However, on very acid, low [cation exchange capacity \(CEC\)](#) soils, excess application of potassium fertilizer could induce magnesium deficiency for some crops.

8. **Changing the pH.** Lime is used to raise the pH of acid soils. One milliequivalent (me) of calcium is required to remove 1 me. of hydrogen. The speed of the reaction depends on how finely the lime is ground. Beware of products with claims such as “200 pounds of product X, a unique and highly effective blend is equal to 2,000 pounds of 60 percent ECC Ag Lime.” Changing the pH is discussed in more detail later in this chapter.

Table 4.1. Preferred soil pH range of various crops.

Soil pH	5.0	5.5	6.0	6.5	7.0	7.5	8.0
				Alfalfa and sweet clover			
				Bluegrass			
			Peas and onions				
			Beets, red and white clover				
		Corn, milo, soybeans and vetch					
		Sorghum, sudan grass and orchard grass					
		Cotton, wheat, barley and oats					
		Fescue grasses					
		Watermelons and sweet potatoes					
		Rye					

pH Capacity and Intensity

Two types of soil pH are of concern: **capacity** (reserve) and **intensity** (activity).

Capacity

Some H⁺ ions will be adsorbed on the cation exchange sites (not in solution). These adsorbed H⁺ ions are sometimes referred to as reserve or potential acidity. The **buffer pH** is the test used to estimate **lime requirement**. The lime requirement is the amount of ag lime (calcium and/or magnesium carbonate) required to neutralize the H⁺ from the soil exchange sites and in the soil solution. The cations of Ca⁺⁺ and Mg⁺⁺ in the ag lime replace the H⁺ on the soil and/or organic matter negatively charged exchange sites.

Cation Exchange Capacity (CEC) refers to the exchange of one cation for another on the surface of a soil particle or colloid. Soils vary in CEC value because of makeup of the solid part of the soil. The solid part includes decaying plant materials, [humus](#), clays, sands, silts, and other mineral components. The CEC value of a soil is measured in milliequivalents /100 grams. Clay components of soil may have a CEC value of 10 to 80 me/100 g. while organic humus particles will have CEC values of 100 to 200 me/100 g. A Valentine sand might have CEC values near 3-6 me/100 g., while Sharpsburg soils might be closer to 16-25 me/100 g. The CEC value of a soil is mainly a function of clay content and organic matter ([see Figure 4.1](#)).

[Table 4.2](#) illustrates the relationship between soil pH, buffer pH and lime requirement for soils with different soil textural classifications. Each soil in [Table 4.2](#) is 70 percent base saturated (30 percent hydrogen saturated); that is, 70 percent of the exchange capacity is filled by basic cations such as Ca^{++} , Mg^{++} , K^+ , and sodium (Na^+) and very small amounts of micronutrient bases such as Zn^{++} . The soil pH (measurement of active hydrogen) values are basically the same for all three soils, but note differences in “reserve H^+ ”, 1.8 to 7.5 me/100g which is measured by the buffer pH and why the amount of lime required to raise the soil pH to 6.5 is 4 tons/acre for the silty clay loam soil compared to 1 ton/a for the loamy sand.

Table 4.2. Influence of cation exchange capacity (CEC) on soil pH (active acidity), buffer pH (reserve acidity) and lime requirement for three soil textural classes.

	Soil texture	CEC exchange capacity		Exchangeable H		
		me/100g	%	Base saturation	Soil pH	Buffer pH
Loamy sand	6	1.8	70	5.6	6.8	1
Silt Loam	14	4.2	70	5.5	6.6	2
Silty clay loam	24	7.5	69	5.6	6.2	4

Intensity

This is the soil pH that is most familiar. It is important to remember that soil pH is a measure of the H^+ **activity** of the soil solution. It is **not** a measure of the total acidity of the soil. The amount of H^+ in the soil solution is a function of the proportion of soil cation exchange capacity that is satisfied by H^+ ions, not the total amount of exchangeable H^+ in a given soil ([Table 4.2](#)). [Table 4.3](#) shows the expected pH range for most agricultural soils.

Reaction

The numerical designation of reaction is expressed as pH. With this notation, pH 7 is neutral. Values lower than 7 indicate acidity; values higher, indicate alkalinity. Most soils range in pH from slightly less than 2.0 to slightly more than 11.0, although sulfuric acid forms and pH may decrease to below 2.0 when some naturally wet soils that contain sulfides are drained.

The descriptive terms to use for ranges in pH are as follows:

Ultra acid	< 3.5
Extremely acid	3.5-4.4
Very strongly acid	4.5-5.0
Strongly acid	5.1-5.5
Moderately acid	5.6-6.0
Slightly acid	6.1-6.5
Neutral	6.6-7.3
Slightly alkaline	7.4-7.8
Moderately alkaline	7.9-8.4
Strongly alkaline	8.5-9.0
Very strongly alkaline	> 9.0

Table 4.3. pH ranges and degrees of acidity of alkalinity for mineral soils

How is Soil pH Determined?

The most common technique for determining pH is with a pH meter, using glass and reference electrodes. Before electronic devices were available, color indicators were used. These were dyes which changed color at certain pH values. Kits containing mixed indicator dyes are still available. The degree of accuracy varies but most are not as accurate as pH meters, especially for soil.

The pH in a [soil sample](#) will vary, depending on handling and sample preparation. It would be best to determine soil pH within the range of moisture content found in the field. This is not possible with current pH meters. With laboratory pH meters, the standard ratio of soil:water used is 1:1.

Why Does Soil pH Change?

Several factors influence soil pH. Some of these are:

1. **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.
2. **Precipitation.** As annual precipitation increases, leaching of Ca and Mg increases, allowing the pH to decrease. For example, most Nebraska soils were formed from a calcareous parent material; however, increased precipitation in the eastern part has moved the lime layer deeper in the soil than in western Nebraska, where the lime layer is still at the surface. When moving from east to west across the state the pH goes from acid to alkaline.
3. **Native vegetation.** Soils formed under prairie (grasses) tend to be less acid than soils formed under forests. Residue from coniferous (evergreen) trees is more acidic than from deciduous (broadleaf) ones. Further, roots of growing plants produce CO_2 and small amounts of organic acids which increase soils acidity.
4. **Crop grown.** Legumes remove more calcium and magnesium (replaced with hydrogen) than some grasses, such as corn or sorghum. Removing the basic cations decreases OH^- ions and increases H^+ thus lowering the pH.
5. **Nitrogen and other acid forming fertilizers and organic material (manure, crop residue and soil organic matter).** These are all potential sources of H^+ which lowers the pH. Nitrogen sources such as [anhydrous ammonia](#), [ammonium nitrate](#) and [urea](#) require about 1.8 pounds of CaCO_3 per pound of actual nitrogen to neutralize the H^+ when the nitrogen is converted to NO_3^- . All nitrogen fertilizers have an acidifying effect.
6. **Burning fossil fuels.** Acid rain? This is not a serious problem for most agricultural production areas of Nebraska. However, the acidifying effect of nitric and sulfuric acids from burning fossil fuels has and can seriously influence the vegetation in industrial areas where the acid-forming compounds are not removed from gases released from burned fossil fuels.
7. **Irrigation water.** Irrigation water pumped from groundwater sources often has quite a bit of calcium and magnesium dissolved in it which makes it "hard water." This is a significant source of cations which offset the acidifying effects of fertilizer or organic matter.

Changing the Soil pH

Lowering soil pH

For other than small areas or for extremely high valued crops, it probably is uneconomical to attempt to reduce soil pH. For example, the amount of [elemental sulfur](#) required to reduce soil pH depends on [soil texture](#) and the amount of free calcium carbonate (lime) in the soil.

Raising Soil pH

Liming: Liming acid soils to improve productivity has been a management practice for over 20 centuries. Lime is applied primarily to reduce soil acidity. Calcium deficiency has not been observed affecting plants in Nebraska. The preferred range of soil pH for most crops has already been discussed ([Table 4.1](#)).

In review, the possible benefits from liming acid soils are:

1. Increased microbial activity, resulting in the release of some plant nutrients.
2. Increased availability of nutrients such as [phosphorus](#), molybdenum, [potassium](#), calcium and magnesium.
3. Increased [nitrogen](#) fixation for legumes by symbiotic bacteria.

4. Alfalfa and sweet clover are easier to establish at pH of 6.5 or above.
5. Reduction of aluminum and manganese toxicity on certain strongly acid sands. This is not yet a recognized problem in Nebraska.

To Lime or Not to Lime?

The first question concerning lime application is, 'Is it going to be profitable?' Unfortunately, the answer is not a simple "yes" or "no," but an "it depends." For example, first consider the amount of lime in the irrigation water and depth to the soil's lime layer. In general, for corn, soybean, wheat and milo production, the probability of an economical response is usually greater than 50 percent when the soil pH goes below 5.6.

In brief, a [soil test](#) is always necessary to determine how much lime to apply. Take care to not over-lime soils. (Sandy soils require less lime and are easier to over-lime than finer textured soils). The lime recommendation given is the amount of 60 percent Effective Calcium Carbonate lime material needed to raise the soil pH to 6.5 in a 6-inch depth of soil. More lime is required if the incorporation depth will be deeper.

No Tillage: No-till fields frequently have pH values of 5.6 or below in the top 1 to 3 inches. In these situations, reduced rates of lime can be broadcast or the producer can apply the regular rate of lime just prior to tillage.

Liming Materials

The most common material used for liming soils is ground limestone. Limestones range from pure calcium carbonate to mixtures of calcium carbonate and calcium-magnesium carbonate (dolomitic limestone).

Quality of Agricultural Limestone

Effective Calcium Carbonate (ECC) is evaluated on its ability to neutralize soil acidity, that is, to effect a change in the pH of the tillage layer of the soil within a specified time. Generally a three-year base is used.

The criteria used for determining quality of ag lime are:

1. Purity — neutralizing power as percent calcium carbonate.
 2. Fineness of grind — measured by percent passing 8 and 50 mesh sieves.
 3. Water content — does not directly influence ECC but it does influence the amount of material to apply.
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Nitrogen as a Nutrient

In this lesson, you will be able to describe the forms of nitrogen found in the soil. The nitrogen cycle and how nitrogen is lost in the environment will be thoroughly discussed. Forms of nitrogen utilized by the plant and the concept of nitrogen credits for such factors as legumes, manure, residual soil nitrogen, and irrigation water will be introduced.

Biological Fixation of Nitrogen

The primary means by which [nitrogen](#) is added to [soil](#) are biological [nitrogen fixation](#) and atmospheric deposition. Fixation is the conversion of dinitrogen gas, which is chemically quite unreactive, to nitrogen combined with other elements, such as oxygen or hydrogen, which can readily undergo chemical reactions.

The atmosphere contributes about 11.4 pounds of nitrogen per acre to soils annually (Stevenson, 1982). Biological nitrogen fixation accounts for 8.2 pounds or about 72 percent of the nitrogen contributed per acre per year. Biological nitrogen fixation occurs symbiotically (dinitrogen-fixing bacteria, such as *Rhizobium* bacteria 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 nitrogen (NH₄⁺), nitrate nitrogen (NO₃⁻), and nitrite nitrogen (NO₂), deposited in precipitation. The amount of nitrogen added each year

from atmospheric deposition varies considerably with [climate](#) and nearness to industrial sources of atmospheric nitrogen, but generally this deposition is too small to significantly affect crop production.

Forms of Nitrogen in the 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) 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 as you move south and east in the Great Plains.

Through thousands of years of development, soils in the Midwest have accumulated significant quantities of organic matter. Yet, organic matter levels have declined due to the cultivation of virgin soils. This has increased organic matter oxidation and decreased soil organic matter nitrogen for crop uptake ([Figure 5.1](#)). Soils that once contained 4 to 5 percent organic matter may contain only 1 to 2 percent 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 judicious fertilizer use may help maintain or slightly increase organic matter levels with time.

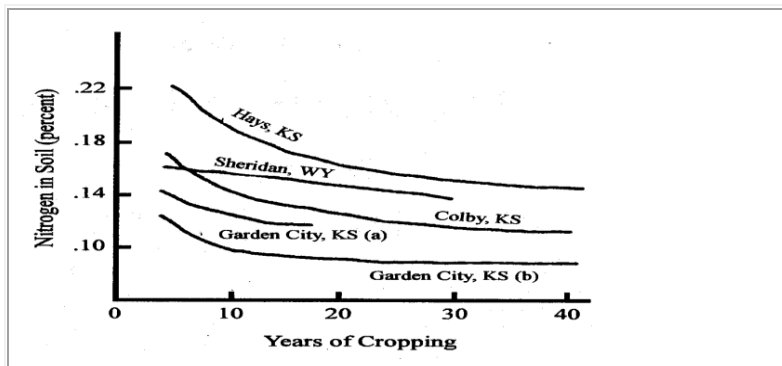


Figure 5.1.
The influence of tillage on organic nitrogen in soils in the Midwest. [Adapted from Hase, et al. (1957)]

The Nitrogen Cycle

Ammonium (NH_4^+) and nitrate (NO_3^-) are the predominate inorganic forms of nitrogen in soils. Ammonium exists in exchangeable and nonexchangeable forms. Nitrite (NO_2) 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 5.2](#)) shows reactions that various inorganic nitrogen compounds undergo in soil. The nitrogen cycle, as typically described, 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](#).

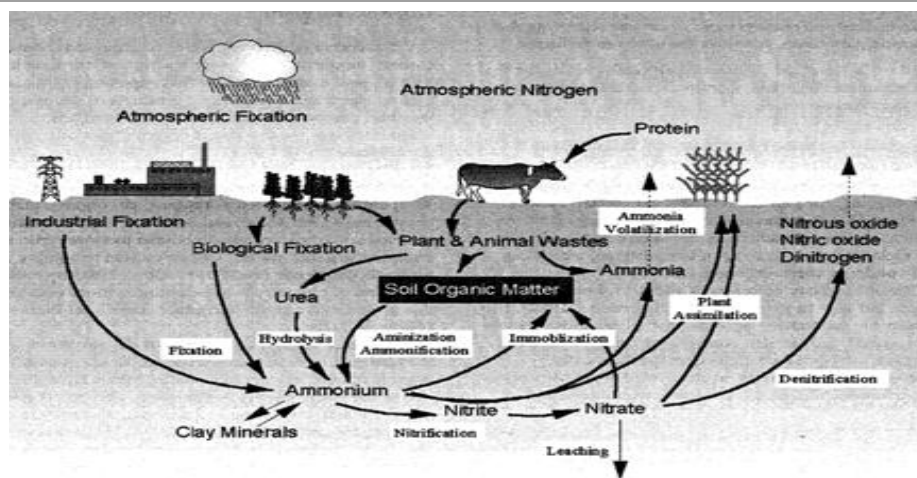
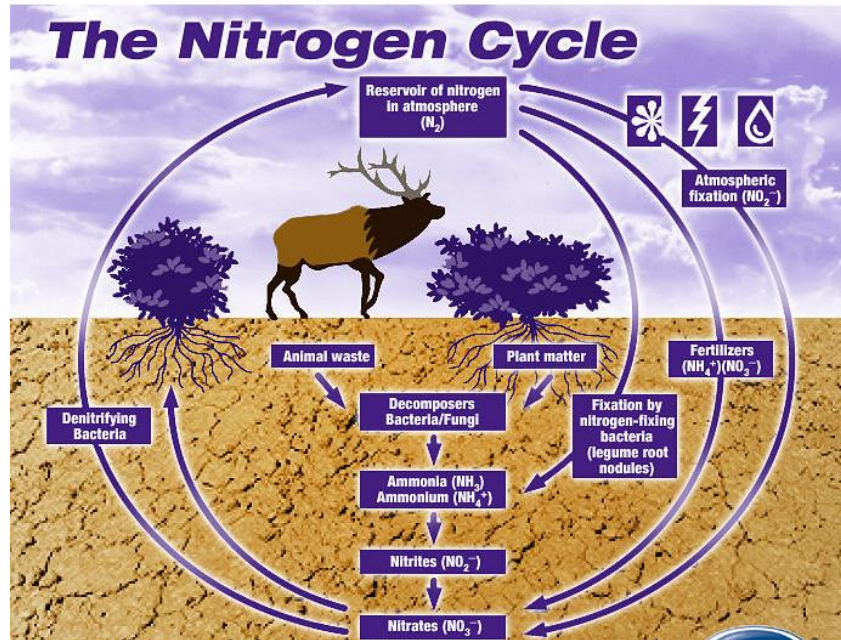


Figure 5.2. The nitrogen cycle

Nitrogen Cycle

- * ~79% of air is N₂ gas
- * N is essential to plants and animals
- * Plants and animals can't use N₂ gas
- * Usable N: ammonia (NH₃) or nitrate (NO₃⁻)
- * Conversion of atmospheric N₂ to NH₃ and NO₃⁻:
 - *Nitrogen fixation*
 1. Aquatic ecosystems: blue-green algae
 2. Terrestrial ecosystems: bacteria on root nodules of legumes (peas, beans, alfalfa, clover)
 3. Lightening
- * Nitrogen RETURNS to soil by:
 1. decomposition of once living things
 - ammonifying bacteria + fungi
 2. exists in soil as nitrate (NO₃⁻), nitrite (NO₂⁻), and ammonia (NH₃)
- * Nitrogen returns to atmosphere by:
 1. denitrifying bacteria

Nitrogen Cycle and Humans:

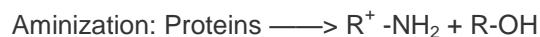
1. Nitrogen required for genetic materials (DNA, RNA, amino acids)

Nitrogen Fixation

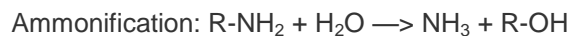
As described earlier, fixation is the process of converting dinitrogen gas to chemically reactive forms — where nitrogen combines with other elements such as oxygen, hydrogen, and carbon. These forms are dependent on fixation. Lightning fixes nitrogen into various oxides that rain and snow deposit. Typically, this is 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.

Nitrogen 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 (CO₂). For example, urea is an amide added directly to soil either in animal urine or as commercial fertilizer.

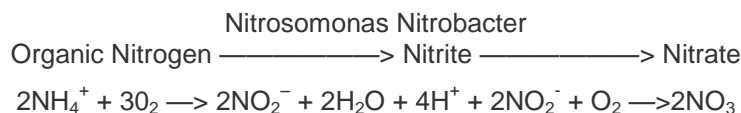


Ammonification is the second step of mineralization in which amino (NH₂) groups are converted to ammonium. Again, microorganisms (primarily autotrophic) accomplish this action.



Nitrification

Microbial activity is also responsible for the two steps of **nitrification**. Nitrosomonas (obligate autotrophic bacteria) convert ammonium to nitrite. 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.

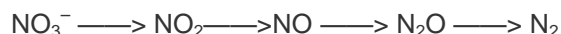


Mineralization and nitrification are influenced by environmental factors that affect biological activity such as temperature, moisture, aeration, [pH](#), and so forth. Nitrification, for example, occurs very slowly at cold temperatures and ceases once the temperature declines below freezing.

Denitrification

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

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



Denitrification losses from saturated soil will vary with temperature and the amount of carbon (organic matter) available. [Table 5.1](#) illustrates the effect that time and temperature can have on potential nitrogen losses from denitrification.

<i>Time (days)</i>	<i>Temperature (degrees F)</i>	<i>Nitrogen loss (percent)</i>
3	75 - 80	6
5	55 - 60	10
10	55 - 60	25

Ammonia Volatilization

Ammonia (NH₃) 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 is lost as a gas.

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 on the surface are ideal conditions for ammonia loss. Precipitation or irrigation of 1/2 inch or more is adequate to move urea far enough into the soil to minimize volatilization loss.

Nitrogen Leaching

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 nitrogen form most susceptible to leaching](#). Nitrate leached below the root zone (four to six feet) for most agronomic crops will eventually leach downward until it reaches a saturated zone. Nitrate leached below four to six feet is generally unrecoverable by most crops except deep rooted species such as alfalfa.

Immobilization

Immobilization, or the temporary tying up of inorganic nitrogen by soil microorganisms decomposing plant residues, is not strictly a loss process. Immobilized nitrogen will be unavailable to plants for a time, but will eventually become available as residue decomposition proceeds and populations of microorganisms decline ([Figure 5.5](#)). 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.

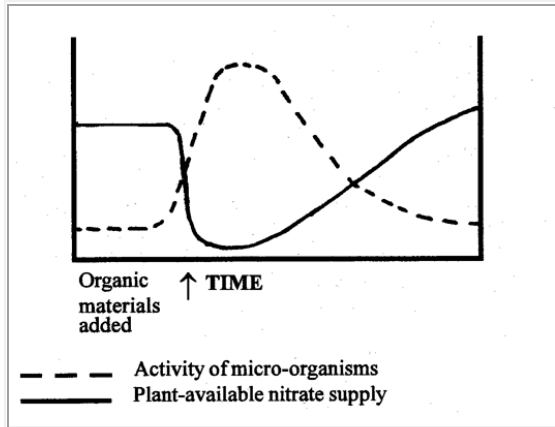


Figure 5.5.
Levels of nitrogen available to plants based on microbial decomposition.

The duration of the nitrate depression period during immobilization depends 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 about 50 percent carbon and 5 percent 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.

When a plant residue with a wide C:N ratio is incorporated into the soil, microbial decomposition starts. Microorganism populations increase greatly, evidenced by increased release of CO₂ leaving the soil through respiration. The microorganisms take nitrogen from the soil for proteins. Consequently, for a time the concentration of inorganic nitrogen in the soil declines, and may be deficient for plant growth. As residue decomposes, the C:N ratio narrows. At a ratio of approximately 17:1, nitrogen becomes available for plant use. Decomposition continues until the ratio is approximately 11:1 or 10:1.

Table 5.2. Typical carbon-to-nitrogen ratios for selected organic materials

Source	C:N Ratio
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

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.

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 closely as possible to the time of crop uptake. Ideally, nitrogen might be applied several times during a growing season.

Nitrogen Accounting and Credits

Efficient nitrogen fertilizer use requires that the producer give proper credit for non-fertilizer nitrogen sources before determining the nitrogen rate. Significant nitrogen sources include soil organic material and soil residual nitrate (determined by 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 testing irrigation water). 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

When possible, the farmer should rotate crops such as corn and grain sorghum that heavily use nitrogen with crops 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 after soybeans is not because of the additional nitrogen in the soil from the soybeans, but because the low C:N ratio of soybean residue immobilizes less soil nitrogen and mineralizes nitrogen from residue sooner the next 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 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 after corn. Implementing a corn-soybean rotation in 1984.

Summary

Nitrogen is usually the nutrient most limiting 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 by 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.

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Phosphorus and Potassium in the Soil

This lesson explains the importance of phosphorus fixation and describes methods for applying phosphorus and the advantages (and disadvantages) of each. It also describes the three forms of potassium and how form determines availability of potassium to plants.

Phosphorus

Next to [nitrogen](#), [phosphorus](#) (P) is by far the most limiting nutrient in Nebraska for crop production. However, while nitrogen is limiting on most all soils for grain crops, native levels of phosphorus are adequate in many of Nebraska's soils even for irrigated corn. This makes it important to know when to use phosphorus fertilizers and how to manage them for maximum effectiveness. If not, the return of the fertilizer investment is, for all practical purposes, lost.

Importance of Phosphorus to Plants

Phosphorus is a component of the complex nucleic acid structure of plants, which regulates protein synthesis. Phosphorus is, therefore, important in cell division and development of new tissue. Phosphorus is also associated with complex energy transformations in the plant.

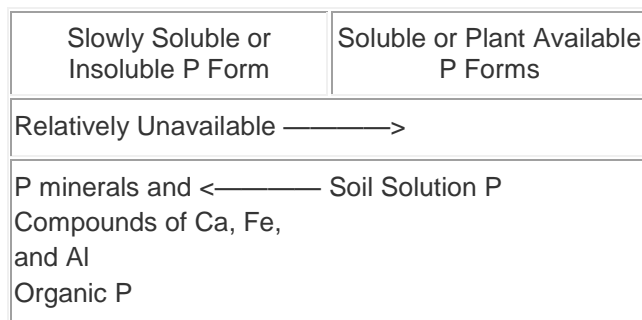
Adding phosphorus to soil low in available phosphorus promotes root growth and winter hardiness, stimulates tillering, and often hastens maturity.

Plants deficient in phosphorus are stunted in growth and often have an abnormal dark-green color. Sugars can accumulate and cause anthocyanin pigments to develop, producing a reddish-purple color. This can sometimes be seen in early spring on low phosphorus sites. These symptoms usually only persist on extremely low phosphorus soils. It should be noted that these are severe phosphorus deficiency symptoms and crops may respond well to phosphorus fertilization without showing characteristic deficiencies.

The Soil Phosphorus Problem

Phosphorus is adsorbed by plants in the ionic forms H_2PO_4^- and HPO_4^{2-} . General knowledge of ion exchange in soils would predict that these anions are not retained by the negative charged soil colloids, but move in the soil similar to nitrogen. However, phosphorus does not leach. In fact, it moves very little, even with large amounts of precipitation or irrigation. The reason for this apparent anomaly is that the soil solution contains only a very small amount of available phosphorus in these ionic forms at any one time. In fact, most soils contain less than 0.00005 grams phosphorus per liter or 0.0000068 ounces phosphorus per gallon of soil. It has been estimated that the phosphorus in the soil solution must be replenished on an average of about twice every day for normal crop growth. This is the basic phosphorus problem — to adequately re-supply the soil solution as the crop roots remove available phosphorus from the soil solution. It is the soil's ability to re-supply the soil solution that dictates whether the crop will need additions of fertilizer phosphorus and whether those additions will be effective in the forms applied.

The ability of the soil to re-supply the soil solution with phosphorus is dependent on the complex chemistry of the soil system. However, the system can be viewed very simply with the following diagram:



This is an equilibrium reaction. As soil solution phosphorus is removed by crop roots, more phosphorus becomes available from the slowly soluble sources. However, if soluble fertilizer phosphorus is placed in the soil, it reverts into slowly soluble or insoluble forms, removing soluble phosphorus from the soil

solution. This phenomenon is often called “fixation.” **Fixation** is the primary reason why placement of phosphorus fertilizer is important. Placement of phosphorus is an attempt to limit fixation. This is done by banding the phosphorus fertilizer near the seed or by dual placement with [anhydrous ammonia](#) bands. The goal is to limit soil-fertilizer contact, while placing available sources of phosphorus from the fertilizer in a position of a high probability root contact.

The above relationship is sometimes shown in terms of labile and [non-labile phosphorus](#) forms according to the following relationship:



In this relationship, **non-labile phosphorus** refers to slowly available forms, while **labile phosphorus** is an intermediate form that is rather weakly adsorbed or bound to various compounds and clay in the soil (solid phase). This is the primary phosphorus source supplying the soil solution.

The equilibrium relationship shown above between non-labile or insoluble phosphorus forms and labile phosphorus is affected by many factors, such as size of the slowly available pool, soil temperatures, kind of compounds in the pool, kind and amount of clay in soil, and the [pH](#) of the soil solution. [Figure 6.1](#) shows the general relationship between soil pH and phosphorus availability, which is based on the kinds of phosphorus compounds associated with the various pHs. At high soil pH, most phosphorus is in the form of calcium compounds. At low or acid pH, phosphorus is combined with iron and aluminum compounds. Maximum phosphorus availability occurs at a soil pH between 6.5 to 7.0. This is why one of the most important benefits of liming acid soils is improving phosphorus availability. Reducing the pH of calcareous soils would also increase the availability of phosphorus in the soil solution by changing some of the solid phase compounds into compounds of higher solubility. Sulfur will reduce the soil pH; however, the cost is prohibitive for field crops because of the high sulfur rates required.

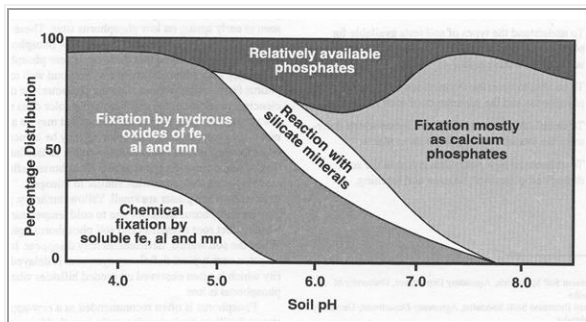


Figure 6.1.
Soil phosphorus compound in relation to soil pH.

[Figure 6.2](#) characterizes phosphorus additions and removals from the soil system in addition to the inorganic minerals. Organic phosphorus in the form of plant residues, manures, or from the [soil organic matter](#) can contribute greatly to the phosphorus in the soil solution for crop growth. In some soils organic phosphorus can contribute 50 percent of the available phosphorus. Since availability of organic phosphorus is dependent on decomposition of the organic matter, soil temperature and moisture are important factors regulating how fast organic phosphorus is made available.

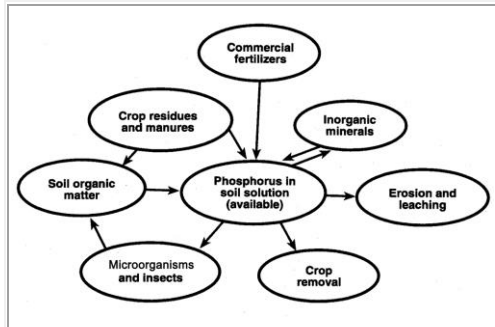


Figure 6.2.
Relation of additions and losses of phosphorus in a soil system.

As previously indicated, available or soil solution phosphorus can revert to slowly soluble mineral forms. This fixation may also occur when available phosphorus is used by microorganisms in the decomposition of residues. This type of fixation is called immobilization and can be either long- or short-term.

The Plant Problem

While the soil system limits the amount of phosphorus in the soil solution at any one time and limits its re-supply, the plant root also has its problems. The concentration of roots in the soil volume is relatively small. It has been calculated that roots contact only about one percent of the soil volume. Phosphorus enters the root primarily by diffusion (90-98 percent), which can occur only if the phosphorus is very close to the root. Very little phosphorus enters the root by mass flow in the water (one percent). Root growth is essential for adequate phosphorus uptake or the soil solution needs to be replenished frequently. Actually since roots contact such a small amount of the soil, the soil solution in the areas of root contact must be replenished more often than twice a day or phosphorus deficiencies will occur. This makes the labile forms (those weakly bound to compounds or clay) very important in soil phosphorus supply.

Summary

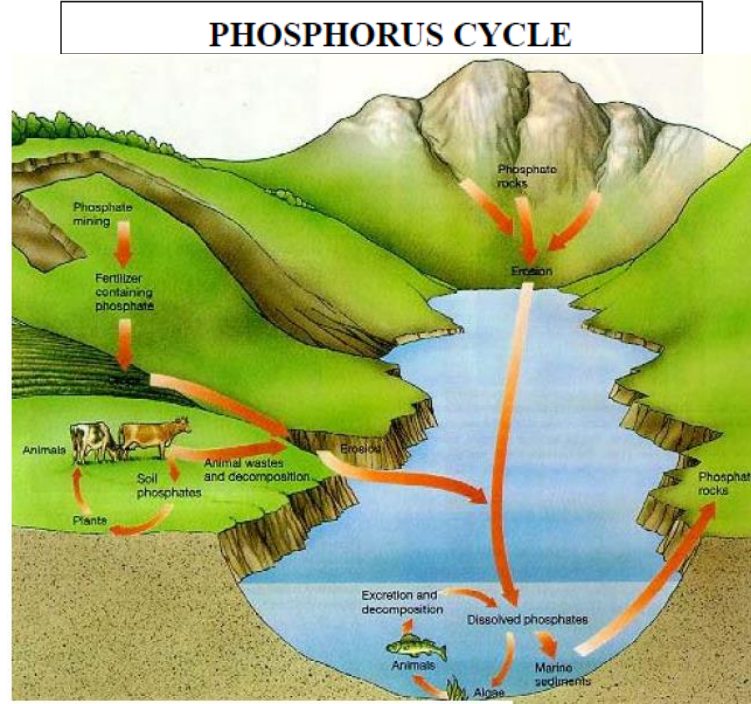
Soil phosphorus is relatively stable in soil. It moves very little when compared to nitrogen. In fact, this lack of mobility is due to the rather limited solubility of soil phosphorus compounds. Because of the limited solubility of these compounds, fertilizer phosphorus will become much less available as it reverts back to soil phosphorus compounds. Fertilizer phosphorus that reverts back to soil phosphorus compounds is not lost completely, but becomes slowly available to crops over several years. The rate depends greatly on soil type. For most Nebraska soils, applying more fertilizer phosphorus than needed for optimum yields is probably not economically justified.

Phosphorus availability is controlled by three factors: soil pH, amount of organic matter, and proper placement of fertilizer phosphorus. Acid soils should be limed to bring soil pH up to nearly 6.5. The pH of alkaline soils (over 7.0) probably cannot be practically lowered for better phosphorus availability.

Organic matter maintenance is an important factor in controlling phosphorus availability. Mineralization of organic matter provides a steady supply of available phosphorus. Organic soil phosphorus may represent 30-40 percent of the phosphorus available to Nebraska crops, and may be a major factor affecting phosphorus availability during wet, cold springs.

Placement of phosphorus is the best practical control of phosphorus availability. Placing phosphorus with seed wheat has given much better results than broadcast applications. Banding phosphorus two inches to the side and two inches below the seed of row crops provides a ready source of phosphorus for the

young seedling; however, soil phosphorus must be deficient before yields can be expected to be increased.



Phosphorus Cycle

* **Major environmental reservoir:** rocks

1. Leaching: water dissolves phosphates in rocks and carries to lake, stream, etc.
2. Dissolved phosphate: used by plants and passed through food chain
3. **Animals return phosphorus to environment by:**
 - * excretion
 - * death and decay

Phosphorus Cycle and Humans:

1. **Phosphates mined for fertilizers** → returns P to soil
2. **Erosion:** P in soil and rocks washed away into water systems

Potassium

Potassium (K) is an essential plant nutrient. Because it is required in large amounts by plants, [potassium](#) is referred to as a macronutrient (Black, 1957). The terms primary and secondary elements also refer to [macronutrients](#).

The major portion of potassium is contained in minerals such as feldspar and mica, and clays such as montmorillonite, vermiculite and illite. The total amount of potassium is important. However, of immediate concern to crop production is the portion of this nutrient that is in an exchangeable (available) form for plant use. Potassium is an exchangeable cation. The potassium ion has a positive charge and binds with the negatively charged soil particles.

Potassium is absorbed by plants in larger amounts than either magnesium or calcium; in fact, nitrogen is the only nutrient absorbed in larger amounts than potassium. Potassium is a vital component of

numerous plant functions, including nutrient absorption, respiration, transpiration, and enzyme activity. Potassium is unique because it does not become part of plant compounds, but remains in ionic form in the plant. Potassium remaining in plant residues after harvest and in manure are quickly returned to the soil by water leaching through the plant materials and manure.

Source

Nebraska soils are “mineral” soils, which implies that these soils were formed from minerals such as feldspar, mica, hornblends, etc., and secondary minerals and clays. Because different minerals contain varying amounts of potassium, and since all soils are not formed from the same minerals, it is important to note that soils differ in their ability to supply potassium to a growing crop. Evidence of this variability is shown in [Table 6.1](#).

The most commonly used chemical extracting agent to estimate exchangeable and solution potassium is 1/10 molar ammonium acetate at pH 7. However, this test does not measure total potassium in the soil. The reported value from the chemical analysis is an index of the soil’s ability to supply potassium to different crops. [Table 6.1](#) indicates the difference in exchangeable potassium, as determined by the potassium soil test for soils found in various parts of the Midwest. It can be seen that soils vary in their ability to provide extractable potassium to the crops being grown.

Form and Availability

The behavior of each plant nutrient in soil is unique. Each nutrient’s behavior is a combination of attributes that depends on the parent minerals involved and the solubility and mobility of the nutrient in question. Potassium, unlike nitrogen and phosphorus, is not associated to any great extent with organic matter. Total amounts of potassium in soil will vary from 0.3 to more than 2.5 percent. While total content of potassium is important, it is of little value in determining how well a given soil can supply potassium to growing plants. The general terminology used to describe potassium is shown in [Figure 6.3](#).

1. Relatively Unavailable Forms

Depending on soil type, from 90 to 98 percent of soil potassium is in this form. Minerals containing most of the potassium are feldspar and mica. These minerals are the source of soil potassium, and they release potassium very slowly to the more available forms as they weather and break down.

Figure 6.3. Three forms of soil potassium

Relatively unavailable K ←	↔ Slowly available K ↔	↔ Readily available K
90-98 percent of total	1-10 percent of total	1-2 percent of total
Non exchangeable K	Exchangeable K (90 percent of 2 percent)	
	Soil Solution K (10 percent of 2 percent)	

2. Slowly Available Forms

Potassium in this form is part of the internal structure of the clay minerals forming the colloidal fraction of the soil. Slowly available potassium cannot be replaced by ordinary cation exchange processes and is referred to as “non-exchangeable” potassium. As shown in Figure 6.3, this form is in equilibrium with the available forms and, consequently, acts as an important reservoir of slowly available potassium. An equilibrium exists between “non-exchangeable,” “exchangeable” and “soil solution potassium,” as shown by the arrows in Figure 6.3. Because of this equilibrium, it is possible for some of the potassium applied as fertilizer to be temporarily converted to the “non-exchangeable” form. This is an important reaction in that it helps reduce leaching of potassium from applied fertilizer, especially on sandy soils.

3. Readily Available Forms

Readily available potassium is composed of exchangeable potassium and potassium in the soil solution. Exchangeable potassium is absorbed on the soil colloid surfaces and is available to plants. However, higher plants obtain most of the potassium from the soil solution phase.

The equilibrium between these different forms of potassium is “dynamic.” That is it is always changing; thus, that portion of the total potassium in the different forms ranges from one to two percent for readily available; one to ten percent for slowly available; and 90 to 98 percent in unavailable form.

Table 6.1. Exchangeable potassium for crop producing soils from different areas¹

Soil depth inches	Soil type and location		
	<i>Clarion silt loam Story County, Iowa</i>	<i>Hall silt loam Dawson County, Nebraska</i>	<i>Thurman loamy sand - Merrick County, Nebraska</i>
	<i>Exchangeable potassium (lbs./acre 6 inches)²</i>	<i>Exchangeable potassium (lbs./acre 6 inches)²</i>	<i>Exchangeable potassium (lbs./acre 6 inches)²</i>
0-6	143	1,488	247
6-12	97	992	156
12-18	61	725	87
18-24	33	712	72
24-30	30	1,020	71
30-36	33	1,358	89
Total	397	6,295	722

¹North Central Regional Potassium Studies, Research Bulletin 494, Iowa State University, Ames, Iowa

²Determined on field moist samples, Iowa State Soil Testing Lab.

Table 6.2. Relative proportions of total potassium in available and unavailable forms

<i>Forms of potassium</i>	<i>Percent of total potassium</i>	<i>Pounds per acre in six inches</i>
Readily available	2	247
Slowly available	8	1235
Relatively unavailable	90	12,103

Factors Influencing Potassium Behavior in Soil

The exact mechanism by which some of these factors influence the reaction of potassium in soil is not clearly understood. Some factors that are known to influence potassium in soil are: (1) soil type, (2) temperature, (3) wetting and drying cycles, (4) pH and (5) aeration and moisture.

Fortunately, the majority of Nebraska's soils abound with minerals that readily release potassium from the non-exchangeable form. Also, most of Nebraska's soils are rich in potassium-bearing minerals throughout the subsoil, which reduces the influence of factors, such as temperature and moisture content.

Normally, as the topsoil dries, potassium becomes less available to plants. However, with abundant potassium in the subsoil, lack of availability is not a problem. Some of the sandy soils in Nebraska do not have abundant potassium in the subsoil; and, thus, the soil test for potassium is more important on these soils.

Losses of Soil Potassium

Potassium losses are caused by:

1. Crop removal
2. Fixation
3. Leaching

Fixation and leaching are not serious problems for Nebraska soils. As was previously discussed, fixation can result in temporary “tie-up” of potassium. Over a period of time, however, potassium eventually becomes available. Leaching is not a problem on silt and loam soils, but can be a problem on sandy soils.

By far, crop removal accounts for the largest loss of potassium from soil. In general, potassium content of grain is less than straw or stover. Corn cut for silage would remove about 195 pounds of potassium per acre. Much of this could be returned in the form of animal manure applications from the livestock operation. Corn harvested for grain would leave the stover in the field; and, since potassium is water soluble, it would be quickly returned to the soil. [Table 6.3](#) shows rates of potassium removal for common crops grown in Nebraska.

Table 6.3. Average Removal of Potassium by Crop Production

<i>Crop</i>	<i>Yield</i>	<i>K₂O Removed Pounds/Acre</i>
Corn	150 bushels/acre	35
Grain stover	6300 bushels/acre	160
Wheat	60 bushels/acre	15
Grain Straw	5000 bushels/acre	90
Soybeans	50 bushels/acre	70
Alfalfa	4 tons/acre	100

Summary

The nature of soil potassium can be summarized by [Figure 6.4](#). Available soil potassium is found associated with the clay complex and soil solution. It is in equilibrium with the slowly available minerals, which are constantly supplying available potassium. Potassium is added by fertilizers and crop residues. Fertilizer potassium may be fixed and become slowly available; it may be lost by crop removal, leaching and erosion.

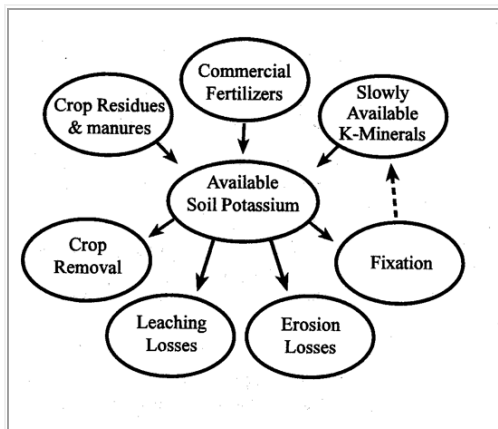


Figure 6.4.
Available potassium in relation to additions and losses.