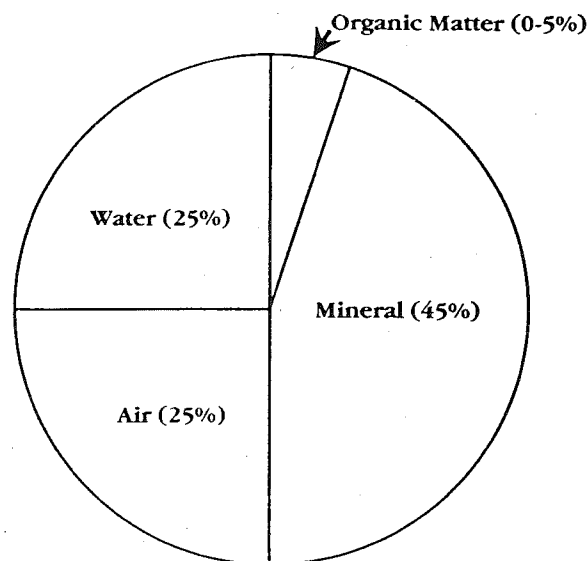


SECTION I

AN INTRODUCTION TO SOIL

Soil is a complex natural material made of disintegrated rocks and decayed organic material which provides nutrients, moisture, and support for land plants. Soil is a three-phase system of solid (minerals and organic materials), liquid (water), and gas (air) as shown below.

Phases of Soil



PHYSICAL PROPERTIES OF SOIL

Soils are usually characterized by their **physical and chemical** properties. These properties determine how productive the soil will be.

Texture: The relative proportions of sand, silt, and clay. Sand, silt and clay are known as the soil separates.

Structure: The aggregation of soil particles into definite forms that are characteristic of a soil's history and composition.

Density: How compact the soil is; the mass of a soil divided by its volume.

Porosity: The amount and size of space between soil particles; related to soil compactness and the bulk density of the soil.

Consistency: The ability of soil particles to stick together. This is related to the amount and type of clay in the soil and is a measure of the soil's behavior under mechanical stress.

Color: A measure of value, chroma, and hue. It indicates a soil's composition and history. Soil color is determined using the Munsell Color Chart (available through agricultural supply companies).

Temperature: Degree of hotness or coldness which contributes to the success of microbial and chemical activity and seed germination.

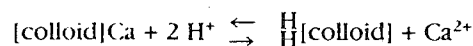
CHEMICAL PROPERTIES OF SOIL

Cation Exchange

The USDA Soils Laboratory defines cation exchange as the interchange of a cation (positive ion) in the soil solution with another cation on the surface of colloidal clay or humus. Essential nutrient cations in the soil colloids include calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and non-essential nutrient cations like hydrogen (H^+), aluminum (Al^{3+}), and sodium (Na^+).

These ions maintain ionic equilibrium with cations in the soil solution. The cationic exchange at the soil-water interface is regulated by the type and quantity of ions present. Cations on the soil colloids are referred to as "exchangeable" because they can be available for plant growth. Although more dilute than those contained on the soil colloids, nutrients in solution are directly available for plant use.

A simple cation exchange reaction is illustrated below in a soil with high levels of adsorbed calcium and optimum temperature and moisture conditions:



The hydrogen ions are supplied by organic decay that results in mineral and organic acids. The H^+ ions replace the Ca^{2+} ions on the colloid because there are more of them and they are held more strongly than calcium ions by the colloid.

If the soil became less acid (less H^+) or limestone was added to the soil (increases Ca^{2+}), the reaction would occur in the opposite direction. On the other hand, if the soil became more acid or calcium was removed by leaching or crop use, the reaction would proceed to the right at a faster rate.

In real conditions, the colloid has many cations on its surface. When there is enough rain to remove calcium from the soil, the reaction will proceed to the right. In low rainfall climates, the reaction occurs less often, which keeps the soil at a pH 7 or more.

Cation Exchange Capacity (CEC)

Cation exchange capacity refers to the total number of cations a soil can adsorb through cation exchange. CEC is usually expressed as milliequivalents (meq) of cations per 100 grams of soil.

Sandy (coarse) soils usually have a low CEC. As the soil texture becomes more fine, CEC values generally increase. Soils also increase in CEC with an increase in organic matter content (humus).

CEC values are also affected by the type and amount of clay present. The young, expandable clays such as montmorillonite and vermiculite generally have higher CEC values than older nonexpanding clays like the kaolinites and illites.

Calcareous soils may or may not be associated with salt-affected soils. Due to the low solubility of CaCO₃, some soils are 30% lime and yet are not saline. Because calcareous soils will visibly effervesce (fizz) when exposed to 2.5 N hydrochloric acid, they are easily identified.

Salt-Affected Soils

These soils contain excess amounts of either soluble salts or exchangeable sodium or both.

Saline Soils

Although salinity does not affect the physical properties of soil, it is harmful because osmotic pressure can create an artificial drought. This occurs because increased salt in the soil solution reduces the availability of soil water to plants. In extreme cases, water can actually be drawn out of the plant due to osmotic pressure, resulting in dehydration and death. Saline soils are often called white alkali due to the white salt encrustations on the soil surface.

Sodic Soils

Sodic soils are soils in which the exchangeable sodium percentage is high enough to cause a change in soil flocculation. In extreme cases, sodium ions disperse the mineral colloids, which then form a tight soil structure. This structure slows the infiltration/percolation of water. The pH of the soil due to sodium-water hydrolysis can increase to greater than 8.5, which results in dissolution of organic matter in the soil. The dispersed humus is carried upward by capillary action, making the soil black. This type of soil is often referred to as black alkali, gumbo, or slick spots. Sodic soils frequently occur in semi-arid and arid regions in small irregular areas.

Saline/Sodic Soils

These salt-affected soils contain large amounts of soluble salts and a high percentage of exchangeable sodium. They are similar to saline soils in appearance and character except that the soluble salts are leached out by artificial drainage. After leaching the soluble salts, the soils become sodic and degrade in quality.

Saline soils do not respond to chemical amendments. Only leaching the salts through adequate drainage reclaims these soils. Saline/sodic and sodic soils do respond to calcium amendments and drainage. In the case of sodium-affected soils that contain high amounts of free lime, sulfur can be added as an amendment to reclaim the soil.

Chemical Criteria for Calcareous and Salt-Affected Soils

Soil Type	pH	ECe mS/cm*	SAR**
Calcareous	7.5-8.4	< 2.0	< 13%
Saline	< 8.5	> 2.0	< 13%
Sodic	> 8.5	< 2.0	> 13%
Saline/Sodic	< 8.5	> 2.0	> 13%

*The current standard unit of conductivity is milliSiemens which is equivalent to mmhos.
**SAR is the acronym for sodium adsorption ratio which predicts the degree of sodium accumulation on the soil colloids.

The above criteria assume that conductivity and SAR measurements are made on saturated paste extracts (EC_p). However, since it is very time consuming to obtain a saturated paste extract, a method for measuring conductivity in a 1:1 soil/water suspension has been recommended by the North Central Region - 13 Soil Testing Committee of the United States. The table below shows the relationship between conductivity and degree of salinity for the 1:1 method based on four broad categories of soil texture.

Texture	Degree of Salinity (1:1 Soil/Water Suspension)				
	Non Saline	Slightly Saline	Moderately Saline	Strongly Saline	Very Strongly Saline
	EC 1:1			mS/cm	
Coarse sand to sandy loam	0-1.1	1.2-2.4	2.5-4.4	4.5-8.9	9.0 +
Loamy fine sand to loam	0-1.2	1.3-2.4	2.5-4.7	4.8-9.4	9.5 +
Silt loam to clay loam	0-1.3	1.4-2.5	2.6-5.0	5.1-10.0	10.1 +
Silty clay loam to clay	0-1.4	1.5-2.8	2.9-5.7	5.8-11.4	11.5 +

Acid Soils

Acidic soils are usually found in humid regions and result from high rainfall (leaches lime and other metallic bases) and crop production. Crop production acidifies the soil in two ways. During plant growth, roots give off hydrogen ions which are acidic and must be neutralized by the soil lime. Second, most fertilizers (especially those containing ammonium nitrogen) are acidic in their soil reaction. For every pound (kilogram) of ammoniac nitrogen that is applied to the soil, 1.8-2.0 lbs (1.8-2.0 kg) of lime are dissolved and neutralized.

For soils that have little lime, acid can quickly overcome the buffering capacity of the lime. These soils become increasingly acidic and eventually release soluble aluminum, which results in further acidification and toxicity. Crop growth is reduced and lime must be applied to bring the soil back to profitable production. The soil analysis called "buffer pH" or "SMP buffer" predicts the amount of lime needed to bring the soil to a normal pH.

Soils With Problem Textures

Soils are made of particles that vary in size and shape. Scientists have grouped the particles by size, and refer to the groups as "separates." Soil separates range from very small clay particles to large sand particles. A loam soil is made of sand, clay, and silt particles. To estimate soil texture, the "feel" method is often used. See page 5 for this procedure.

Since soil separates vary so much in chemical make-up and crystal structure, they also vary in mineral and nutrient content. In addition, management of soil is influenced by soil type. The following table illustrates several management problems associated with soils of various textures.

Estimating Soil Texture

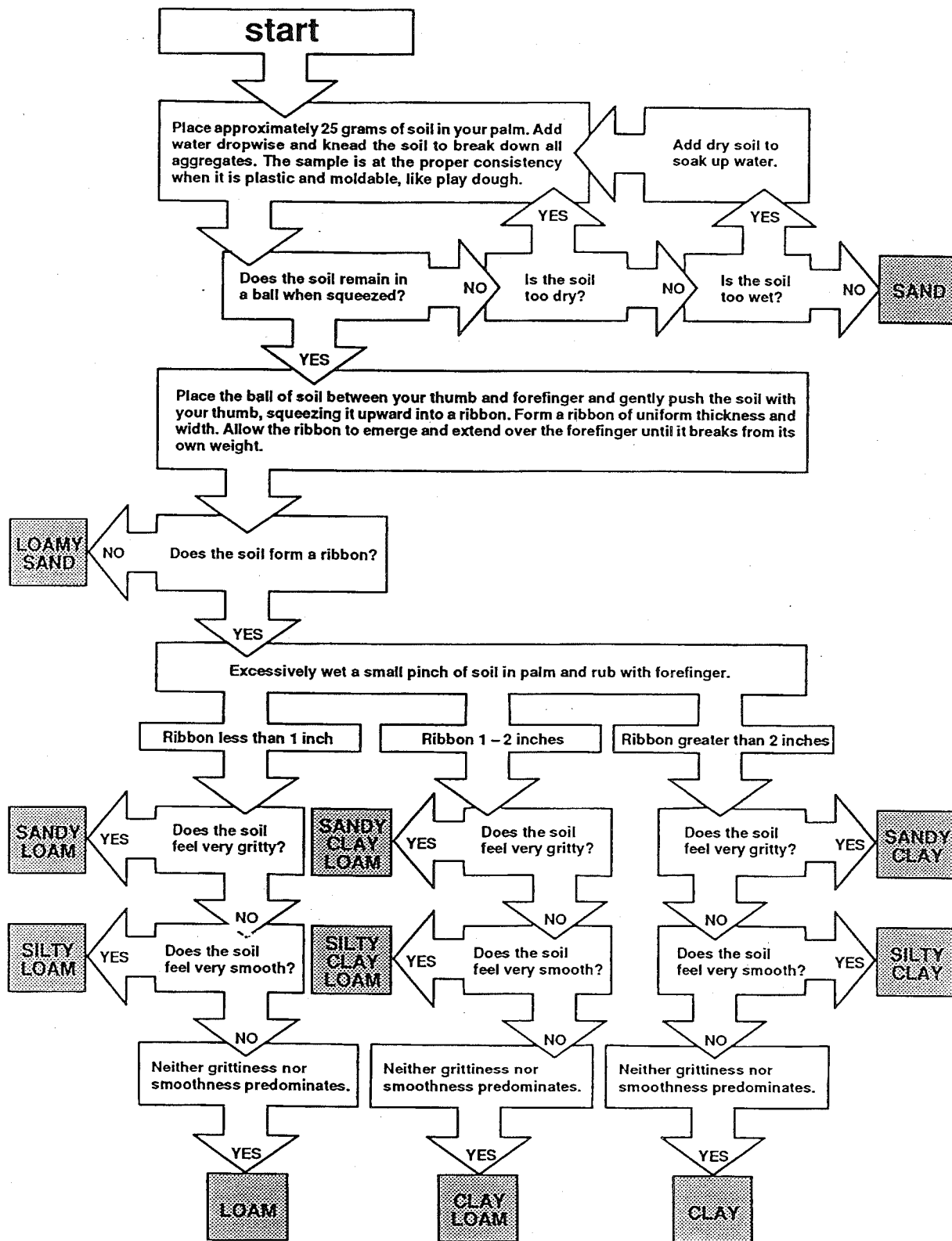


Chart developed by Dr. Steve Thein, Department of Agronomy, Kansas State University, Manhattan, Kansas

SOIL NITROGEN

Of the 16 essential nutrients, nitrogen is the nutrient most likely to be deficient worldwide. Nitrogen is used extensively in plant growth and must be present in the plant for cell division. Nitrogen is also vital to protein production in a biological system. Without nitrogen, cell division and protein synthesis stops and the plant eventually dies. Adequate nitrogen increases water use efficiency and absorption of other nutrients by the plant.

Many soils are deficient in nitrogen. To compensate for lack of nitrogen, many soils are over-fertilized. Ironically, over-fertilization often causes a decrease in profit, rather than an increase. Although plants require a certain amount of nitrogen, any nitrogen applied and not used by the crop is wasted. This excess nitrogen can contaminate groundwater supplies, currently a major environmental concern.

Nitrogen is used by plants in two forms, ammonium (NH_4^+) and nitrate (NO_3^-). Ammonium ions are present in soils through decomposition of organic tissue or manure application. Nitrate is the final form of nitrogen decomposition, but can also be supplied by fertilizers, irrigation and precipitation (*See Nitrogen Transformation in the Soil illustration*). Other sources are also shown in this illustration.

Available nitrogen is lost from soil in several ways:

a) Volatilization—Nitrogen fertilizer not properly tilled into the soil is lost in gaseous form to the air. This is especially true for alkaline soils during hot weather.

b) Anaerobic denitrification—When a soil is flooded, oxygen is absent (anaerobic) and nitrogen is converted to nitrogen gas (N_2) by anaerobic soil bacteria. The gas is then lost to the air.

c) Leaching—Excluding crop production, this is the most significant way to lose nitrogen from soil. Leaching occurs in areas of heavy rainfall or where irrigation is used.

Normally, ammonium (NH_4^+) does not leach from soil because the positive charge is attracted and “held” by the negative charge on the surface of clay and humus particles. However, when NH_4^+ is transformed to NO_3^- , the (+) charge is lost and the soil no longer attracts the available nitrogen. Water percolating through a soil profile leaches and depletes the mobile nitrate from the upper layers to the lower layers and even into the groundwater if leaching is excessive. *Excessive nitrate leaching is most likely in fields where overfertilization has occurred.*

Nitrate in groundwater is a major environmental and public health concern. High nitrate levels in drinking water (>10 parts per million) are linked with health problems (i.e., methemoglobinemia) resulting in miscarriage or “blue babies”.

Calculating Nitrogen Fertilizer Application

Before applying nitrogen fertilizer, consider a realistic yield goal and calculate the nitrogen requirement for the crop based on this goal. Subtract the following from the nitrogen requirement:

- residual nitrate in soil
- nitrate from irrigation
- nitrate from decay of organic matter
- nitrate released from animal and/or green manure

Example (U. S.)

A farmer expects a yield of corn to be 170 bushels per acre. The extension agent says it takes 2 lbs of N to produce 1 bushel of corn. So, the nitrogen requirement is $2.0 \times 170 = 340$ lbs of N/hectare.

Previously, the farmer applied 10 tons/acre of beef manure, which has about 14 lbs of nitrogen/ton. From the manure, 50% of the nitrogen is available during the first year after application. Testing shows the soil organic level* is 1.8%. At a depth of 24 inches**, nitrate-nitrogen measures 15 ppm (parts per million). Irrigation water† analysis shows nitrate-nitrogen levels at 6 ppm. The farmer usually uses 18 inches (1.5 acre feet) of irrigation water per hectare of land in a growing season.

*Organic Matter Nitrogen- % soil organic matter $\times 22 =$ approximate N mineralized/year (varies with location and soil texture)

**Residual Soil Nitrate- ppm nitrate in soil $\times 0.3 \times$ inches of sample depth = lbs/acre of available nitrate (0.3 is based on a soil bulk density of 1.2 g/cm^3)

†Irrigation Water Nitrogen- ppm nitrate in irrigation water = lbs N applied/acre ft of water irrigated.

Example Calculation

Residual Nitrate = $15 \text{ ppm} \times 24 \text{ inches} \times 0.3 = 108 \text{ lbs N}$
Irrigation Water Nitrogen = $6 \text{ ppm} \times 2.7 \times 1.5 = 24.3 \text{ lbs N}$
Organic Matter Nitrogen = $1.8\% \times 20 = 36 \text{ lbs N}$
Manure Nitrogen = $10 \text{ tons} \times 14 \text{ lbs/acre} \times 50\% = 70 \text{ lbs N}$
Nitrogen Requirement = $170 \text{ bushes/acre} \times 2.0 = 340 \text{ lbs/acre}$

Therefore:

$340 \text{ (required)} - (108 + 24 + 36 + 70) = 110 \text{ lbs/acre}$
additional N required

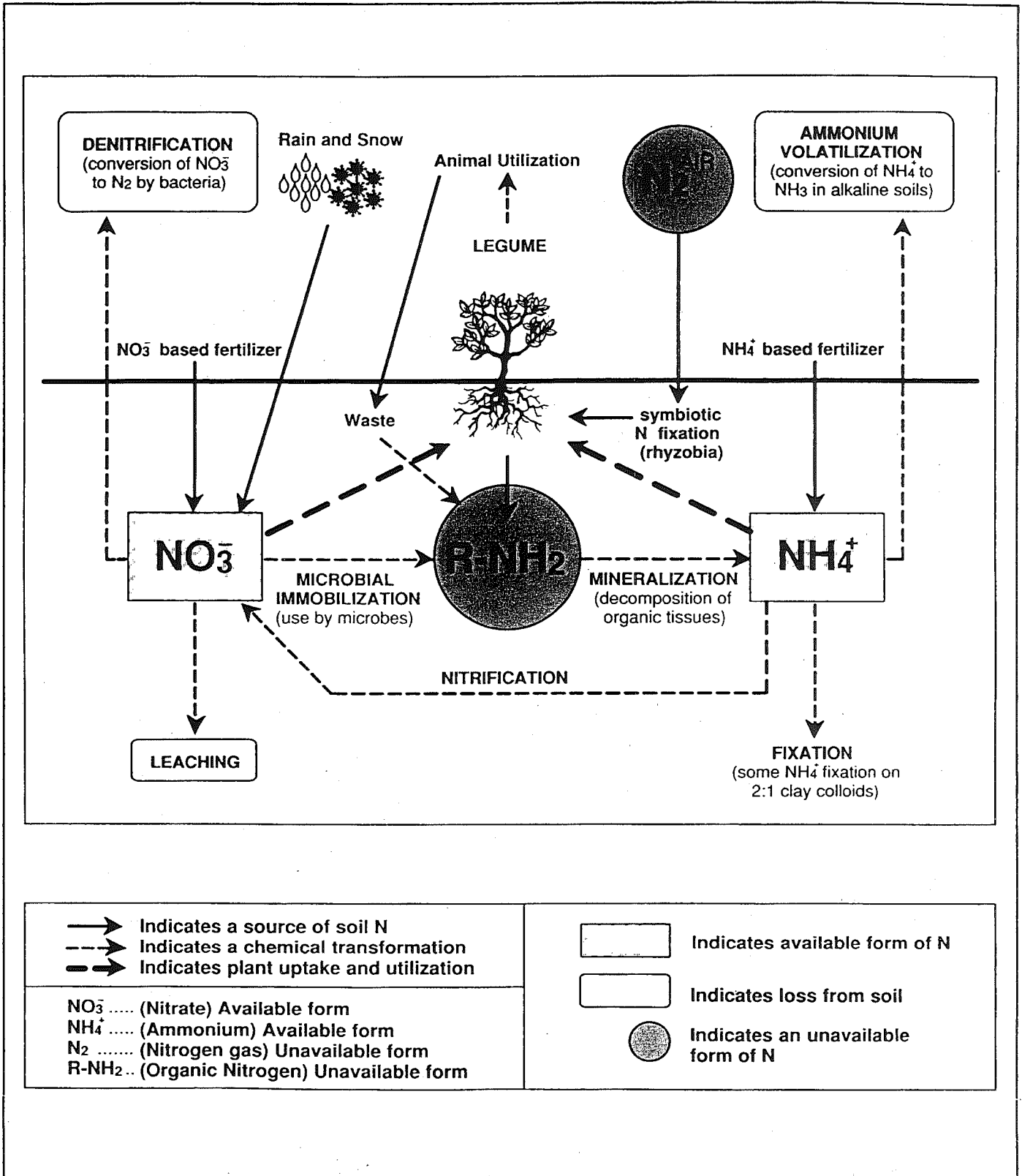
Applying more than the recommended 110 lbs/acre would show little or no return on money, invested into fertilizer and greatly increases the probability of nitrogen loss due to leaching.

Example (metric)

A farmer expects a yield of corn to be 150 hectoliters per hectare. A local soils laboratory has determined that it takes 2.6 kg of N to produce 1 hectoliter of corn. So, the nitrogen requirement is $2.6 \times 150 = 390$ kg of N/hectare.

Previously, the farmer applied 22 metric tons/hectare of beef manure, which has about 7 kg of nitrogen/metric ton. From the manure, 50% of the nitrogen is available during

THE NITROGEN CYCLE



PPM VERSUS LBS/ACRE IN SOIL

Laboratories normally multiply ppm NO_3^- -N by 2 to convert it to lbs/acre NO_3^- -N. This is based on the assumption that a mineral soil weighs 2,000,000 lbs per acre furrow slice. An acre furrow slice is one acre of soil (43,560 square feet) at a depth of 6.67 inches (average furrow depth). However, this conversion is not truly accurate because the depth of a furrow slice varies, as does the depth of a soil sample. A better conversion is based on the average weight of one acre of mineral soil to a depth of one inch equals 300,000 lbs. Using this, the conversion is:

ppm NO_3^- -N as analyzed \times 0.3 \times depth of soil sample (inches) = lbs/acre

For example, if a soil sample was sampled to a depth of 12 inches, and the analysis showed 16 ppm NO_3^- -N, then $16 \times 0.3 \times 12 = 57.6$ lbs NO_3^- -N/acre.

A Final Word of Caution

Nitrogen is available to plants in two major forms. The form most likely to be abundant is nitrate. The ammonium ion (NH_4^+) is also available. However, most soil analyses for available N measure only nitrate. This is usually adequate for fertilizer recommendations since ammonium levels are normally low **except in soils recently fertilized with nitrogen.**

Most nitrogen fertilizers contain a lot of ammonium. Under normal growing conditions, when soils are warm, ammonium converts to nitrogen in 2-3 weeks, making nitrate the most abundant form of soil nitrogen.

SOIL ACIDITY

Soils become acidic for several reasons. Under normal conditions, lime in the soil acts as a "buffer", and neutralizes the acid introduced into the soil by rain, plant growth, fertilizer, and organic decay. Once the lime is used up, there is no longer a buffer to neutralize the acid present in the soil. When this happens, the pH decreases quickly and the soil has a high percentage of soluble exchangeable hydrogen (H⁺) and aluminum (Al³⁺). This creates a soil that is toxic to plant growth. Adding lime to acidic soil returns the buffering ability and raises the pH to a range where toxic aluminum precipitates out of the soil solution.

The most common acceptable method of determining lime requirement is to measure pH on an SMP extraction of the soil. In this method, a buffer is added to an acidic soil. The response of the soil, measured as an increase in pH, is related to the metric tons of lime (as CaCO₃) needed per hectare to raise the soil pH to either 6.5 or 7.0, depending on the soil manager's decision and the return on the investment in the crop.

Lime Requirement Table (U.S.)

Buffer pH	Tons/Acre of Pure Limestone* (as CaCO ₃) Required to Raise Buffer pH	
	To pH 7.0	To pH 6.5
6.8	0.1	0.1
6.7	0.7	0.6
6.6	1.2	1.0
6.5	1.9	1.6
6.4	2.7	2.3
6.3	3.4	2.9
6.2	4.2	3.6
6.1	5.1	4.3
6.0	5.7	4.8
5.9	6.7	5.7
5.8	7.5	6.4
5.7	8.4	7.1
5.6	9.1	7.7
5.5	9.8	8.3
5.4	10.7	9.1
5.3	11.5	9.8
5.2	12.4	10.5
5.1	13.1	11.1
5.0	13.9	11.8
4.9	14.7	12.5

*Values based on tons of pure, fine CaCO₃ with a calcium carbonate equivalent (CCE) of 100.

If using limestone other than 100 CCE, calculate the required tons by dividing the number of tons from the above table by the assayed CCE, expressed as a decimal percentage.

Example: If your buffer pH is 6.6, and you wish to raise

the soil pH to 7.0, then add 1.2 tons/acre of 100 CCE limestone to the top 8 inches of soil. If the CCE of the limestone you want to use is 87, then apply $1.2/0.87 = 1.37$ tons/acre to bring the pH to 7.0.

Lime Requirement Table (Metric)

Buffer pH	Metric Tons/Hectare of Pure Limestone* (as CaCO ₃) Required to Raise Buffer pH	
	To pH 7.0	To pH 6.5
6.8	0.2	0.2
6.7	1.4	1.2
6.6	2.4	2.0
6.5	3.8	3.2
6.4	5.4	4.6
6.3	6.8	5.8
6.2	8.4	7.2
6.1	10.2	8.6
6.0	11.4	9.6
5.9	13.4	11.4
5.8	15.0	12.8
5.7	16.8	14.2
5.6	18.2	15.4
5.5	19.6	16.6
5.4	21.4	18.2
5.3	23.0	19.6
5.2	24.8	21.0
5.1	26.2	22.2
5.0	27.8	23.6
4.9	29.4	25.6

*Values based on metric tons of pure, fine CaCO₃ with a calcium carbonate equivalent (CCE) of 100.

If using limestone other than 100 CCE, calculate the required metric tons by dividing the number of metric tons from the above table by the assayed CCE, expressed as a decimal percentage.

Example: If your buffer pH is 6.6, and you wish to raise the soil pH to 7.0, then add 2.4 metric tons/ha of 100 CCE limestone to the top 20 cm of soil. If the CCE of the limestone you want to use is 87, then apply $2.4/0.87 = 2.76$ metric tons/ha to bring the pH to 7.0.

ALKALINE SOILS

In arid and semi-arid regions, native lime content in the soil is usually high enough to create a calcareous condition. Calcareous soils contain free particles of calcium and/or magnesium carbonate. These soils have a pH greater than 7.5 and will visibly effervesce (fizz) when 10% hydrochloric acid (muriatic acid) is added dropwise to the soil.

Alkaline soils can affect the availability and efficiency of phosphorus and many metal micronutrients as well as the length of time that herbicides remain in the soil. Banding phosphorus in row crops and applying micronutrients in chelated form can often help overcome these conditions.