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ABSTRACT

This manual is designed to help agricultural education students to determine and provide the proper kinds and amounts of nutrients for the field crops they produce. The manual provides many learning situations regarding field crops--for example, determining nutrient needs, diagnosing nutrient shortages, and selecting and applying fertilizer and lime. The manual contains seven chapters that cover the following topics: crop nutrient requirements; soil chemistry and plant nutrient absorption; determining nutrient needs of crops; nutrient sources; fertilizer selection; fertilizer application; and lime selection and application. Each chapter includes objectives, practical applications, student exercises, science and mathematics concepts, and key terms, as well as information sheets illustrated with line drawings. A bibliography lists 12 suggested readings and 6 slide sets covering course content. (KC)

AGDEX $\frac{100}{532}$

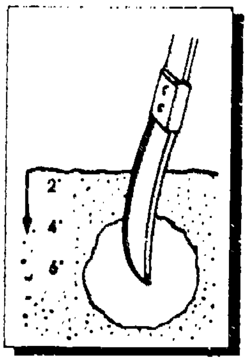
FIELD CROP NUTRITION

Applied Science Concepts

Student Manual

**OHIO AGRICULTURAL EDUCATION
CURRICULUM MATERIALS SERVICE**

Agricultural Education Service
Ohio Department of Education
and
Department of Agricultural Education
The Ohio State University



FIELD CROP NUTRITION – Applied Science Concepts

Adapted by
Charles R. Miller

Original edition written by
Clarence R. Fridline

Under the direction of

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Contents

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Foreword

Plants, in general, are an interesting and unique part of our world. They are nature's chemical factories. When supplied with minerals, water, air, and sunlight, plants synthesize all the substances that support and nourish all other life forms. Growing conditions for field crops can vary from farm to farm, and even from field to field on the same farm. Many crop producers consider the provision of sufficient nutrients for crop plants as the "key that unlocks the door" to high crop yields.

Field Crop Nutrition - Applied Science Concepts is for students interested in determining and providing the proper kinds and amounts of nutrients for the field crops they produce. This student manual provides many learning situations regarding field crops – for example, determining nutrient needs, diagnosing nutrient shortages, and selecting and applying fertilizer and lime. After studying this manual, students should be able to select and use fertility practices for their crop growing situations.

Objectives and Applications

A list of *objectives* are provided at the beginning of each chapter in this manual; *practical applications* and *student exercises* are provided at the end of each chapter. To develop effective field crop nutrition programs, use these objectives as study guidelines, and apply the exercises to the student's crop growing situation.

Science and Math Concepts

A list of *science concepts* are also provided at the beginning of each chapter. These highlight and define the numerous science concepts involved in the study of plant nutrition. These lists will help the reader discover how science and math concepts relate to effective crop growing.

Key Terms

Each area of occupational study has its own unique terms. These terms are just part of the language for that area. Understanding these terms helps the student learn and comprehend the information presented. These *key terms* are listed at the end of each chapter. If the student is unsure of a term, he/she should review that portion of the chapter discussing the term.

As with many subjects involving agricultural production, field crop production has some complex areas of study. Some examples are the mathematical formulas used to determine the cation exchange capacity of a soil and the phosphate and potash requirements. The use of these complex items will depend on the time available and the interests of the teacher and students using this manual.

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Chapter 1

Crop Nutrient Requirements

Introduction

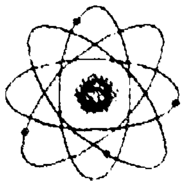
Plants are a vital and unique part of our world. They can **synthesize** (put together) the substances they need to store food and grow. The required ingredients for this process are called **elements**. Plants require 16 elements for healthy growth. An element that supplies nourishment or promotes plant growth is a **nutrient**. This chapter describes nutrient functions in plants and nutrient deficiency symptoms in field crop plants.

OBJECTIVES

After studying this chapter you should be able to do the following:

- Provide the name and chemical symbol of each plant nutrient. (Chemical symbols are often used in place of names when referring to nutrients – for example, N represents nitrogen and P represents phosphorus.)
- Classify nutrients according to amounts used by crops. (For example, nutrients used in large amounts produce nutrient shortages more often than do nutrients used in small amounts.)
- List nutrient functions and the effects they have on crop plant growth.
- Identify crop plant growth characteristics that signal an existing nutrient shortage.

SCIENCE CONCEPTS



This chapter covers the following science concepts:

- Plants use the elements and chemical compounds available in their environment as nutrients for growth and survival.
- Each nutrient is responsible for specific plant growth functions.
- Lack of a specific nutrient causes specific deficiency symptoms.

TABLE 1 Essential nutrients for plant growth (sources and chemical symbols)

Nutrient	Source	Chemical Symbol
	NONMINERAL NUTRIENTS	
Hydrogen	Water	H
Oxygen	Air	O
Carbon	Air	C
	MINERAL NUTRIENTS	
Primary, Major, or Macronutrients		
Nitrogen	Soil and fertilizer (some plants use nitrogen from the air)	N
Phosphorus	Soil and fertilizer	P
Potassium	Soil and fertilizer	K
Secondary or Minor Nutrients		
Calcium	Soil and fertilizer	Ca
Magnesium	Soil and fertilizer	Mg
Sulfur	Soil and fertilizer	S
Trace or Micronutrients		
Boron	Soil and fertilizer	B
Manganese	Soil and fertilizer	Mn
Zinc	Soil and fertilizer	Zn
Copper	Soil and fertilizer	Cu
Iron	Soil and fertilizer	Fe
Chlorine	Soil and fertilizer	Cl
Molybdenum	Soil and fertilizer	Mo

Sixteen **essential nutrients** are obtained from air, water, soil, or fertilizer. For example, as shown in Table 1, *hydrogen* is obtained from water, and *oxygen* and *carbon* are obtained from air. These three nutrients are **nonmineral nutrients**. The remaining 13 nutrients are available in the soil (and fertilizer) and are **mineral nutrients**. The mineral nutrients are subdivided into the following three groups and discussed in more detail later:

1. **Primary, major,** or **macronutrients**
2. **Secondary** or **minor nutrients**
3. **Trace** or **micronutrients**

Table 1 also lists each nutrient's chemical symbol.

Plants require certain amounts of mineral and nonmineral nutrients to maintain proper growth and health. For example, Figure 1 shows the amount of each nutrient required to produce 150 bushels of corn per acre. The total amount of *mineral* nutrients supplied by soil and fertilizer (nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, and micronutrients) is approximately 626 pounds. This means that the remaining weight (about 95%) of the 150-bushel corn crop comes from carbon, hydrogen, and oxygen - the *nonmineral* nutrients supplied by air and water.

In addition, Table 2 gives the amounts of the primary nutrients used by several crops to produce the indicated yields. These amounts vary depending on the current soil properties and weather conditions.

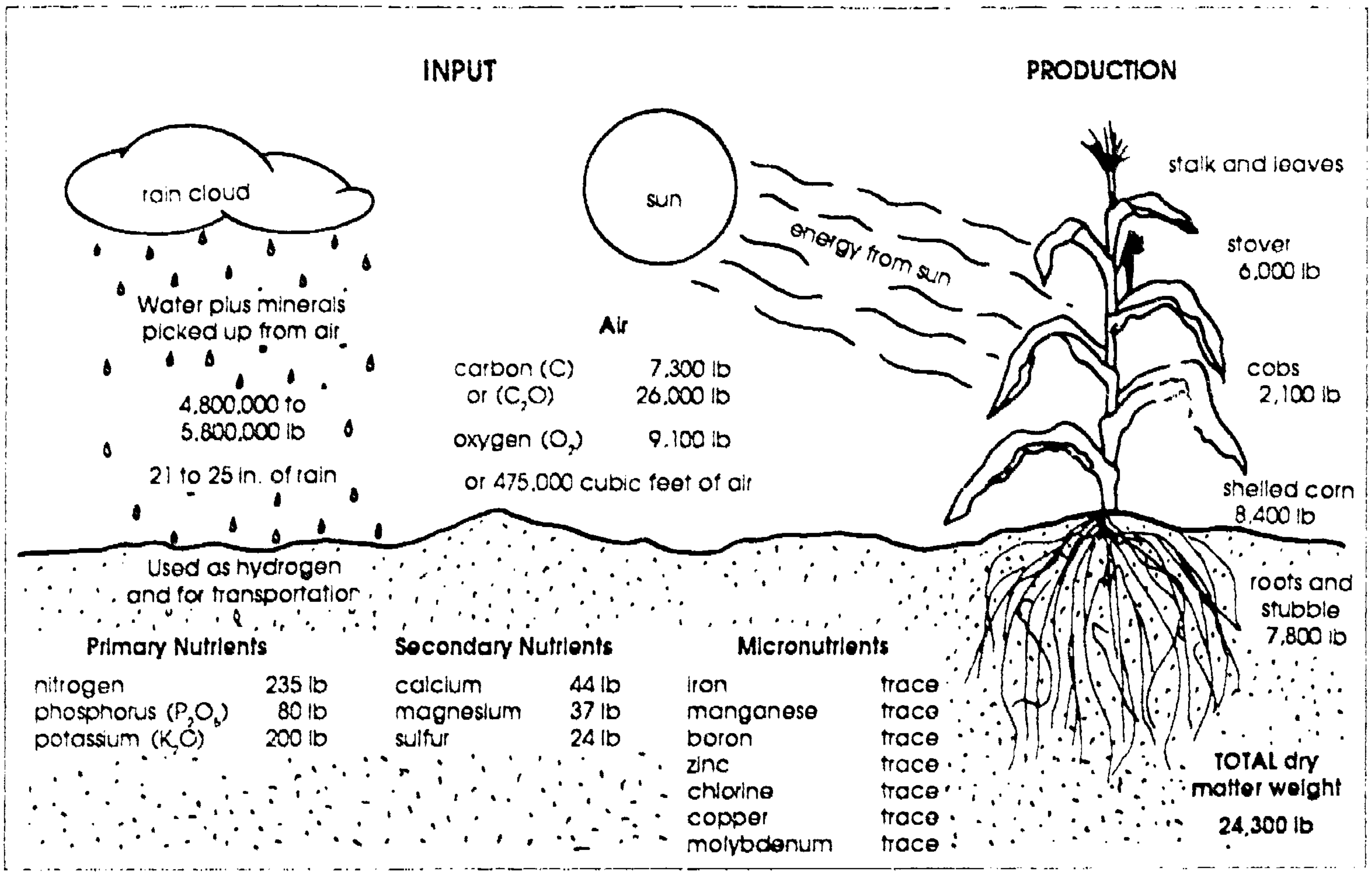


FIG. 1. The nutrients required to produce 150 bushels of corn per acre

TABLE 2. Approximate pounds per acre of primary nutrients used by crops to produce the indicated yields

Crop (Yield)	N	P_2O_5	K_2O
		(pounds/acre)	
Alfalfa (6 T)	340 *	80	360
Corn (150 bu)			
Grain	135	55	40
Stover	100	25	160
Corn - silage (26 T)	235	80	235
Grasses - cool season (3.5 T)	140	45	175
Oats (100 bu)			
Grain	65	25	20
Straw	35	15	100
Sorghum - grain (7,600 lb)			
Grain	105	30	30
Stover	80	50	230
Soybeans (50 bu)	190 *	40	70
Sugar beets - roots (25 T)	100	50	250
Tobacco - burley and cigar filler			
Leaf (3,000 lb)	105	25	185
Stems and suckers (2,000 lb)	55	15	65
Wheat (55 bu)			
Grain	70	35	20
Straw	30	5	50

*Inoculated legumes fix nitrogen from the air.

(Courtesy National Plant Food Institute)

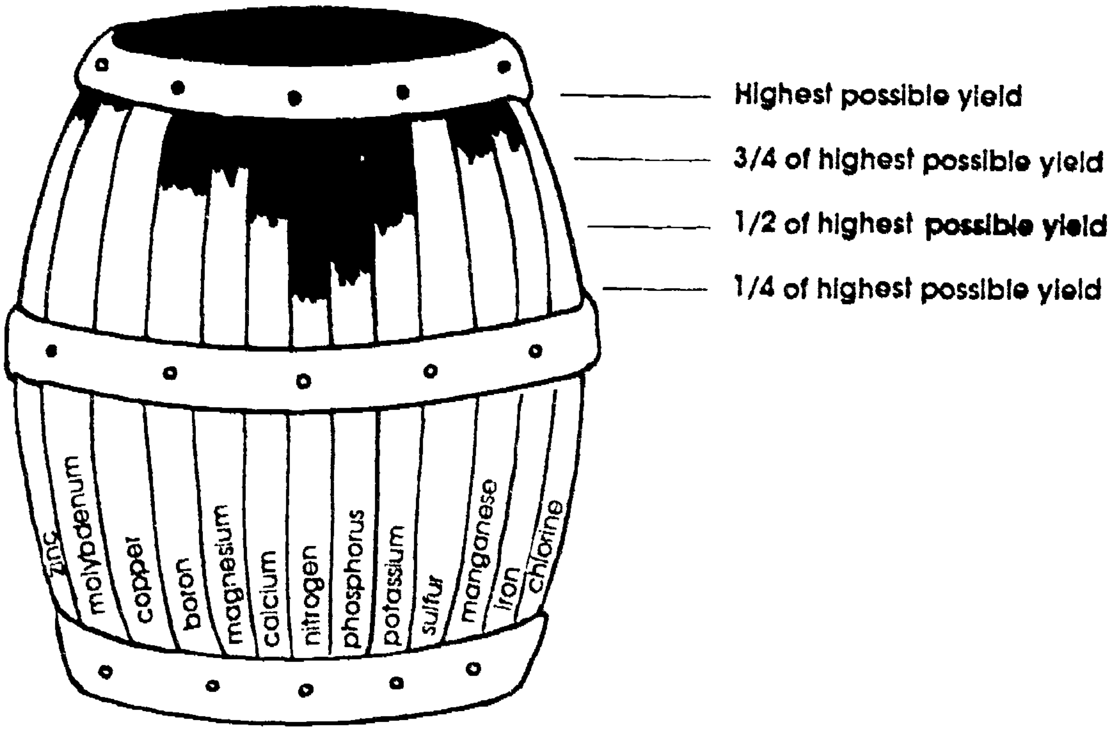


FIG. 2. Like a barrel that holds only as much water as permitted by its shortest stave, a crop yield is limited by the nutrient in shortest supply.

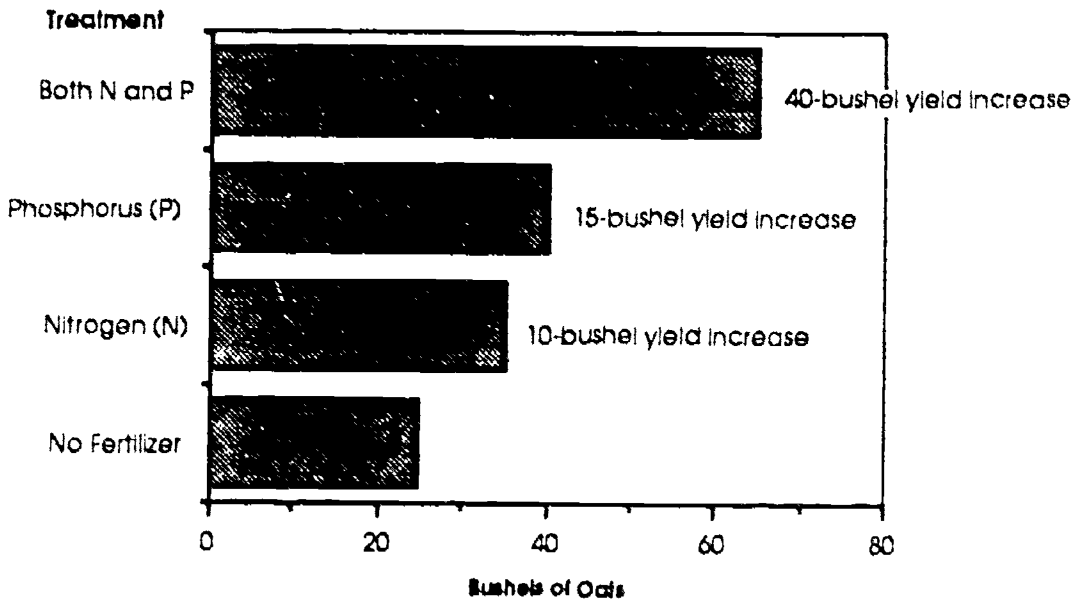


FIG. 3. Nitrogen and phosphorus fertilizer applications affect oat crop yields.

Nutrients must be available in adequate amounts to ensure proper plant growth. If even one nutrient is lacking, proper growth does not occur. For example, as illustrated in Figure 2, a barrel can hold only as much water as its shortest stave. Likewise, a crop yield can be only as high as the nutrient in shortest supply permits. In Figure 2, nitrogen is shown as the "shortest stave." This concept also applies to the other nutrients included in this figure. *Nutrients needed in large amounts - such as nitrogen, phosphorus and potassium - are more likely to be deficient than those needed in smaller amounts.*

If two nutrients are in short supply, the addition of either may produce small increases in yield. When both are adequately supplied, the yield is higher. This effect is **nutrient interaction**. A graphic representation of this effect is shown in Figure 3. In this case, applying nitrogen increases the yield 10 bushels per acre over the yield produced with no fertilizer. When only phosphorus is applied, the yield increases 15 bushels per acre. When both nutrients are applied, the yield increases 40 bushels per acre over the yield produced with no fertilizer.

Nutrient Functions in Crop Growth

Each of the 16 essential nutrients have specific functions in plants. Carbon, hydrogen, and oxygen are needed for photosynthesis and respiration. The 13 mineral nutrients are needed for plant processes and serve as growth **catalysts** (substances that initiate a reaction) and **regulators** (substances that maintain order in a process).

PRIMARY NUTRIENT (Macronutrient) FUNCTIONS

Nitrogen (N)

Nitrogen performs the following functions in plants:

1. *Prevents chlorosis* (a low-chlorophyll condition) – Since nitrogen is an important part of chlorophyll molecules, a nitrogen shortage can cause the plant's chlorophyll content to decrease. This, in turn, slows **photosynthesis** – the process used by plants to convert carbon dioxide (CO_2), water (H_2O), and light energy to carbohydrates (CH_2O) and oxygen (O_2). These carbohydrates provide the energy plants need for growth and survival.

2. *Induces vigorous, rapid plant growth* – Cell division requires nitrogen - the "growth nutrient." If it is in short supply, cell division slows or stops. When this happens, the amount of leaf area exposed to the sun is reduced. This reduced leaf area then limits the amount of photosynthesis taking place.

3. *Increases protein content of crops* – **Proteins** are important parts of the protoplasm (a living part of each plant cell). They promote the development of plant structure and serve as a catalyst for chemical reactions necessary for growth. Nitrogen is part of the **amino acids** that form these proteins. If an adequate amount of nitrogen is present, it increases the level of plant protein.

4. *Nourishes soil microorganisms* – Microorganisms are microscopic animals or plants such as bacteria or protozoans. Nitrogen nourishes the soil microorganisms responsible for organic matter decomposition in the soil.

Phosphorus (P)

Phosphorus is used by plants in smaller amounts than nitrogen and potassium. However, inadequate amounts of phosphorus can seriously affect plant growth. Phosphorus performs the following functions in plants:

1. *Produces early root formation and growth* – Phosphorus is always found in abundance in young meristematic (growth) tissue.
2. *Promotes cell division* – Cells require adequate amounts of phosphorus for proper cell division.
3. *Supplies energy for seedling germination* – An adequate phosphorus supply is extremely important in germination. Phosphorus is stored in the seed and supplies the energy needed for cell division during early growth.
4. *Aids photosynthesis* – Phosphorus is needed for photosynthesis. Also, protein synthesis decreases when phosphorus is deficient.
5. *Encourages flower formation and seed development* – The early maturity and quality of grain crops depend upon adequate phosphorus supplies.

Potassium (K)

With the exception of nitrogen, crop plants in general, require more potassium than any other nutrient. Some plants even require more potassium than nitrogen. Potassium performs the following functions in plants:

1. *Improves stalk and straw strength* – By improving stalk and straw strength, potassium reduces the amount of stalk and straw lodging (breaking).
2. *Aids protein manufacture* – Potassium manufactures proteins from amino acids.
3. *Produces winter hardiness* – Legumes and winter annual small grain crops are more hardy during the winter months with adequate potassium supplies.
4. *Aids the formation and* ***translocation*** *(transfer) of starches, sugars, and oils to storage areas* – Potassium helps form and transfer these energy sources to each plant's storage area (e.g., ear of corn). As a result, seeds are more plump and fully developed.
5. *Improves disease resistance*

SECONDARY (Minor) NUTRIENT FUNCTIONS

Calcium (Ca)

Calcium is necessary for plant growth and the maintenance of a desirable soil pH range. It performs the following functions in plants:

1. *Promotes early root formation and growth*
2. *Increases soil organism activity* – Soil organisms promote organic matter decomposition.
3. *Improves the plant's uptake of other nutrients*
4. *Reduces the solubility and toxic effects of certain elements* – Calcium reduces soil acidity which, in turn, reduces the solubility and toxic effects of elements such as iron and aluminum.
5. *Bonds cells* – Calcium pectate is the compound that forms the bond between cell

walls to hold cells together. Elemental calcium is also found in cell walls and forms a protective sieve that allows nutrients to enter the cell.

6. *Neutralizes organic acids in plants* – Calcium neutralizes carbon-based acid compounds present in plants. If calcium is not available, these acids react with other nutrients needed by the plant (e.g., magnesium). These interactions prevent the plant from using the nutrients.

Magnesium (Mg)

Magnesium, like calcium, is a nutrient that helps to maintain the correct soil pH and improves the plant's nutrient uptake. It also performs the following functions in plants:

1. *Is present in the chlorophyll molecule* – Magnesium is the only mineral nutrient present in the chlorophyll molecule. If magnesium is deficient, there is less chlorophyl present. Consequently, less photosynthesis takes place.
2. *Acts as a phosphorus carrier*
3. *Promotes the formation of oils, fats, and acids in the translocation of starch* – Magnesium promotes the formation of these substances in the translocation of starch from the leaves to the plant's storage areas (e.g., grain).

Sulfur (S)

Sulfur performs the following functions in plants:

1. *Is a part of the amino acids that form plant proteins*
2. *Promotes dark green growth* – Sulfur promotes photosynthesis resulting in vigorous plant growth.
3. *Stimulates seed production*
4. *Increases root growth and promotes nodule formation on legumes*
5. *Assists development of enzymes and vitamins*
6. *Is required for chlorophyll formation*

MICRONUTRIENT FUNCTIONS

The micronutrients, also known as **trace elements**, are boron, manganese, copper, zinc, iron, chlorine, and molybdenum. Small quantities of these elements are required when compared to the amounts required of the primary and secondary nutrients. However, *all the micronutrients are necessary for plant growth.* Although only a trace of some micronutrients is required by plants, *a shortage of any of them can cause yield losses.*

Boron (B)

Boron performs the following functions in plants:

1. *Enables normal germination of pollen grains and growth of pollen tubes*
2. *Is required for normal cell division*
3. *Is required for protein formation and the metabolism of carbohydrates and water*
4. *Is essential for seed and cell wall formation.*
5. *Is associated with sugar translocation.*

Copper (Cu)

Copper performs the following functions in plants:

1. *Is needed for chlorophyll formation*
2. *Acts as a catalyst in some plant processes* (Although copper is required to promote certain reactions, it is not found in the product formed.)

Iron (F)

Iron performs the following functions in plants:

1. *Is required for chlorophyll formation*
2. *Is needed in respiration*
3. *Acts as an oxygen carrier*

Manganese (Mn)

Manganese performs the following functions in plants:

1. *Serves as part of the plant's enzyme system* - Manganese is a catalyst and activates important reactions within the plant. Therefore, it is used repeatedly.
2. *Maintains chlorophyll production* - A manganese deficiency reduces chlorophyll production, and as a result, limits photosynthesis .
3. *Accelerates germination and maturity*

Molybdenum (Mo)

Molybdenum performs the following functions in plants:

1. *Is necessary for nitrogen fixation by bacteria in legume nodules.*
2. *Aids nitrate use and breakdown during protein formation*

Zinc (Zn)

Zinc performs the following functions in plants:

1. *Is an important part of plant enzyme systems* - Zinc is responsible for protein formation.
2. *Is required for flower and seed production* - A zinc deficiency delays plant maturation and seed ripening.
3. *Is required for chlorophyll production and carbohydrate formation*

Chlorine (Cl)

Chlorine performs the following functions in plants:

1. *Is required in the chemical breakdown of water in the presence of sunlight*
2. *Activates several enzyme systems*
3. *Is seldom, if ever, in short supply in soil* - Too much chlorine can be harmful to some crop growth and quality.

Nutrient Deficiency Symptoms in Crops

FIG. 4. Poor soil drainage can retard or prevent plant growth.

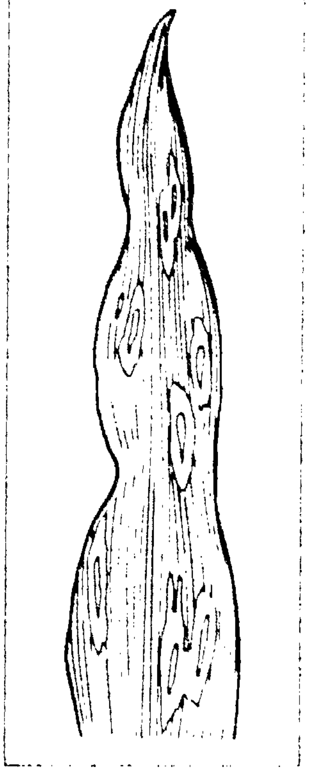


FIG. 6. This corn leaf is affected by Helminthosporium leaf blight. Small spots apear and gradually spread across the entire leaf surface.

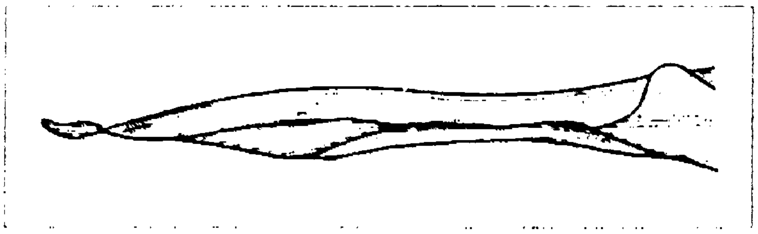


FIG. 5. A corn leaf affected by drought can roll up to the width of a pencil.

After examining Table 2 on page 3, it is obvious that the nutrient requirements of different crop plants can vary. For example, corn requires more nitrogen than any other crop listed in the table, and alfalfa requires more potassium. When these nutrient requirements are not met, some crop plants show distinct signs. These **hunger signs** are generally abnormal plant growth.

It is important to realize that in addition to nutrient shortages, other conditions can cause abnormal plant growth. Cold weather, disease, insect damage, and lack of sunlight are all potential causes of abnormal plant growth. Chemical herbicides or insecticides, if improperly applied, may also cause abnormal growth. In addition, soil conditions, such as poor drainage and low organic matter content, influence plant nutrient use. As shown in Figure 4, poor soil drainage can inhibit corn growth. Figures 5, 6, and 7 also illustrate abnormal growth conditions caused by factors other than nutrient shortage.

Some nutrient deficiency symptoms (*hunger signs*) are easy to identify; others are difficult to identify without considerable knowledge and experience. Unfortunately, many identifiable hunger signs occur too late in the growing season to permit correction of the problem. If this is the case, correct the nutrient deficiency the following season. *Note that plant growth and yield can be affected long before the nutrient deficiency is severe enough to be observed on the plant.*

FIG. 7. Burned leaf tips and edges are signs of chemical damage.

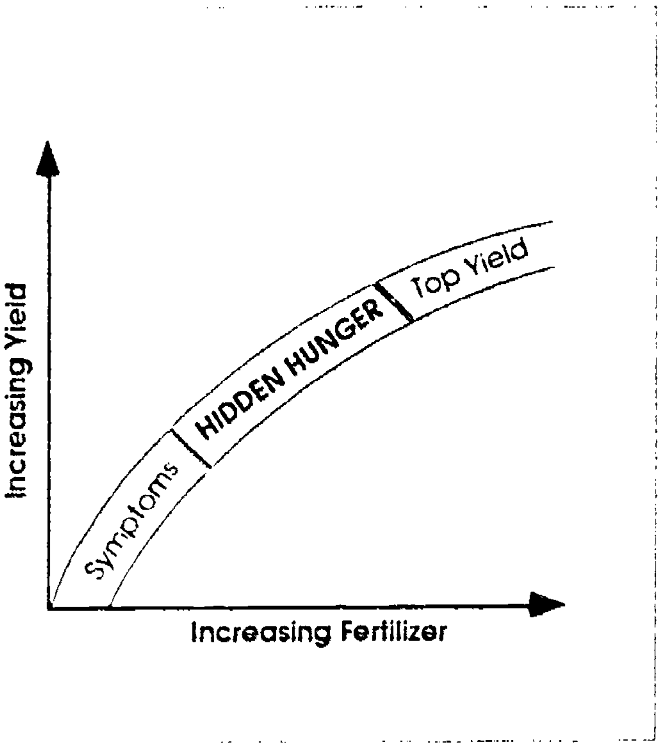


FIG. 8. The problem of detecting nutrient shortages (hidden hunger) is still present as yield goals increase

FIG. 9. *Left:* a corn plant that received the corrent amount of nitrogen; *right:* a corn plant that did not receive the correct amount of nitrogen. This plant is stunted and has yellow leaves. *(Courtesy Fertilizer Institute)*

As illustrated in Figure 8, the possibility of "hidden hunger" should always be considered – no matter what the yield goal is. As "hidden hunger" implies, nutrient deficiencies may not show on crop plants. Therefore, always use soil testing and plant analysis to determine the kinds and amounts of nutrients needed. These diagnostic tools remove much of the guesswork in determining nutrient needs for each crop to be grown. They also aid in planning the best possible soil fertility management program.

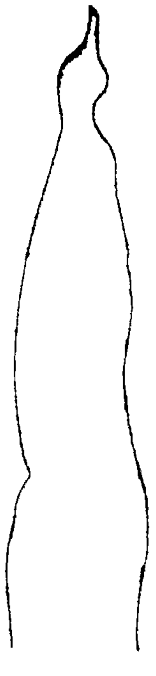


FIG. 10. Nitrogen hunger in corn produces yellowing or browning on the leaf tip [illegible] midrib

PRIMARY NUTRIENT DEFICIENCY SYMPTOMS

Nitrogen Deficiency Symptoms

Nitrogen is necessary throughout the crop plant growing season. The following are nitrogen-deficiency symptoms:

1. *Yellow, stunted plants* – (see Figure 9). The lower leaves, which are older, show this yellowing condition first.
2. *Lower leaves with brown tips* – Corn, small grains, and other grass plants show this symptom (see Figure 10). This browning condition eventually spreads to the midrib and then over the entire leaf. If nitrogen is in extremely short supply, the upper leaves also turn brown.

Figure 11 illustrates an ear of corn produced with an existing nitrogen shortage. This ear is underdeveloped with small, glossy kernels and a tip lacking kernels.

Corn requires more nitrogen to produce a high yield than any other crop listed in Table 2. Therefore, it is more likely to show nitrogen deficiency symptoms. Since legume crops, (e.g., alfalfa) make their own nitrogen, deficiencies are less likely to occur in these crops.

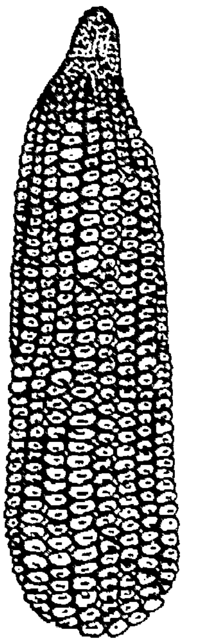


FIG. 11. Nitrogen hunger in corn produces underdeveloped ears: small, glossy kernels; and a lack of kernels at the tip

Phosphorus Deficiency Symptoms

Phosphorus moves freely in plant tissue. Therefore, when a deficiency occurs, phosphorus in older tissues is transferred to the actively growing tissues. This reaction retards overall growth. For this reason phosphorus deficiency symptoms are not as easy to identify as nitrogen and potassium deficiency symptoms.

The following symptoms are often produced by a phosphorus deficiency:

1. *Small, very dark green or bluish-green plants*
2. *Reddish-purple leaves* – Some plants, such as corn, show this symptom when the plants are less than one foot tall. Figure 12 illustrates the effects of different amounts of phosphorus fertilizer on the growth of young corn plants. If phosphorus is deficient, sugars accumulate in the plant tissues. This accumulation promotes the formation of anthocyanin (a pigment causing reddish-purple leaves during autumn). Use caution when diagnosing phosphorus deficiency. Since other conditions can also cause reddish-purple leaves, check for other symptoms of phosphorus deficiency.
3. *Small, twisted ears of corn with underdeveloped kernels* – Phosphorus shortages interfere with pollination and kernel fill of the ear (see Figure 13).

Note: Conducting a plant analysis or soil test confirms the existence of a phosphorus deficiency.

FIG. 12. Varying the amount of phosphorus applied to corn plants affects the plants growth. (*Courtesy Potash and Phosphate Institute*)

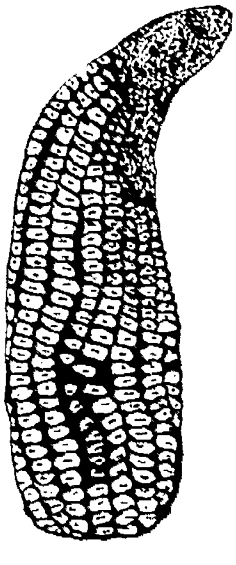


FIG 13. Phosphorus deficiency produces short, curved ears with underdeveloped kernels

Potassium Deficiency Symptoms

Plants require more potassium than they require of other nutrients. For example, some crop plants require more potassium than nitrogen (see Table 2 on page 3). The following are symptoms of potassium deficiency:

1. *Premature leaf death* – When a potassium shortage exists, the nutrient moves from older leaves to younger leaves. Consequently, the older leaves die prematurely. Initially the leaves turn yellow or brown at the margins, but eventually they turn completely brown (see Figure 14).
2. *Weak stalks and straws* – A potassium deficiency produces this symptom on corn and small grains. Lodging (breaking of the stem) eventually occurs (see Figure 15). Figure 16 shows the stalk and ear of a potassium-deficient plant and those of a healthy plant.
3. *Stunted ears of corn and "chaffy" kernels* – These potassium deficiency symptoms in corn are shown in Figure 17. If you twist these ears in your hands, the ears feel spongy.
4. *Poor quality soybean seed* – Potassium deficiencies discolor and disfigure soybean seeds. Figure 18 shows the difference between normal soybeans and those produced under potassium-deficient conditions. A potassium shortage also affects soybean grain quality.

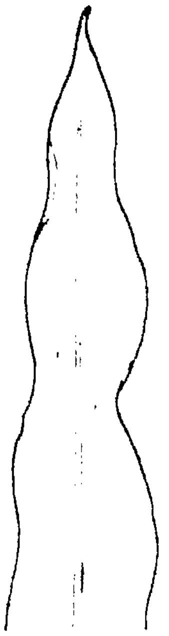


FIG 14 Potassium deficiency causes the plant leaf tips and edges to turn brown or yellow

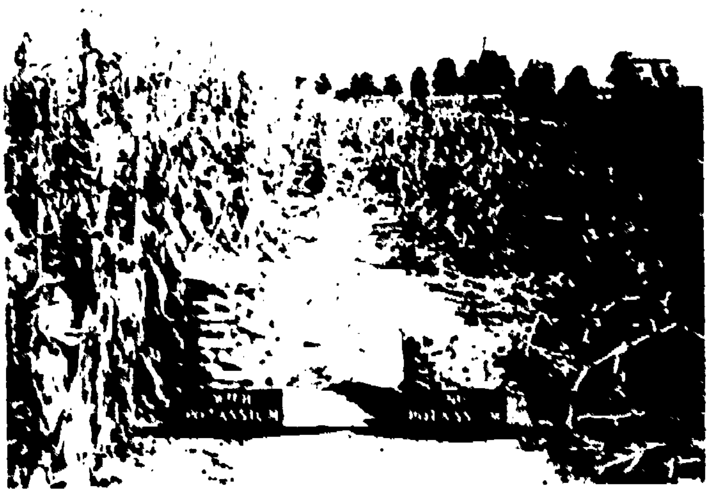


FIG. 15 Potasium deficiency causes weak corn stalks like these shown on the right. *(Courtesy Potash and Phosphate Institute)*

FIG. 16. *Left:* normal ear and stalk; *right:* ear and stalk with potassium deficiency *(Courtesy Potash and Phosphate Institute)*

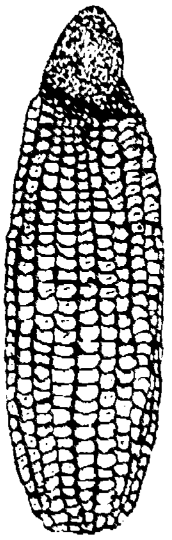


FIG 17. Potassium deficiency produces a spongy, 'chaffy' ear.

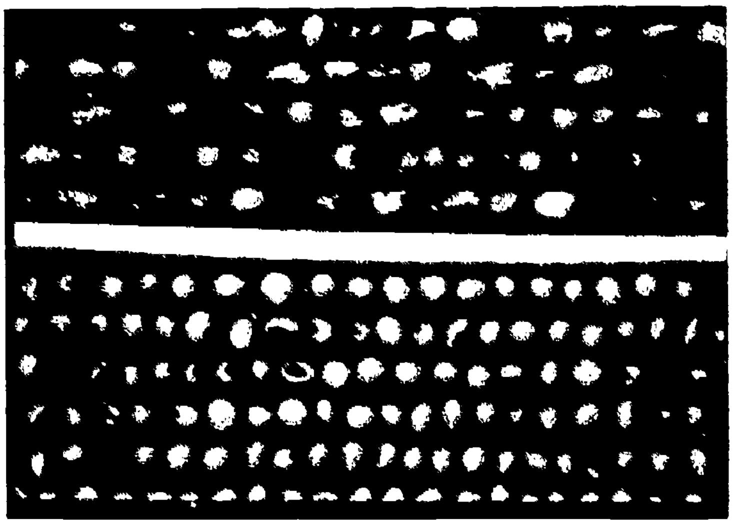


FIG. 18 *Top* potassium-deficient soybeans, *bottom* normal soybeans *(Courtesy The Fertilizer Institute)*

SECONDARY NUTRIENT DEFICIENCY SYMPTOMS

Calcium Deficiency Symptoms

Calcium is an **immobile element**. That is, it does not move from the older plant tissues to the younger plant tissues. Consequently the following symptoms are produced:

1. *Underdeveloped terminal buds* – The young leaves in terminal buds have a hooked appearance and die back at the tips and along the leaf margins.
2. *Wrinkled leaves*
3. *Leaf margins marked with a light green band*
4. *Short, heavily branched roots*
5. *New leaves with almost colorless tips* – This symptom occurs in corn and small grain crops.
6. *New leaves that are still folded and not fully emerged* – This symptom is seen in corn and small grain crops. The leaves are not fully emerged and are covered with a gelatinous material that causes them to stick together.

Magnesium Deficiency Symptoms

During a magnesium deficiency, magnesium readily moves from older plant tissues to the younger tissues. Therefore, as with nitrogen and potassium, deficiency symptoms often appear first on the lower leaves. These symptoms include the following:

1. *Leaves with white tissue between the veins* – In many plants, such as soybeans, leaf tissue between the veins turns white and the veins remain green (see Figure 19). As the leaves age, the leaf tissue turns uniformly pale, then yellow, and eventually brown.
2. *Leaves with curled margins*
3. *Weak stalks*
4. *Lower leaves with yellow or white streaks* – This symptom occurs in corn plants (see Figure 20).

FIG. 19. Soybean leaf with magnesium deficiency shows white tissue between green veins. *(Courtesy Potash and Phosphate Institute)*

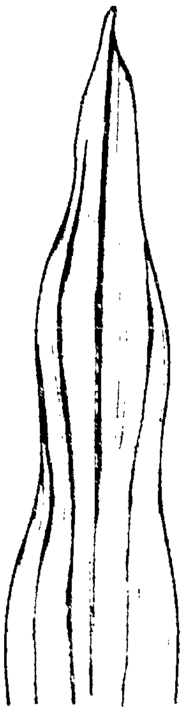


FIG. 20. Magnesium deficiency produces white or yellow streaks along corn leaf veins

Sulfur Deficiency Symptoms

The atmosphere supplies large amounts of sulfur. Each year rainfall deposits 15 to 25 pounds of sulfur per acre in the soil. Sulfur is also contained in commercial fertilizer, and it is seldom in short supply for crop plants in the eastern regions of the corn belt. If a shortage does occur, the symptoms are as follows:

1. *Similar to nitrogen deficiency* – Sulfur deficiency symptoms are similar to nitrogen deficiency symptoms with one exception: sulfur does not move from older to younger plant tissues when a deficiency is present.
2. *Stunted young plants*
3. *Light green to yellow leaves* – The leaf veins remain lighter in color than other leaf tissue.
4. *Thin, spindly stems*

MICRONUTRIENT DEFICIENCY SYMPTOMS

Boron Deficiency Symptoms

Boron deficiency symptoms are more likely to occur in crops grown in alkaline (high lime), sandy, or low organic matter soils. Also, periods of high rainfall or dry weather can reduce boron availability. Alfalfa, sugar beets, and clover are crops most likely to show deficiency symptoms. Since boron does not move from older plant tissues to younger tissues, deficiency symptoms usually appear in young leaves at the top of the plant and also at growing points. These deficiency symptoms follow:

1. *Yellow or red leaves at the top of the plant* – This symptom occurs in alfalfa and clover. The terminal buds may also die.
2. *Stunted plants with few flowers*
3. *Dark brown spots on the root (beet) of the sugar beet plant* – This symptom sometimes appears as dry rot.

Copper Deficiency Symptoms

Like the other micronutrients, plants need copper in very small amounts. Normally, copper shortages are not a problem in most crop growing situations. However, deficiency symptoms are most likely to appear in alfalfa, wheat, and oats. Soils in which shortages are more likely to occur are peats; mucks; and light-color, upland soils. Climatic conditions influence copper availability in soils. For example, high temperatures combined with high moisture may cause copper to be bound by soil organic matter.

The copper deficiency symptoms for wheat and oats are the following:

1. *Twisted, gray leaves*
2. *Dead leaf tips*
3. *Young seed heads that are bending over*
4. *Poor seed set* – Yields may be only one-half to two-thirds of normal yield.

The copper deficiency symptoms for alfalfa are the following:

1. *Stunted plants*
2. *Yellow leaves*
3. *Dropping of bottom leaves*

Iron Deficiency Symptoms

Although iron deficiency symptoms are rarely a problem in field crops, sorghum can show deficiency symptoms if the soil is poorly aerated due to packed, wet conditions. On the other hand, ornamental plants, such as roses and azaleas, more often show iron deficiency symptoms. The following iron deficiency symptoms are more common in soils with adequate nitrogen levels and high lime content:

- *Pale, yellow tissue between leaf veins* – The leaf veins remain green. As the deficiency progresses, the entire leaf becomes yellow and eventually turns white.

Manganese Deficiency Symptoms

Manganese deficiency symptoms usually appear in crops grown in peat or muck soils, and in mineral soils with a high lime content. In addition, cool temperatures can increase the severity of manganese deficiency. Plants in poorly drained areas frequently show the most marked deficiency symptoms. The following deficiency symptoms appear initially on the plants' older leaves:

1. *Yellow tissue between leaf veins* – The veins remain green.
2. *Dead spots in yellowed tissue* – This symptom occurs as the deficiency progresses.
3. *Severely stunted plants*

If soil pH is low, manganese may become so available that it produces a toxicity in the plant. This results in crinkled, curled leaves.

Molybdenum Deficiency Symptoms

Legumes need molybdenum for the fixation of atmospheric nitrogen by soil bacteria. Therefore, a molybdenum deficiency in legumes (e.g., soybeans and alfalfa) prevents nitrogen fixation, resulting in a nitrogen deficiency. The following are molybdenum deficiency symptoms:

1. *Yellow leaves* – This symptom is similar to that caused by nitrogen deficiency.
2. *Stunted plants*

Zinc Deficiency Symptoms

Corn is one of the crops most sensitive to zinc deficiency. This deficiency occasionally occurs in soils with unusual conditions; for example, soils with a high lime and phosphorous content. Light-color, sandy soils; badly eroded soils; and subsoils may also be low in zinc. A zinc deficiency usually occurs during the plant's early growth period and produces the following deficiency symptoms:

1. *Yellow-streaked leaves* – This occurs in corn leaves, particularly at the base of newly emerging leaves in the whorl. Young buds turn white or light yellow in early growth. For this reason zinc deficiency in corn is sometimes called "white bud."
2. *Stunted plants with yellow tops* – A severe zinc deficiency produces this symptom.
3. *Immature plants* – This symptom occurs in soybeans.

Chlorine Deficiency Symptoms

Chlorine is essential for crop growth and is seldom, if ever, lacking in soils. However, too much chlorine is harmful to some crops such as tobacco, soybeans, potatoes, and some tree crops.

Practical Application

The following exercises should help you gain knowledge and gather the information required to make correct crop management decisions. Check the box when each item is completed.

1. Determining nutrient functions

Resources

- Notebook
- Chapter 1 of this manual

Procedure

☐ Reproduce the following chart in your notebook. Leave enough space to list nutrients and the indicated information.

☐ Group nutrients according to nutrient type: primary, secondary, or micronutrients. Enter these in your chart.

☐ Record the functions of each nutrient in your chart.

NUTRIENT FUNCTIONS

Nutrient Name	Chemical Symbol	Nutrient Type	Important Functions
Example: Sulfur	S	Secondary	• Forms plant proteins • Stimulates seed production • Increases legume root growth and nodule formation

Practical Application (continued)

2. Identifying nutrient deficiencies (hunger signs) of crop plants

Resources

- Plants showing nutrient deficiency symptoms
- Color slides of plants with nutrient deficiencies
- Color photographs of plants with nutrient deficiencies
- Descriptions of nutrient deficiency symptoms found in this manual

Procedure

☐ Reproduce the following chart in your notebook. Leave enough space to enter the indicated information.

☐ Examine live plants, color slides, and photographs

☐ Complete the chart for each nutrient deficiency noted. Group nutrients according to nutrient type: primary, secondary, or micronutrients.

NUTRIENT DEFICIENCY SYMPTOMS - Hunger Signs

Deficient Nutrient	Nutrient Type	Crop Affected	Growth Stage Affected	Description of Hunger Signs
Example: Phosphorus (P)	Primary	Corn	Mature	• Small, curled ears • Immature kernels on one side of ears

Performance Checklist

The following are examples of nutrient deficiencies to include in your chart. If you include them, check the appropriate boxes.

☐ *Nitrogen* deficiency – corn plant and developed ear

☐ *Phosphorus* deficiency – young corn plant and developed ear

☐ *Potassium* deficiency – corn plant and developed ear

☐ *Magnesium* deficiency – corn and soybean plants

☐ *Boron* deficiency – alfalfa and/or clover plants

☐ *Zinc* deficiency – corn plant

KEY TERMS

■ Following is a list of important terms found in this chapter. Can you define them?

- alkaline
- amino acids
- catalyst
- chlorosis
- element
- essential nutrients
- hunger signs
- immobile element
- lodging
- mineral nutrient
- nonmineral nutrient
- micronutrient
- nutrient
- translocation
- nutrient deficiency
- nutrient interaction
- photosynthesis
- primary nutrient
- protein
- regulator
- secondary nutrient
- soil acidity
- symptom
- synthesize
- trace elements

Chapter 2

Soil Chemistry and Plant Nutrient Absorption

Introduction

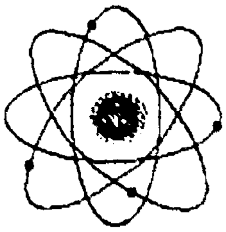
Chapter 1 discussed the 13 mineral nutrients required by plants. Although some plants need large amounts of nutrients and others need very small amounts, all 13 mineral nutrients are vital for good plant growth.

This chapter describes nutrient reactions in the soil and the consequent plant nutrient absorption. If you understand these concepts, you can provide better soil fertility conditions for your crops.

OBJECTIVES

After studying this chapter you should be able to do the following:

- Explain the difference between an element and a compound.
- Explain the difference between an atom and an ion.
- Describe how fertilizer salts react in the soil.
- Describe how nutrients are held in an exchangeable form.
- Explain the cation exchange capacity (CEC) of a soil.
- Explain plant nutrient absorption.



SCIENCE CONCEPTS

This chapter covers the following science concepts:

- Soil is formed through a number of processes.
- Numerous chemical reactions must take place before plants can obtain needed nutrients.
- Certain elements and chemical compounds have positive (+) electrical charges; others have negative (-) electrical charges.
- The electrical charge of an element or compond determines how it will react with other elements or compounds.
- Compounds are transformed through chemical reactions occurring in the soil.
- Nutrients are able to move through the soil.

Elemental Nutrients and Compounds

When referring to plant nutrients, we generally use the element name – for example, nitrogen, phosphorus, and potassium. However, when a nutrient is in its elemental form, it is usually not available for plant use. To be available to plants, this elemental nutrient must combine with another element (or elements) to form a **compound**.

Following are three examples using the primary nutrients to illustrate the concepts of compound formation and the resultant nutrient absorption:

1. NITROGEN

In its elemental form, nitrogen is a gas that comprises about 21 percent of the earth's atmosphere. However, it cannot be used by plants in this gaseous state. Therefore, nitrogen must combine with another element to form a compound before it can be used by plants. For example, when one part *nitrogen* combines with three parts *oxygen*, the compound **nitrate** (NO_3) is formed. Also, when one part *nitrogen* combines with four parts *hydrogen*, the compound **ammonium** (NH_4) is formed. Both of these compounds make nitrogen available for plant use. Plants commonly obtain most of their nitrogen from the nitrate compound (NO_3).

2. PHOSPHORUS

Phosphorus is seldom found in its elemental form because it is very unstable. When exposed to air it bursts into flame; therefore it must be immersed in water. Consequently, phosphorus is typically found and used in the compound form: **phosphate** (H_2PO_4).

3. POTASSIUM

Potassium (like phosphorus) is unstable in its elemental form. Since it bubbles violently when immersed in water, it has very little practical use in this form. Therefore, potassium must be combined with another element(s) to be useful. **Potash** (K_2O) is the form in which most potassium is supplied to soil.

Properties of Atoms, Ions, and Salts

Each particle of soil, organic matter, or plant nutrient carries an **electrical charge**. This electrical charge is either **positive** (+) or **negative** (-). How nutrients react in the soil and eventually become available for plant use is determined largely by the electrical charge each nutrient carries. Like charges repel each other; unlike charges attract each other. Consequently, the like poles of magnets repel each other, and the unlike poles attract each other.

Clay and organic matter particles in the soil carry negative (-) charges; many plant nutrients carry positive (+) charges. If plant nutrients carry positive charges, they are attracted to the negative charges of the clay and organic matter particles (see Figure 21). Therefore, these plant nutrients are held in the soil. On the other hand, if the plant nutrients have negative charges, they are repelled by the clay and organic matter particles. What happens to these negatively charged nutrients is explained later.

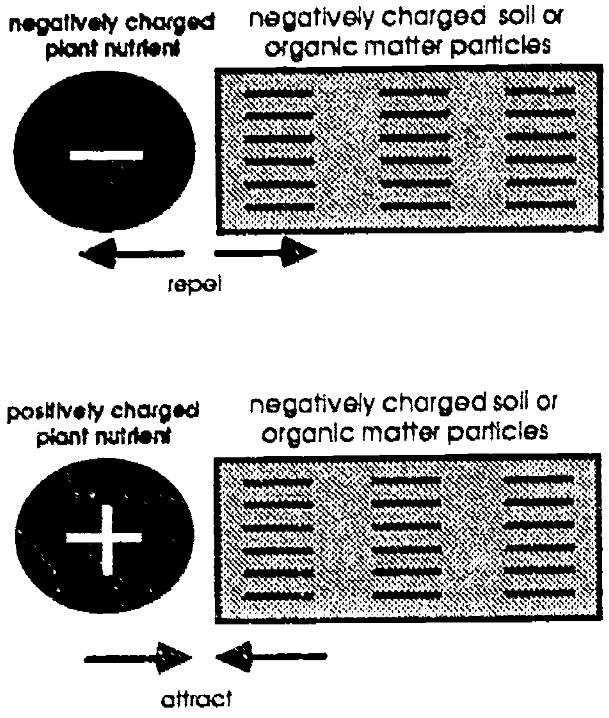


FIG. 21. *Top:* Like charges repel each other.
Bottom: Unlike charges attract each other.

ATOMS AND IONS

An **atom** is the smallest existing particle of an element. When the atoms of two different elements combine, a compound is formed. The previous section described the formation of the plant nutrient compound nitrate (NO_3 - the element nitrogen combined with the element oxygen). In such a reaction, the chemical elements change from electrically **neutral** (neither positive nor negative) atoms to electrically charged **ions**. An ion is an atom or a combination of atoms having either a positive (+) or negative (-) electrical charge. An ion carrying a positive charge is called a **cation**; an ion carrying a negative charge is called an **anion**. Since nitrate (NO_3) and phosphate (H_2PO_4) carry negative charges, they are anions.

SALTS

Plant nutrients added to soils through commercial fertilizers are usually **salts**. Some nutrient salts dissolve in the **soil solution** (soil water); others are more stable. When stable salts dissolve in the soil solution, the free ions react with ions present in the soil. These reactions form new salts that are more insoluble than the original salts. Thus, depending on the nutrient's solubility, one of the following two conditions can exist in the soil:

1. If a nutrient salt is very soluble or unstable in the soil solution, it dissolves completely; therefore, plants are able to absorb it very easily. This is the case with nitrate (NO_3). Also, since nitrate completely dissolves and becomes a part of the soil solution, it can be **leached** (dissolved out) from the soil by water drainage.
2. If a nutrient salt is converted to a very stable form, only a small supply of nutrient is immediately available to the plant. However, as the plant absorbs this supply of nutrients in the soil solution, the stable salt slowly dissolves. This process allows the nutrient to be held in **reserve** until it can be used by the plant. Phosphate (H_2PO_4) is a salt that reacts in this way when applied to the soil.

Plant Nutrient Sources in the Soil

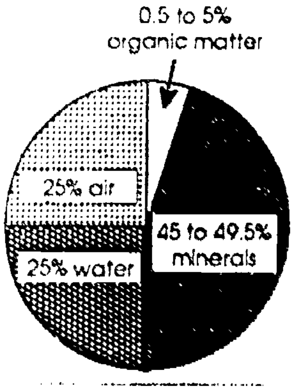


FIG. 22 Composition of a typical mineral soil

As shown in Figure 22, soil is composed of minerals, air, water, and organic matter. Soil nutrients are supplied to plants through the following means (see Figure 23):

- Weathering of rocks
- Decomposition of organic matter
- Soil solution transportation

Two other nutrient sources are shown in Figure 23: commercial fertilizer and limestone. These two sources, needed for most crop growing situations, are added to the soil as supplements.

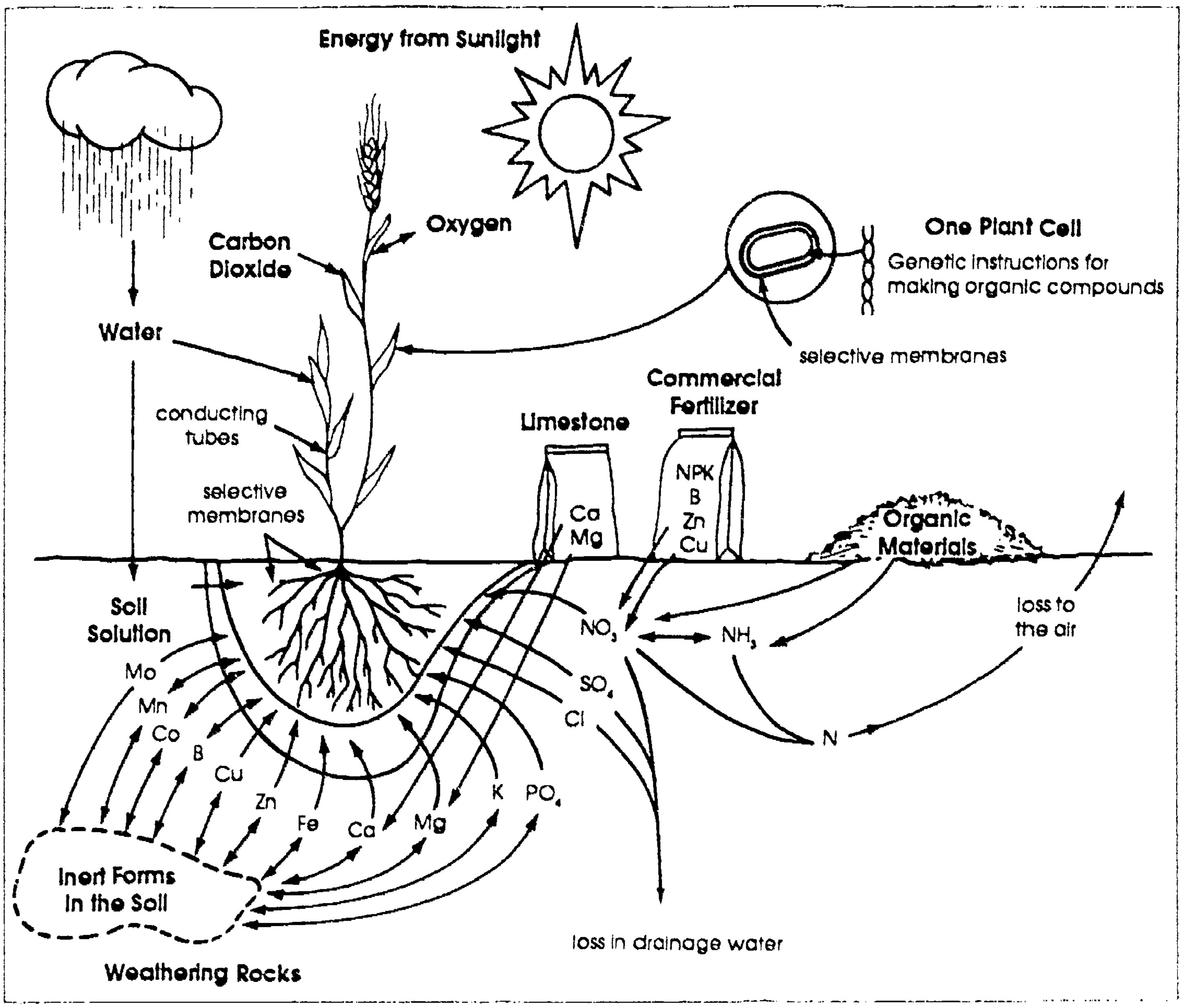


FIG. 23. Plant composition is controlled by genetics (inherited characteristics) and soil and environmental conditions.

WEATHERING OF ROCKS

The weathering or breaking down of rocks forms the mineral part of the soil and supplies some nutrients (see Figure 23). During weathering the action of water, air, and extreme temperature changes breaks down large rock fragments into small soil particles (see Figure 24 on page 24). These soil particles often contain large amounts of phosphorus, potassium, calcium, and magnesium. (Molybdenum, manganese, boron, copper, iron, and zinc are also usually present, but in much smaller amounts.) As shown in Figure 23, soil minerals are not a source of nitrogen; however, nutrients have been added to the soil to meet plant requirements. The quantity of each nutrient present depends on the rock from which the soil was formed – that is, whether the rock was shale, sandstone, or limestone. This rock is called **parent material.**

Even though the rock or parent material is broken down into small particles during weathering, the nutrients are not available for plant use. Weathering is a slow process, and in most soils it cannot provide enough nutrients for good plant growth. Further action by water, air, and temperature is required to convert the nutrients to compounds available for plant use. This is also a slow process. For example, it is estimated that the mineral part of some soils may contain as much as 40,000 to 60,000 pounds of unavailable potassium per acre at plow depth. However, there may be only 200 to 300 pounds per acre at plow depth in a form available for plant use.

DECOMPOSITION OF ORGANIC MATTER

Organic matter is an important reservoir of nutrients. Crop residues and manure contain considerable amounts of nitrogen, phosphorus, and sulfur. Soil organic matter holds these nutrient ions in an **exchangeable** form. (This is discussed in more detail beginning on page 25.) In order for these nutrients to be converted from an **organic** compound element (unavailable to plants) to an **inorganic** compound element (available to plants), organic matter decomposition must occur. This decomposition is done by microscopic organisms that digest plant residues (see Figure 25). These soil **microorganisms** are very sensitive to environmental conditions. Therefore, organic matter decomposes best under the following environmental conditions:

1. Soil temperatures are 75° to 90° F (24.08° to 32.48° C)
2. Soil pH is above 6.0
3. Soil has moderate but not excessive amounts of moisture
4. Soil has normal proportions of solids, water, and air. If a soil is waterlogged (excess moisture), it does not contain enough air for microorganisms to decompose organic matter.

During decomposition, organic matter is converted to carbon dioxide, water, and gas. However, a small amount of nitrogen and minerals remains as **humus** (organic part of the soil).

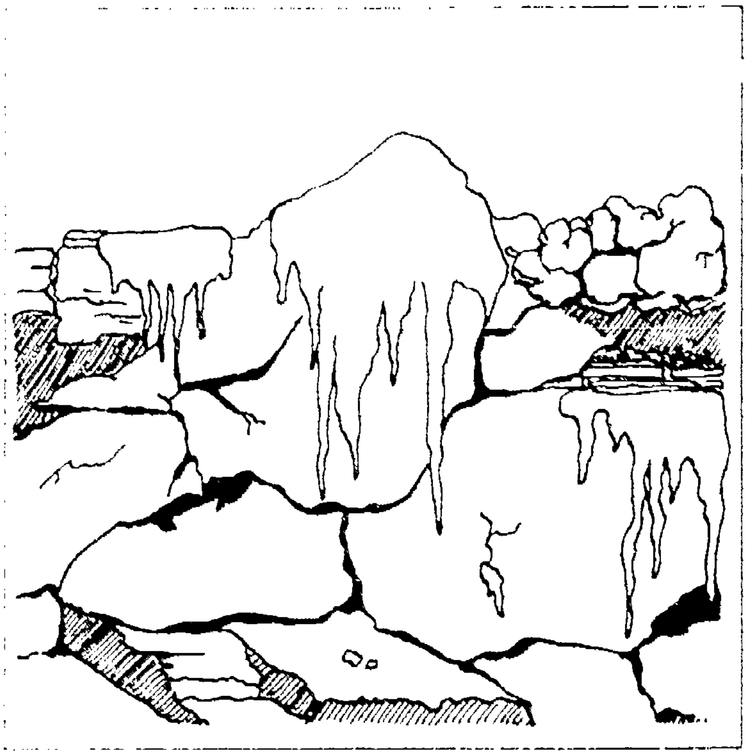


FIG 24. Large rocks are broken down into small particles through the weathering action of water, air, and extreme temperature changes.

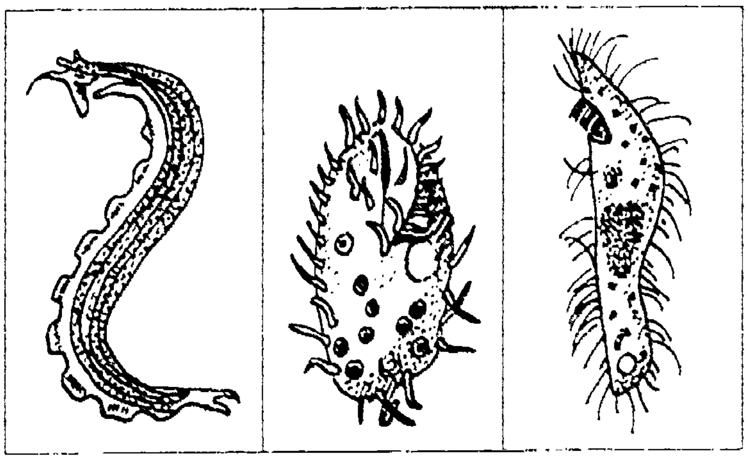


FIG. 25. Soil microorganisms like these digest plant residues and decompose soil organic matter.

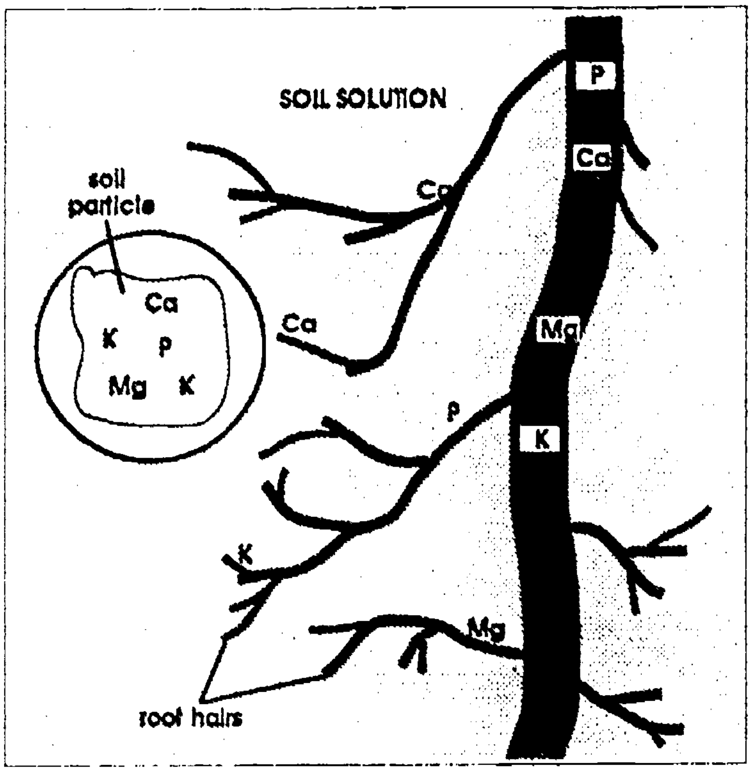


FIG. 26. Plants take up soil nutrients through their root hairs. As nutrients are removed from the soil solution, they are replaced with nutrients from the soil minerals and organic matter.

SOIL SOLUTION TRANSPORTATION

As shown in Figure 22, soil contains about 25 percent water (soil solution). This soil solution provides a means for some nutrients to move into plant roots, but very small amounts of plant nutrients are found in the soil solution of low-fertility soils. However, even in very fertile soils, plants could not survive if they had to depend on only the soil solution nutrients.

Under actual growing conditions, plants remove nutrients from the soil solution. But, as these nutrients are removed, nutrients from the soil minerals and organic matter replace them (see Figure 26). Thus, the amount of plant nutrients in the soil solution remains constant. **Fertile** soils have enough reserve nutrients in soil minerals and organic matter to replace those removed from the soil solution. **Infertile** soils cannot supply enough nutrients to the soil solution from reserves in the soil minerals and organic matter.

Plant Nutrients Held in an Exchangeable Form in the Soil

As mentioned previously, the atoms of the clay and organic matter particles have a negative electrical charge. These negatively charged particles are often referred to as **exchange sites**. Since ions with opposite charges attract each other, positively charged plant nutrient ions are attracted and held by the soil's negatively charged clay and organic matter particles.

TABLE 3. Essential plant nutrients, their chemical symbols, sources, and amounts in soils

		IONS TAKEN UP BY PLANTS			PLANT NUTRIENT CONTENT OF A FERTILE SILT LOAM SOIL	
Element	**Chemical Symbol**	**Ion**	**Chemical Symbol and Electrical Charge**	**Major Source in the Soil**	**Total Amount (Lb/A)**	**Amount Available According to Soil Test (Lb/A)**
Nitrogen	N	Nitrate Ammonium	NO_3^- NH_4^+	Organic matter	4,000	No reliable test*
Phosphorus	P	Phosphate	$H_2PO_4^-$	Organic matter Soil minerals	2,000	50
Potassium	K	Potassium	K^+	Soil minerals	40,000	200
Calcium	Ca	Calcium	Ca^{++}	Soil minerals	10,000	5,000
Magnesium	Mg	Magnesium	Mg^{++}	Soil minerals	8,000	500
Sulfur	S	Sulfate	SO_4	Soil minerals Rainwater	2,000	No reliable test
Manganese	Mn	Manganese	Mn^{++}	Soil minerals	2,000	80
Boron	B	Borate	H_2BO_3	Organic matter	100	2
Copper	Cu	Copper	Cu^{++}	Soil minerals Organic matter	100	No reliable test
Zinc	Zn	Zinc	Zn^{++}	Soil minerals Organic matter	100	50
Iron	Fe	Ferrous	Fe^{++}	Soil minerals Organic matter	50,000	No reliable test
Molybdenum	Mo	Molybdate	MoO_4^-	Soil minerals Organic matter	2	No reliable test
Chlorine	Cl	Chloride	Cl	Soil minerals Rainwater	Variable	No reliable test

*No reliable test for available nitrogen. Organic matter test is used to estimate the N-supplying power of the soil. A soil organic matter content of 3 percent supplies 50 to 90 pounds of N.

Table 3 lists the plant nutrients and their electrical charges. It also shows that the nutrient ions of ammonium (NH_4), potassium (K), calcium (Ca), magnesium (Mg), manganese (Mn), copper (Cu), zinc, (Zn), and iron (Fe) carry positive charges. All positively charged plant nutrient ions held by the soil particles are **exchangeable.** The following explanation of the action of hydrogen and aluminum ions clarifies this term.

HYDROGEN AND ALUMINUM IONS

The acid-causing ions of hydrogen (H) and aluminum (Al) are positively charged. Therefore, they attach to the exchange sites (-) of clay and organic matter particles. The reaction occurs in the following way:

1. First, the exchangeable plant nutrients are held on the exchange sites of the soil (clay and organic matter particles) (see Figure 27). Although this prevents them from leaching into the soil solution, these nutrients are readily available to plants.

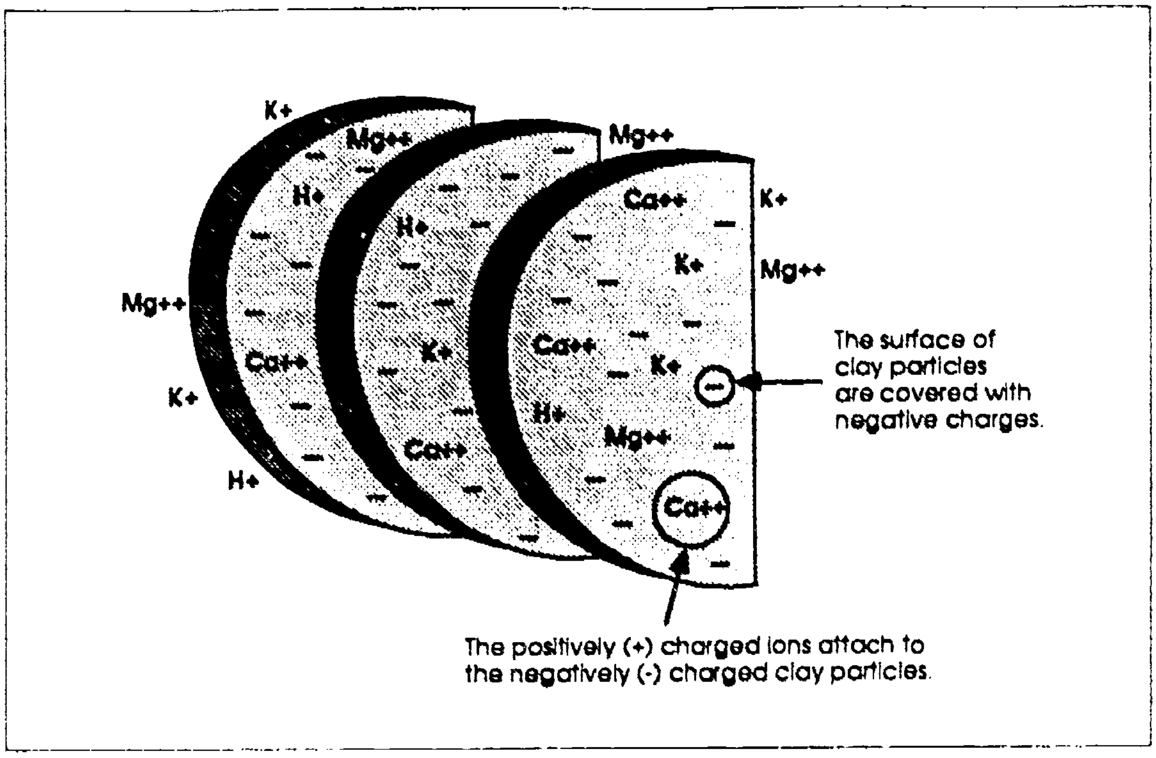


FIG. 27. Negatively charged (-) clay particles attract and hold the positively charged (+) plant nutrient ions.

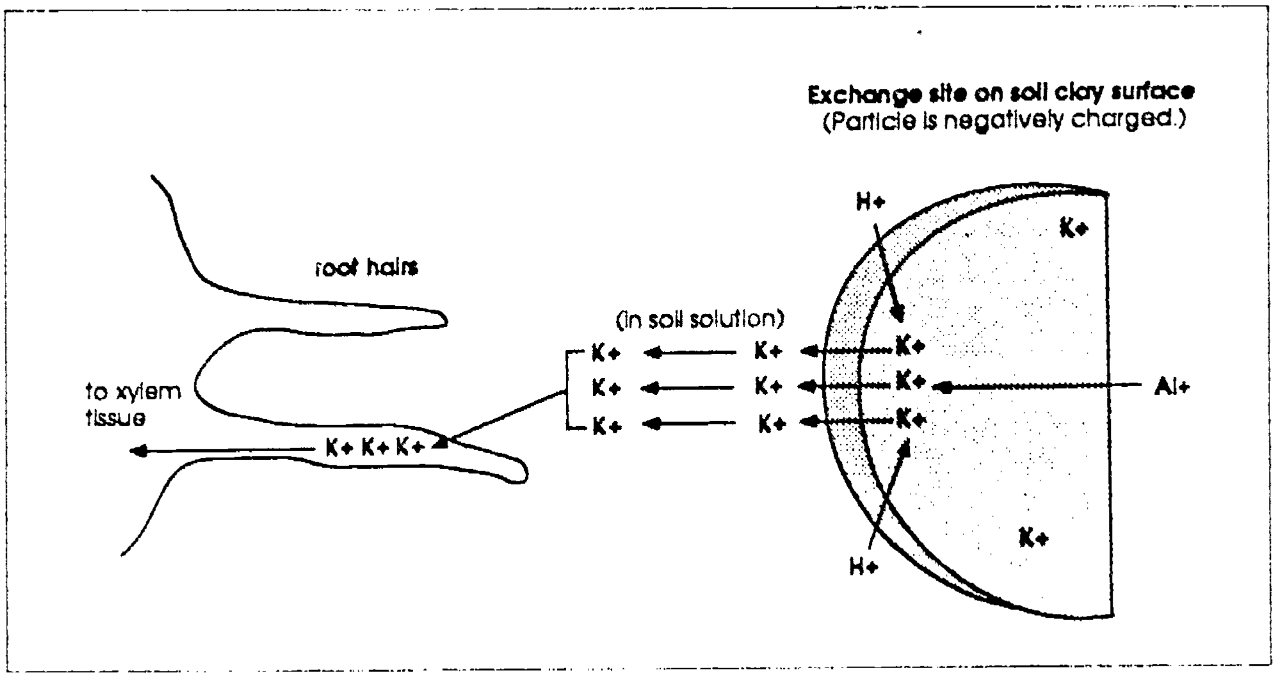


FIG. 28 The plant takes up three exchangeable potassium ions (K^+) from the surface of the clay particle through the soil solution. At the same time, two hydrogen ions (H^+) and one aluminum ion (Al^+) move from the soil solution to replace the potassium ions on the clay particle.

2. Next, the clay particle exchanges a nutrient ion (K^+) needed by the plant for an unneeded ion (H^+ or Al^+) from the soil solution. These exchanges occur at the exchange sites on the clay particle. In Figure 28 three potassium (+) ions move from the exchange site on the clay particle to the plant. They are replaced on the clay particle by two hydrogen (+) ions and one aluminum (+) ion that move from the soil solution to the clay particle.

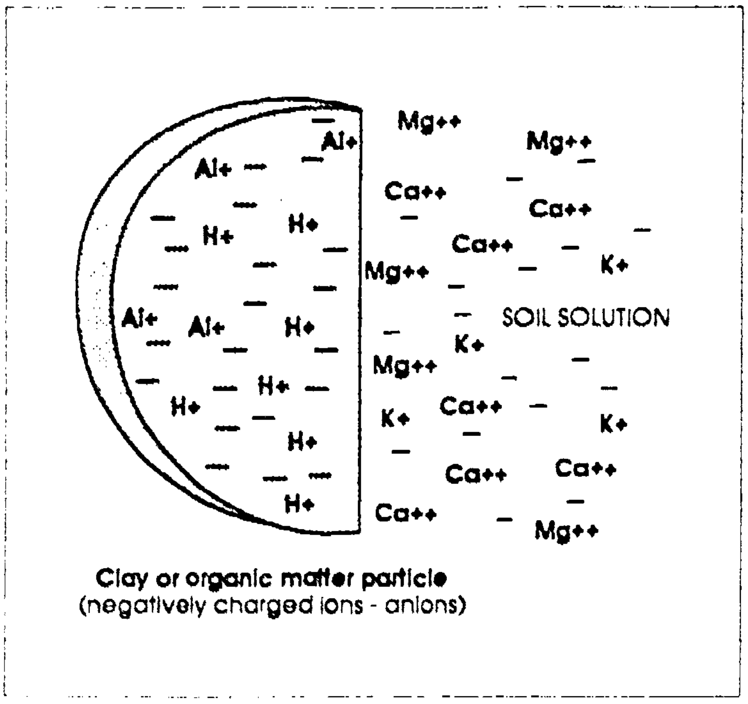


FIG. 29. If the plant nutrients calcium (Ca^{++}), magnesium (Mg^{++}), and potassium (K^{+}) move into the soil solution and no fertilizer is applied or available in the soil to replace them, hydrogen (H^{+}) and aluminum (Al^{+}) ions replace them

TABLE 4. Approximate range of CEC's for different soil textures

Soil Texture	**CEC Range** (milliequivalents)
Coarse (sands)	5 to 15
Medium (silts)	8 to 30
Fine (clays)	25 to 50
Organic soils	50 plus

To summarize, one positively charged ion is exchanged for another positively charged ion. If no potassium, magnesium, or calcium nutrient sources are supplied to a soil, this process reoccurs for each nutrient until there is a concentration of hydrogen and aluminum ions on the exchange sites (see Figure 29). Then the soil is acid and infertile.

CATION EXCHANGE CAPACITY OF SOIL

Soils can be classified by the amount of cations (positively charged ions) they can hold. Those soils high in clay and organic matter content have high cation exchange capacities (CEC). Table 4 gives the approximate CEC's of four soil textures.

The CEC is measured in milliequivalents per 100 grams of soil. A milliequivalent is one milligram atomic weight of hydrogen, or the amount of any other ion that combines with or displaces this same amount of hydrogen. Since the procedure for determining a millequivalent value is complicated, it will not be described here. However, remember that CEC value represents the soil's ability to hold necessary nutrients in reserve.

As shown in Table 4, the cation exchange capacity of a coarse soil is very low compared to other soils. This is due to coarse soil's low clay and organic matter content. A coarse soil is infertile because it cannot hold many positively charged nutrients on its exchange sites to serve as nutrient reserves.

Plant Nutrient Absorption

The plant's **root system** performs the following important functions:

1. *Anchors the plant in the soil*
2. *Absorbs nutrients* - The majority of the plant's nutrients are absorbed through the root system. This process is called **absorption.**
3. *Stores food* - Potato and sugar beet crops store food in their roots.

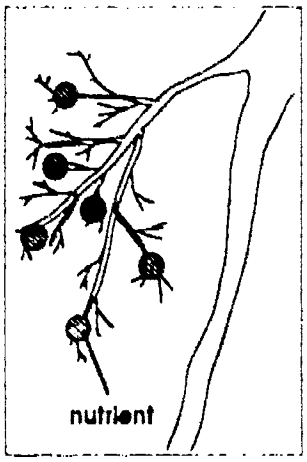


FIG. 30. The root hairs absorb most of the plants nutrients.

Most of the plant nutrients are absorbed at the root hairs of the root system (see Figure 30). These root hairs serve as a screen or sieve when plant nutrients enter the root system. In other words, they are selective in the kinds and amounts of nutrients they allow to enter the root system.

As the root hairs absorb nutrients, they also expel waste elements. Among these waste elements are positively charged hydrogen ions (cations) and some negatively charged ions (anions). As the hydrogen ions (+) separate from the root, they leave negative charges on the root hair surface. Then the positively charged nutrient ions are attracted to these negative charges on the root hair surface. (Refer to Table 3 on page 26 for electrical charges of nutrient ions.) Similarly, the release of negatively charged ions causes the root hair surfaces to be positively charged. Therefore, negatively charged nutrient ions are attracted to these positive charges on the root hairs (see Figure 31).

The nutrients attracted to these negative and postive charges are supplied to plants in the following ways:

1. **Mass flow** - This is the movement of nutrients from the soil solution (water) into the roots. As transpiration takes place in the plant leaves, the water in the roots moves to the leaves where it is most needed. This lowers the water pressure in the roots. As a result, the water pressure in the soil is now greater than the water pressure in the roots. Absorption takes place and water moves from the soil solution into the roots (see Figure 32). Mass flow plays an important part in moving water-soluble nutrient ions into plants.

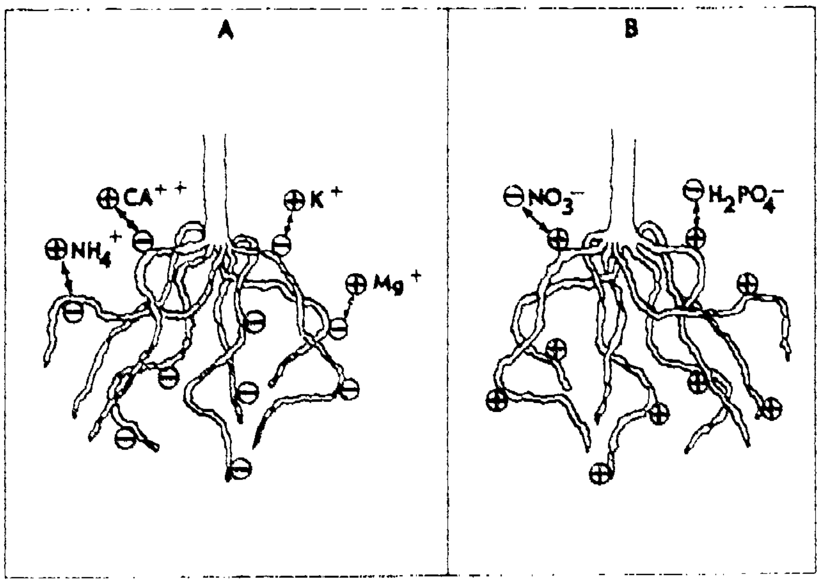


FIG. 31. *A:* If the root hairs have a negative (-) charge, they attract nutrients having a positive charge (+); *B:* If the root hairs have a positive charge, they attract nutrients having a negative charge.

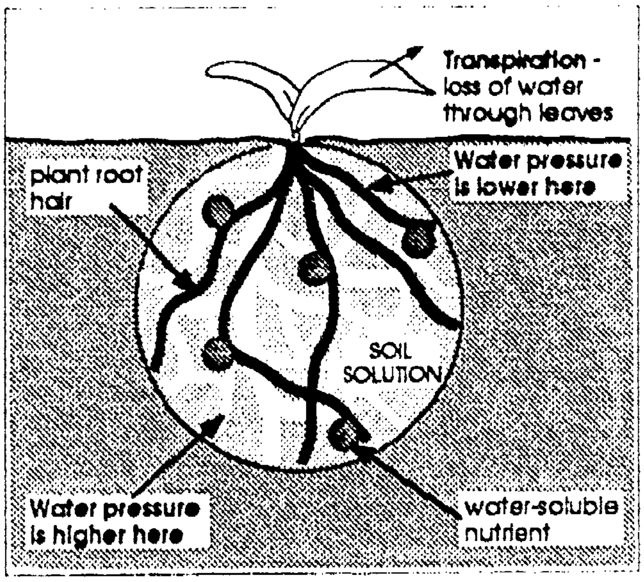


FIG. 32. When the water pressure in the root hairs lowers due to transpiration, water-soluble nutrients move by mass flow into the plant.

2. **Root interception** - As the roots and root hairs grow, they penetrate the soil. In turn, the root hairs come in direct contact with the nutrient ions held on the exchange sites of the clay and organic matter particles. In other words, the roots *intercept* the nutrient ions on the exchange sites (see Figure 33).

3. **Diffusion** - As roots absorb nutrients, the nutrient-ion concentration in the area immediately surrounding the root hairs decreases. Now the soil outside this area has a higher nutrient-ion concentration. So, nutrient ions in this high-concentration area **diffuse** or move into the low-concentration area (near the root hairs) (see Figure 34).

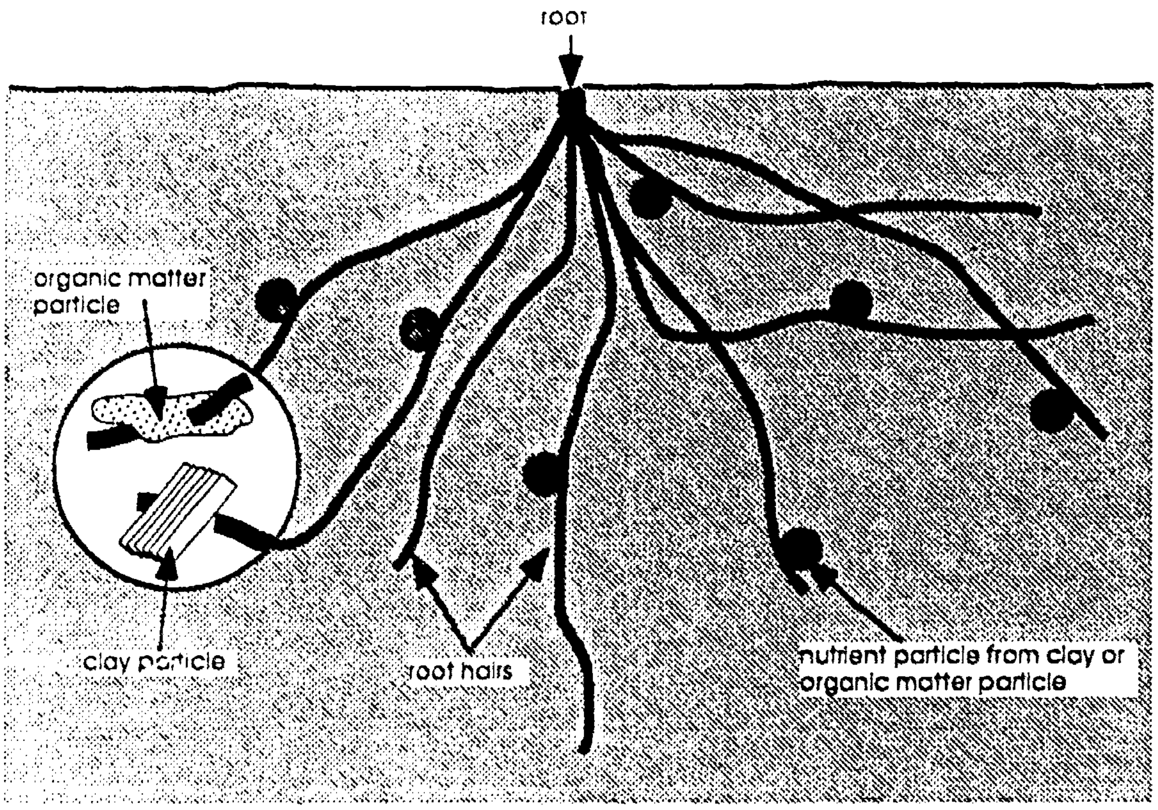


FIG. 33. As roots and root hairs grow, they come in contact with nutrient ions held on the soil exchange sites (clay and organic matter particles). This is called root interception.

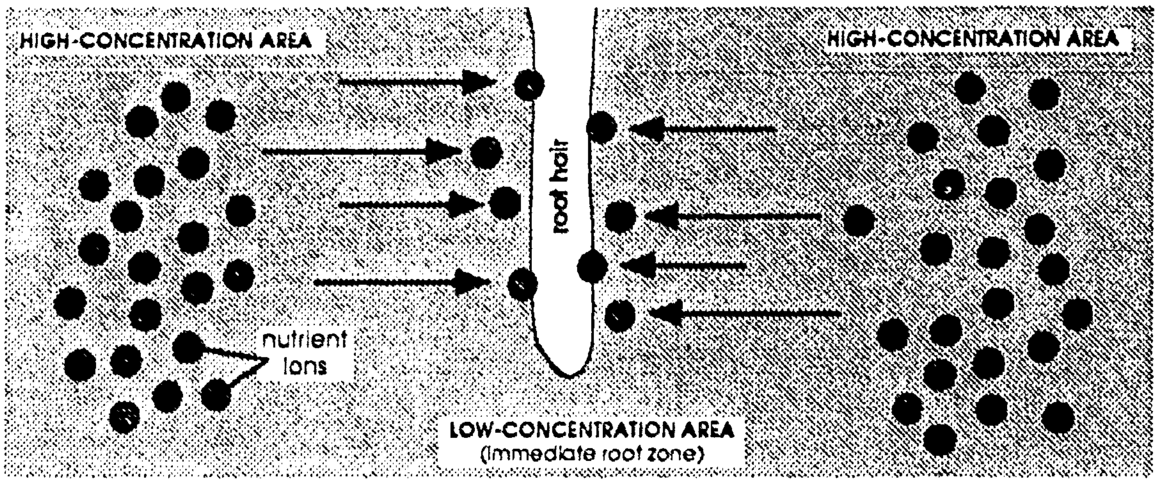


FIG 34. Nutrient ions in high-concentration areas move to low-concentration areas. This is called diffusion.

Plant Nutrient Selection

After nutrients are absorbed by roots, they move through the **xylem** (conducting tissue of the plant) to other plant parts, especially the leaf. The leaf is where the majority of food manufacture takes place.

Each plant species has different food-manufacture and growth processes. As discussed in Chapter 1 - Table 2, the amount of nutrients needed and used is different for each species. If an adequate supply of all needed nutrients are available and absorbed by the plant, certain plant cells determine the amount of each nutrient to use. The action of these cells is determined by **genetics** (inherited characteristics). (Review Figure 23 on page 23.) These cells also determine the kind of organic compounds each plant species produces. For example, soybean seeds contain more than three times as much protein as corn seeds. This is one reason why soil testing laboratories require information about crops to be grown before making fertility recommendations.

KEY TERMS

■ Following is a list of important terms found in this chapter. Can you define them?

absorption
anion
atom
cation
cation exchange capacity
compound
convert
decomposition
diffusion
electrical charge
exchangeable
exchange site
fertile
genetic
humus
infertile
inorganic
ion
leaching
mass flow
microorganism
milliequivalent
negative charge
neutral
organic
organic matter
parent material
positive charge
reserve nutrients
root interception
root system
salt
soil solution
weathering
xylem

Chapter 3

Determining Nutrient Needs of Crops

Introduction

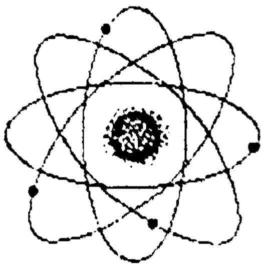
High crop yields demand highly fertile soils. These high yields improve production efficiency and are necessary for you, as a crop producer, to make a profit. For these reasons, you must be sure that any controllable production factors do not limit crop growth or quality. For example, new crop varieties and hybrids capable of producing much higher yields make greater demands on soil fertility. Unless these greater demands are met, you cannot take advantage of the high-yield capacities of these new varieties and hybrids. To produce high crop yields, all the necessary nutrients must be available in sufficient amounts.

OBJECTIVES

After studying this chapter you should be able to determine crop nutrient needs by using the following procedures:

- Determine the crop yield goals for each crop - Crop yield goals are needed to submit a soil sample for testing, to determine the amount and kind of fertilizer to apply, and to prepare an accurate budget.
- Prepare a soil map – This map shows soil types, field boundaries, and field numbers. It also permits more efficient soil sampling.
- Prepare a crop use chart for each field – This chart shows the acres of each soil type, field numbers, and yield goals for each crop to be grown. A crop use chart also increases the accuracy of soil test and crop yield records.
- Obtain representative soil samples – A representative sample provides a clearer picture of the soil type being tested.
- Prepare each soil sample for laboratory testing – A carefully prepared sample aids in obtaining accurate test results.

- Provide the needed information when submitting soil samples for laboratory testing – In order to receive accurate recommendations, requested information must be provided for all the soil types and/or fields sampled.
- Select the kind(s) of soil tests to be made – The previous crop growth and crop yield records are used to determine the soil tests to be made.
- Interpret the soil test reports – These reports are used later to determine the amount, kind, and application method of lime and fertilizer. They must be accurately interpreted.
- Obtain a representative crop plant sample for plant analysis – This sample must be representative to ensure an accurate analysis.
- Provide information requested on the plant analysis questionnaire – When submitting plant samples for analysis, information regarding plant growth, soil conditions, soil test data, and fertilizer must be included.
- Interpret the plant analysis report – This report must be interpreted correctly to remedy any detected nutrient deficiencies or excesses.



SCIENCE CONCEPTS

This chapter covers the following science concepts:

- Many factors affect plant growth.
- Several factors affect the nutrient levels needed for optimum plant growth – two of these factors are the soil's cation exchange capacity and degree of acidity.
- The degree of soil acidity (H^+ and Al^+ ions present in the soil) controls nutrient availability.
- Climatic conditions affect soil pH.
- A soil's cation exchange capacity affects that soil's reserve acidity.
- Exchangeable elements must be present in suitable ratios in order for all elements to be available.
- Representative soil sampling requires following a systematic procedure.
- As the number of individual soil samplings increases, so does the chance that mixing these samplings provides an accurate representation of the area to be tested.

Determining Yield Goals

It is important to accurately estimate yields for the crop(s) to be grown. This estimate helps determine the amount of lime and fertilizer to use. Therefore, when submitting soil samples for testing, also provide yield goals for each crop to be grown. This information increases the accuracy of the lime and fertilizer recommendations you receive. Do not select yield goals based on a neighbor's yield from the previous year. Also, do not select a yield goal based on *desired* expectations. A yield goal based on fact provides true crop growing conditions, resulting in accurate lime and fertilizer application recommendations.

To determine realistic yield goals, consider your soil assets. Also consider past performance and planned future performance for each crop to be grown. Following are some important management practices for maintaining or increasing yield goals:

1. Use recommended hybrids or varieties.
2. Use the most effective methods for weed, insect, and disease control.
3. Use recommended tillage practices for the soil type(s) being cropped.
4. Use recommended planting practices.
5. Use the amount and kind of lime and fertilizer specified in soil test recommendations.
6. Use recommended harvesting procedures.

As outlined above and illustrated in Figure 35, many factors influence yields. Therefore, if low yields are obtained year after year, consider making changes in the crop management practices being used.

PROCEDURES FOR DETERMINING CROP YIELD GOALS

As evident from the information presented in Chapter 2, potential yields vary for different soil types. Agricultural research has determined the potential crop yield for major crops grown on most soil types. This information is available from the Cooperative Extension Service in most states.

A review of this information reveals that yield goals can vary widely within a soil region depending on the soil type, slope, and erosion. Therefore, it is not unusual for a farm to have two or more soil types with different yield potentials.

You must identify the soil type(s) that you are dealing with to properly use potential crop yield information. The following text explains how soil type identification can be done.

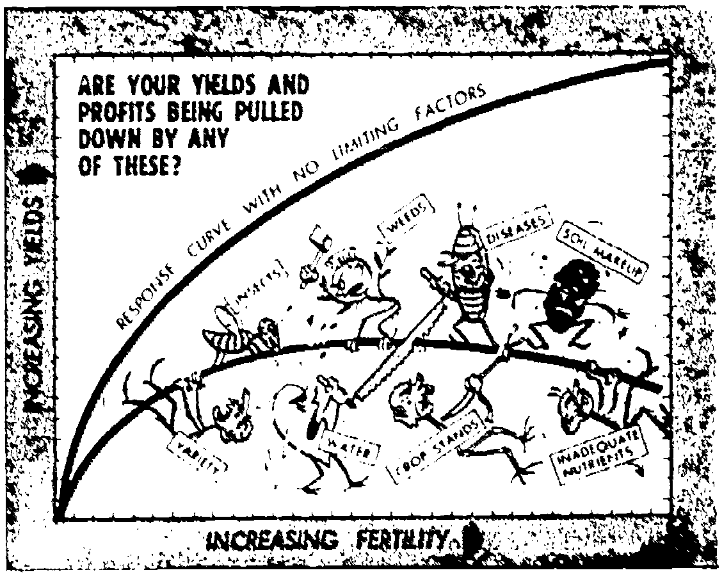


FIG. 35. Crop yields are affected by many factors.
(Courtesy Potash and Phosphate Institute)

Soil Map

Aerial photographs of most individual farms are available at your local county Soil Conservation Service office. An individual farm owner may also have an aerial photograph of his or her farm. If no photograph is available, the county Soil Conservation Service can assist in obtaining one. Using this aerial photograph, a soil map can be prepared. Yield goals for the crops to be grown in each field can be determined from this map. A sample map (shown in Figure 36) includes the following information:

1. Field boundaries
2. Permanent fences
3. Land use (e.g., cropland, pasture, woodland, farmstead, and similar uses)
4. Field acreage
5. Location of streams, ditches, wet spots, and similar features
6. Soil type symbols

Items 1 through 5 above are each represented by a separate symbol when appearing on a soil map (see Figure 37). Since space is limited on farm maps, symbols are used to represent soil types and corresponding descriptive information.

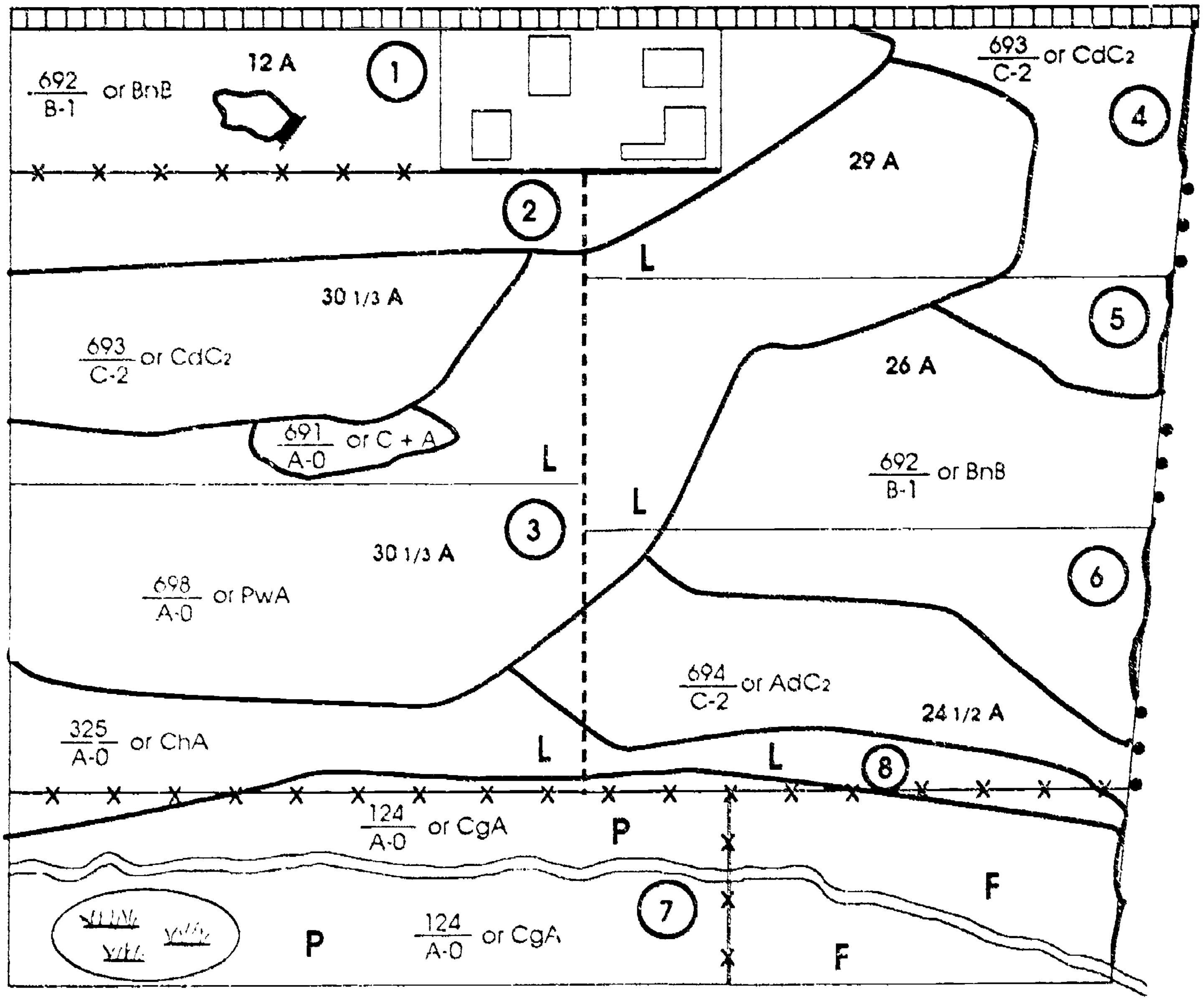


FIG. 36. A soil map

The following soil symbol systems are currently in use:

- **Numbering system**
- **Lettering system**

For example, Figure 36 shows seven soil types on this farm. Each soil type is represented in both letters and numbers: **693/C-2** is a symbol from the numbering system; **CdC2** is a symbol from the lettering system. Both of these symbols represent the same soil type. The name of this particular soil is *Cardington*.

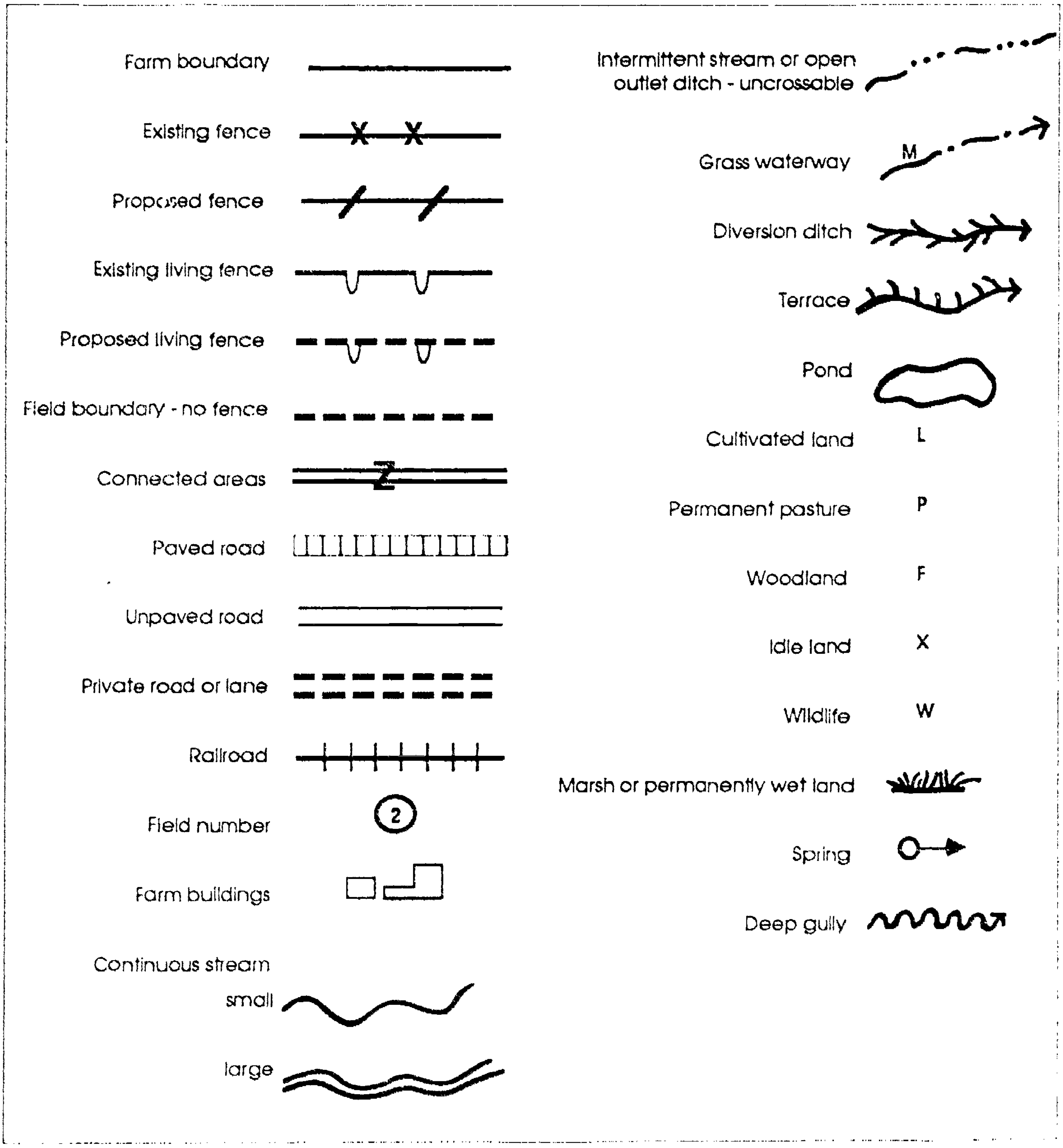


FIG. 37. Soil map symbols

The numbering system (e.g., 693/C-2) has been used for many years. Older soil maps use this symboling system. As shown in Figure 38, the three-digit number above the line (693) describes the soil type. The first digit in this number describes the soil origin and position; the second digit describes the rock (parent material) from which the soil was formed (see Table 5); and the third digit describes the soil profile or natural drainage (see Table 6). If a fourth digit is present, this indicates the soil is of a texture other than silt loam. In other words, if the fourth digit is missing, the soil type is silt loam. Table 7 lists these numbers and their corresponding soil textures. In Figure 38, the letter below the line (C) indicates the slope percentage. Table 8 gives these letters and their corresponding slope percentages. The single-digit number (2) following the slope percentage indicates the amount of erosion. Table 9 lists these numbers and their corresponding amounts of erosion.

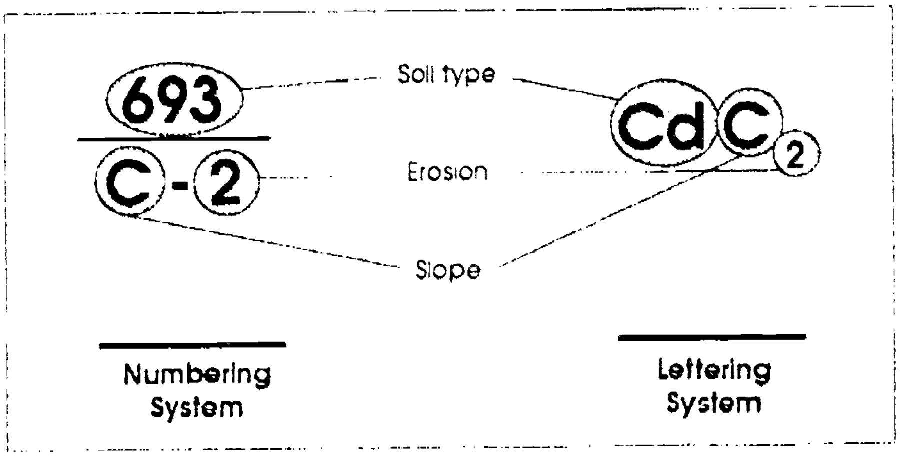


FIG. 38 The numbering and lettering systems for soil maps

TABLE 5. Description of the first digit of the soil numbering system

First Digit	Position and Origin	Development
1	First bottom or allevial	Flood plains
2 or 3	Second bottom or terrace	Old glacial flood plains
4 or 5	Upland	Residential (not glaciated)
6 or 7	Upland	Wisconsin
7 or 8	Upland	Illinois glaciated
9	Upland	Lacustrine (formed from old lake beds)

TABLE 6. Description of the third digit of the soil numbering system

Third Digit (Profile Number)	Natural Drainage
1	Poor
2	Fair to poor
3	Moderately well
4	Well
5 or 6	Excessive
7, 8, or 9	Poor

TABLE 7. Description of the fourth digit of the soil numbering system

Fourth Digit (Texture Number)	Texture Description
0	Sand
1	Loamy sand
2	Loamy fine sand
3	Sandy loam
4	Fine sandy loam
5	Loam
6	Silty clay loam
7	Clay loam
8	Silty clay
9	Clay
No number	Silt loam

The **lettering system** (e.g., CdC2) is newer than the numbering system and will eventually replace it. Symbols used in the lettering system may vary from county to county. Although the soil type may be the same, different letters may be used to represent it. Therefore, if a soil map uses the lettering system, check with your local District Soil Conservation Service before interpreting the symbols. In this particular example the first two letters (Cd) are the soil type symbol (see Figure 38). The letter (C) following the soil type symbol indicates the slope percentage (see Table 8). The digit (2) following the slope percentage symbol indicates the amount of erosion (see Table 9). However, if the erosion is 0 or 1, no digit is used. No symbol is used to describe soil texture in the lettering system.

Determining the Yield Goal

One way to record information about fields to be planted is to draw a map for each field. These **field maps** show each field's number, soil type(s), location, and acreage. A sample field map is shown in Figure 39.

TABLE 8. The amount of slope as designated by letters*

Letter	Slope Percentage or Number of Feet Fall in 100 Feet
A	0 to 2
B	2 to 6
C	6 to 12
D	12 to 18
E	18 to 25
F	25 to 35
G	35 or more

*In the lettering system, no texture description is given.

TABLE 9. Amount of erosion as designated by a number*

Digit	Amount of Erosion
0	More than 14 inches of topsoil
1	Slight erosion, 7 to 12 inches of topsoil
2	Moderate erosion, plow layer mostly topsoil with some subsoil
3	Severe erosion, plow layer mostly subsoil
4	Severely eroded and gullied land

*In the soil lettering system the single-digit number follows the slope letter unless the erosion is 0 or 1 – then no digit is given.

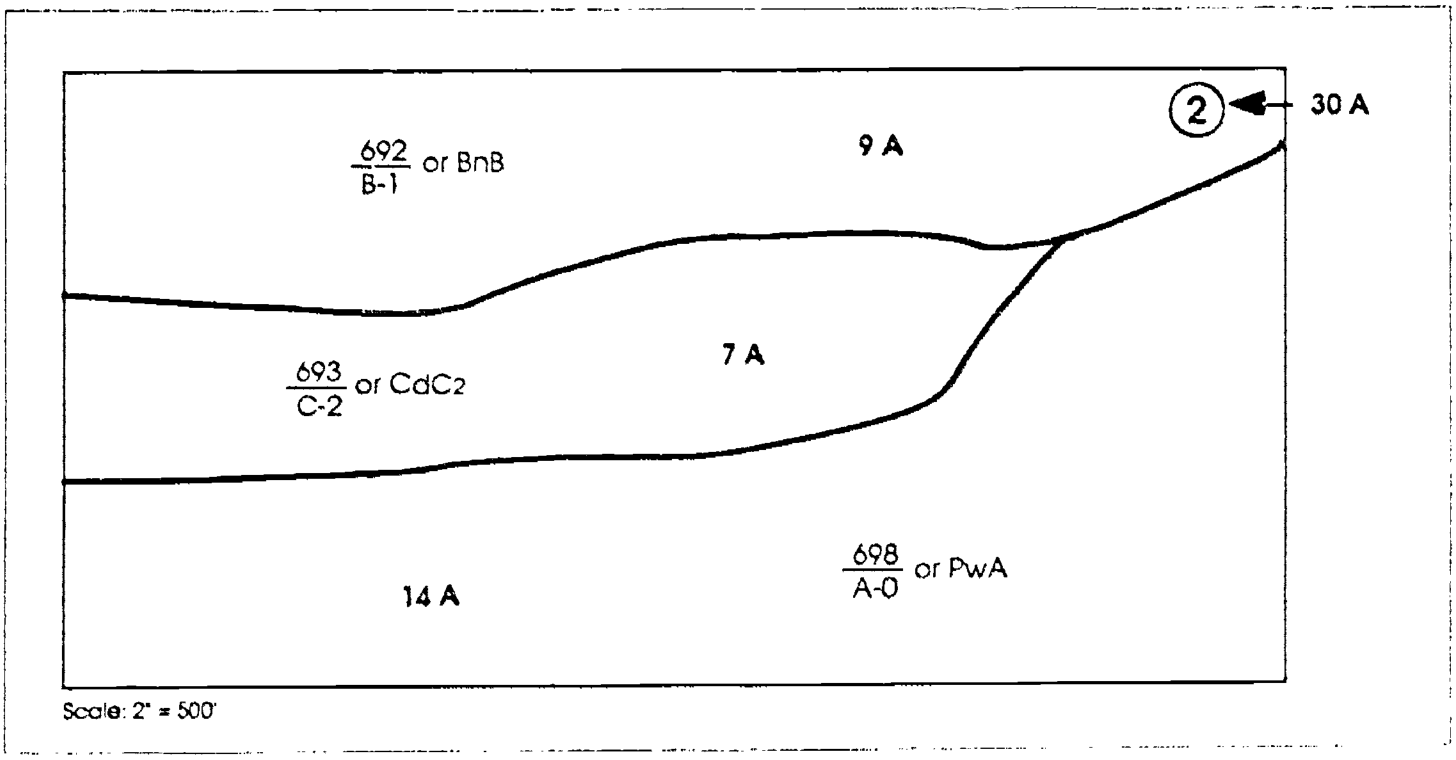


FIG. 39. Field map

TABLE 10. Yield goal determination form

Yield Goal Determination

Field No. 2
Total acres 30
Crop Corn

SOIL CHARACTERISTICS			SOIL TYPE		ACRES	POTENTIAL CROP YIELD		YIELD GOAL
Characteristic	Map Symbol	Characteristic of Area	Map Symbol	Soil Type of Area	Acres of Each Soil Type	Units per Acre	Potential for Each Soil Type (Units/A x Acres)	
Soil texture	No number	Silt loam	692 or Bn	Bennington silt loam	9	160 bu/A	1,440 bu	5,510 bu (total) or 170 bu/A
Slope	B	2% to 6%						
Erosion	1	Slight						
Natural drainage	2	Fair to poor						
Soil origin	6	Wisconsin glaciated						
Soil texture	No number	Silt loam	693 or Cd	Cardington silt loam	7	170 bu/A	1,190 bu	
Slope	C	6% to 12%						
Erosion	2	Moderate						
Natural drainage	3	Moderately well						
Soil origin	6	Wisconsin glaciated						
Soil texture	No number	Silt loam	698 or Pw	Pewamo silt loam	14	180 bu/A	2,520 bu	
Slope	A	0 to 2%						
Erosion	0	None to slight						
Natural drainage	8	Poor						
Soil origin	6	Wiconsin glaciated						
Soil texture								
Slope								
Erosion								
Natural drainage								
Soil origin								

In order to collect all the information needed to make yield goal determinations, use a chart similar to Table 10. The information used to complete Table 10 can be obtained from the following sources:

1. **Soil characteristics** - Determine soil characteristics by interpreting soil type map symbols. Use the field map in Figure 39 and Tables 5 through 9 in this manual.
2. **Soil type** - Soil type names are also determined by interpretation of the map symbols. Obtain the soil type names corresponding to the map symbols from your District Soil Conservation office, Cooperative Extension Service, or soil survey reports (if your county has been surveyed).
3. **Acreage** - If the map is drawn to scale, accurate acreages can be easily determined. Otherwise, the Soil Conservation Service or the Agricultural Stabilization and Conservation Service may be able to provide acreage estimates. Estimates based on information known about the field (e.g., approximate distance between field boundaries) can also be used.
4. **Potential crop yield** - Determine the potential crop yield for the identified soil characteristics and types by using information obtained from the Cooperative Extension Service or other reliable sources.
5. **Yield goal** - The information provided in Table 10 provides a sound basis for determining yield goals. You can choose an appropriate goal by using this information and carefully considering the degree to which each crop management practice will be carried out.

Example - The field map in Figure 39 gives information regarding field soil types, soil characteristics, and acreage. Table 10 gives the information taken from Figure 39, plus the crop yields as determined from information provided by the Cooperative Extension Service.

Diagnostic Methods for Determining Nutrient Needs

As illustrated in Figure 40 on page 42, you can diagnose fertility needs or nutrient shortages by using the following methods:

1. **Field trials** – used extensively by researchers to compare different fertility levels
2. **Soil testing** – laboratory procedures used to determine nutrient shortages in the soil
3. **Plant analysis** – laboratory procedures used to determine nutrient shortages in crop plants

FIELD TRIALS

Field trials are used to compare yields resulting from the application of different kinds and amounts of plant nutrients, and to study nutrient application methods. In addition, agricultural researchers use field trials extensively for comparing other crop production practices.

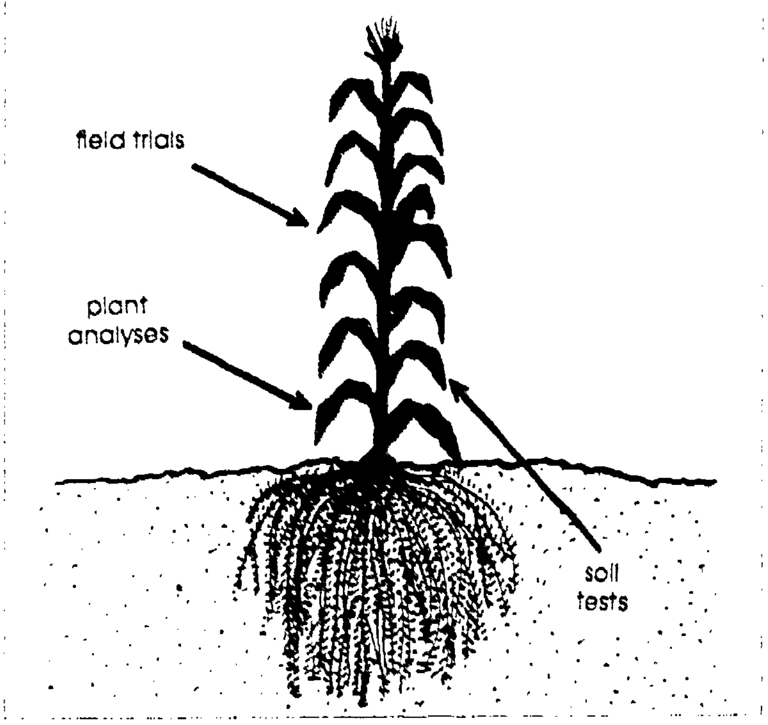


FIG. 40. Fertility needs can be diagnosed by field trials, plant analyses, and soil tests

Observation of nutrient deficiency symptoms is one part of the field trial procedure. Since deficiency symptoms can often be observed in areas of low soil fertility or nutrient imbalance, you can "let your eyes be the soil test." Unfortunately, by the time symptoms can be observed, it is usually too late to correct the problem during the current growing season.

SOIL TESTING

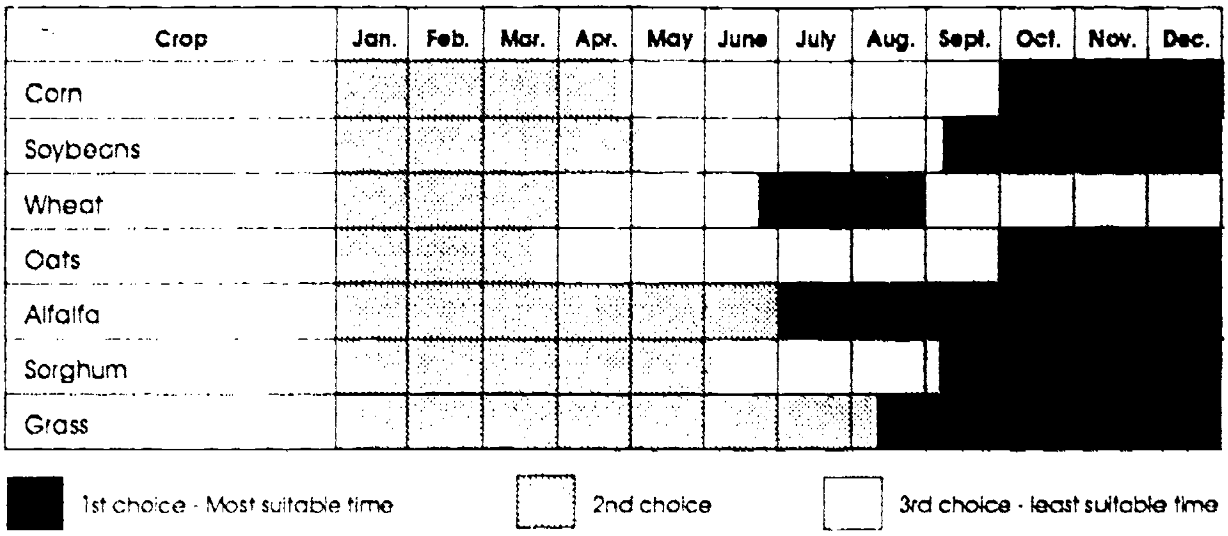
Most states have **soil testing laboratories** operating as part of the state's agricultural research system. The Cooperative Extension Service assists in transporting soil samples to these laboratories. Also, soil testing services are available at some private laboratories. These laboratories can usually be contacted through businesses selling fertilizers or other nutrient additives.

To a great exten , soil testing removes the guesswork from determining the fertility needs for crop production. However, all soil testing procedures must be carefully performed. Otherwise, test results may be misleading and of limited value.

In general, conduct soil tests on all agronomic crop-producing fields about once every three to four years – that is, on fields in which corn, small grains, soybeans, and hay crops are grown. Fields in which vegetables and other high cash value crops are grown may need to be tested more frequently.

The following items must be considered to receive accurate soil test results:

1. When to sample fields
2. How to sample fields



Crop	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Corn	▨	▨	▨	▨	□	□	□	□	□	■	■	■
Soybeans	▨	▨	▨	▨	□	□	□	□	■	■	■	■
Wheat	▨	▨	▨	□	□	□■	■	■	□	□	□	□
Oats	▨	▨	▨	□	□	□	□	□	□	■	■	■
Alfalfa	▨	▨	▨	▨	▨	▨	■	■	■	■	■	■
Sorghum	▨	▨	▨	▨	▨	□	□	□	■	■	■	■
Grass	▨	▨	▨	▨	▨	▨	▨	▨■	■	■	■	■

■ 1st choice · Most suitable time
▨ 2nd choice
□ 3rd choice · least suitable time

FIG. 41. The best times for taking soil samples depend on the crops harvested.

3. How to prepare samples
4. What information to provide regarding the sampled field
5. How to interpret test reports
6. How to keep test result records

When to Sample Fields

Soil samples may be taken whenever soil conditions are suitable. Considering the crop to be grown and using good common sense are probably the best guides when determining the most appropriate time to take samples.

For example, take samples well in advance of the next crop growing season. This gives you plenty of time to interpret laboratory reports and decide the kind and amount of lime and fertilizer to use. Figure 41 shows the periods during the year that are most suitable for sampling fields for different crops. Generally, the best time to sample most fields is shortly after harvest. At this time the field condition and accessibility are usually more suitable. Plus, you have a clearer picture of areas with poor crop growth and low yields. Take separate samples of these areas.

How to Sample Fields

Soil test results can never be more accurate than the soil sample submitted. Taking a representative soil sample of a field is an exacting task, so give careful attention to the procedure used. Each sample should be comprised of many individual cores (or samplings) from one area. It is important to realize that each core taken represents a very small portion of a field's total soil volume. For example, an acre of soil with a depth of nine inches has a volume of 32,670 cubic feet. The representative soil sample submitted for testing this acre measures about one cup. If the area sampled is 10 acres in size and the cup-size sample came from one gallon of cores, the ratio of sample volume to total soil volume would be approximately 1:2,500,000.

SAMPLE BY SOIL TYPE

If the field to be tested has different soil types, take a separate soil sample for each soil type. Different soil types may have different textures, slopes, colors, organic matter contents, and fertility levels. Today's larger farms and fields typically have fields comprised of more than one soil type (see Figure 42).

FIG. 42. The light and dark soils in this photograph indicate this field has different soil types. Do not mix soil types when taking samples *(Courtesy H.E. Ridenour)*

What do you do if the soil test results for one field are different for each soil type? If this occurs, treat each soil type separately, if possible. If this is impractical, meet the needs of the major part of the field. Apply the kind and amount of lime and fertilizer recommended for the majority of the soil. Use your own judgment to determine if an area is large enough for its own fertilizer and lime treatment. For example, a section of the field shown in Figure 43 contains a different soil type but is too small to be treated separately.

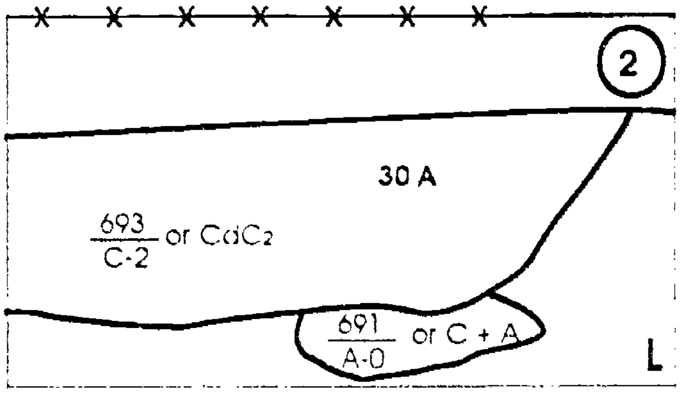


FIG. 43. The section of this field containing a soil type different than the rest of the field is too small to be treated separately.

Field number 2 in Figure 44 has two different soil types. Each of these areas should be sampled separately. Figure 44 also suggests taking 15 cores for sample #1 in field 2 to make it representative of that entire area.

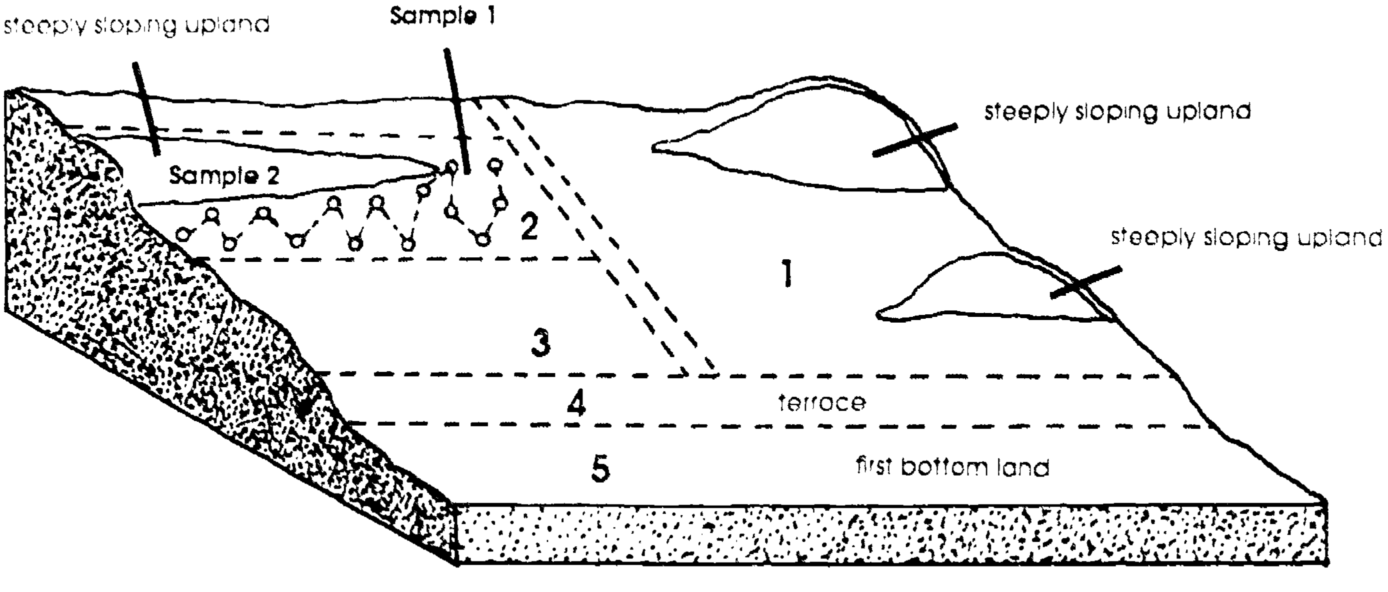


FIG. 44. Since field 2 has two different soil types, take one sample for each soil type

SAMPLE TO THE CORRECT DEPTH

Soil test values for phosphorus, zinc, and organic matter can be greatly affected by the depth at which cores are taken. Therefore, when taking cores be certain to include the plant root zone. For cultivated field crops, take cores to a depth of eight to nine inches so they include the root zone (see Figure 45). When growing a permanent pasture (bluegrass and other turf or lawn grasses), take cores to a depth of three inches (see Figure 46).

FIG. 45. For cultivated field crops, take soil cores to a depth of 8 to 9 inches. *(Courtesy Agronomy Farm, The Ohio State University)*

FIG. 46. In a permanent pasture, take soil cores to a depth of 3 inches. *(Courtesy Agronomy Farm, The Ohio State University)*

SOIL TESTING EQUIPMENT

The following tools can be used for taking soil cores (see Figure 47):

- Soil probe
- Soil auger
- Spade

Soil probes and augers are preferred over spades because they both take uniform amounts of soil from a definite depth.

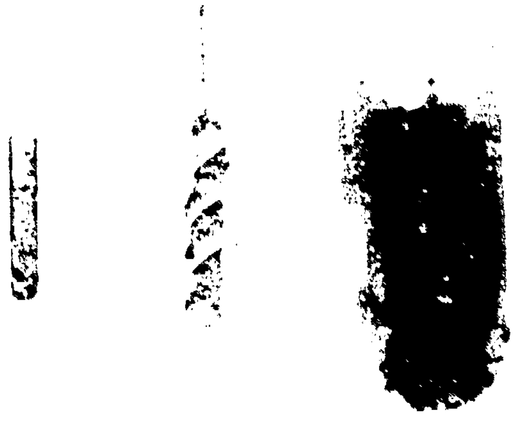


FIG. 47 Tools used for soil sampling – left to right: soil probe, soil auger, and spade

Place all the cores from a particular soil area in a suitable container (e.g., a one-gallon plastic bucket). *The container must be clean.* This is especially important if micronutrient analyses are to be done. Also, do not use a metal bucket for collecting and mixing cores to be analyzed for micronutrients. Soil mixed in a galvanized bucket may pick up zinc from the bucket coating and contaminate the sample.

If several areas are to be sampled, have a supply of plastic or paper bags available. Each area to be sampled should have a designated bag. Place any cores collected from a particular area in that area's designated bag. Clearly indicate on each bag the soil area from which the cores were taken.

OTHER SAMPLING PROCEDURES

Avoid the following areas of a field when collecting soil samples:

1. *Rows in which row crops (e.g. corn) were previously grown* – Banded areas of fertilizer in the rows can make the test inaccurate if cores are taken from these field locations.
2. *Turn rows or other areas where lime or fertilizer may have been spilled* – Extra amounts of supplements can also make the soil test inaccurate if cores are taken from these locations.
3. *Strips near trees or old fence rows* – Nutrients present in these areas may be abnormally high or low when compared to the soil where crop growth is normal.
4. *Dead furrows* – An area of little or no crop growth (Plant growth may be present.)
5. *Any areas in which crop growth differs from the rest of the field* – If these areas are large, take separate samples from each area.

NUMBER OF CORES TO COLLECT

As previously stated, the purpose of taking several soil cores in one area is to get a representative sample. Laboratory test results are no better than the representative sample submitted. As illustrated in Figure 44, take at least 15 cores to make up a representative sample from each soil area. If the area is large or lime and/or fertilizer has been broadcast in the area, take 20 to 30 cores.

If you take the recommended number of soil cores for your area, one or two unrepresentative cores will not affect the test results. This can be compared to dissolving one lump of sugar in a gallon of water: the concentration decreases as the total volume increases.

How to Prepare the Soil Sample

After taking all the cores for a particular area and placing them in the designated bag, prepare this representative sample in the following manner:

1. Break up any lumps or clods in the representative sample. Then spread out the soil to dry (see Figure 48). If you cannot break up the lumps and clods due to excessive soil moisture, allow the sample to air dry first. Do not dry it with artificial heat – this can alter the sample analysis.

2. Next, thoroughly mix the entire contents of the representative sample. Collect approximately one cup of soil for laboratory testing.
3. If you are submitting several representative samples for testing at the same time, clearly mark each sample in the drying area. This prevents sample mix-up.

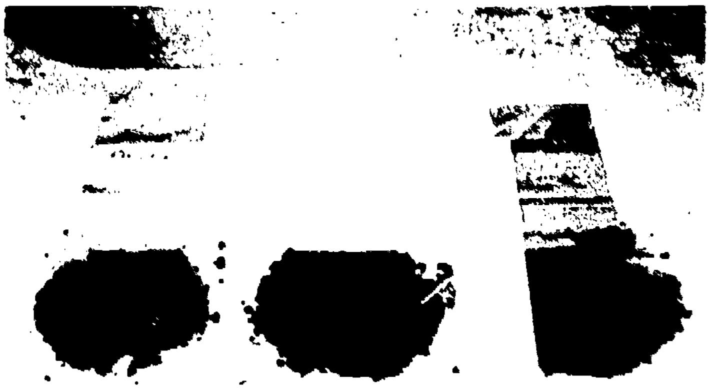


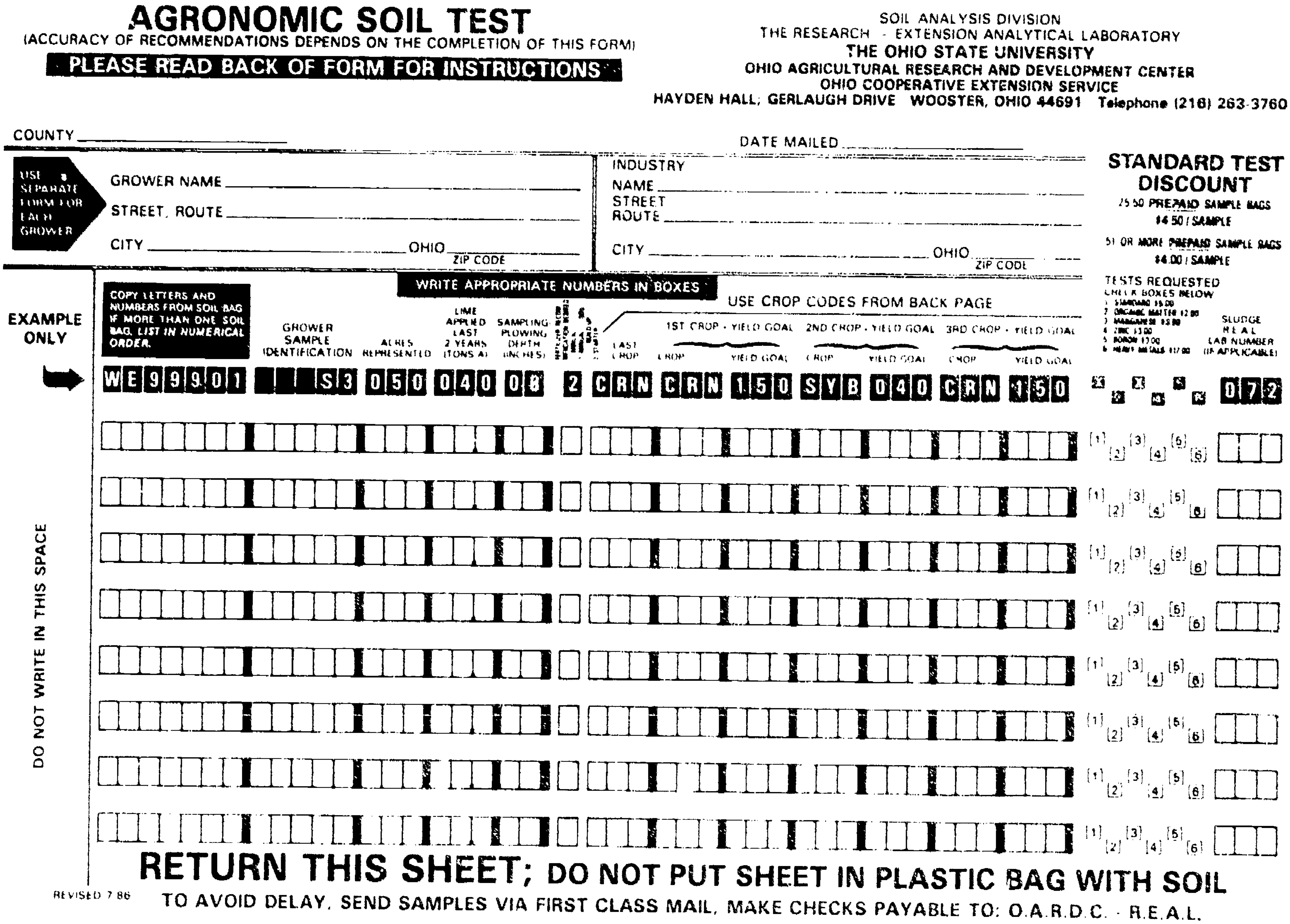
FIG. 48. Carefully separate and mark each sample being air dried. *(Courtesy C R Fndline)*

Providing Information about the Sampled Field

Specific information is needed when submitting the representative soil sample for laboratory analysis. The kind and amount of information can vary depending on where the analysis is to be made. For example, in Ohio, if the Research-Extension Analytical Laboratory is making the laboratory analysis, the samples are usually submitted through the county cooperative extension service office (see Figure 49). Figures 50 and 51 show a sample agronomic soil test form. The following information is generally requested on these forms:

1. *Sample identification* – This can be a single digit, five digits, or a combination of digits and letters up to five spaces. The crop producer selects a different identification code for each sample.
2. *Number of acres represented by the sample* – The number of acres represented is usually from a single-crop field.
3. *Amount of lime applied to the field during the last two years* – This aids the soil analysis laboratory in making lime application recommendations.
4. *Plowing depth* – This is needed to determine the amount of lime to apply. (The relationship between plowing depth and amount of lime is explained later in this chapter.)
5. *Type of fertilizer recommendation desired* – This can be the annual application rate, the annual application rate plus buildup, or a starter fertilizer recommendation. ("Buildup" is associated with soil phosphorus and potassium and will be explained later.) A "starter fertilizer recommendation" is a modified recommendation provided when starter fertilizer will be used with row crops.

FIG. 49. This crop producer is submitting his soil samples and forms to the county cooperative extension service office



AGRONOMIC SOIL TEST

(ACCURACY OF RECOMMENDATIONS DEPENDS ON THE COMPLETION OF THIS FORM)

PLEASE READ BACK OF FORM FOR INSTRUCTIONS

SOIL ANALYSIS DIVISION
THE RESEARCH - EXTENSION ANALYTICAL LABORATORY
THE OHIO STATE UNIVERSITY
OHIO AGRICULTURAL RESEARCH AND DEVELOPMENT CENTER
OHIO COOPERATIVE EXTENSION SERVICE
HAYDEN HALL; GERLAUGH DRIVE WOOSTER, OHIO 44691 Telephone (216) 263-3760

COUNTY ____________

DATE MAILED ____________

USE SEPARATE FORM FOR EACH GROWER

GROWER NAME ____________
STREET, ROUTE ____________
CITY ____________ OHIO ____________ ZIP CODE

INDUSTRY
NAME ____________
STREET
ROUTE ____________
CITY ____________ OHIO ____________ ZIP CODE

STANDARD TEST DISCOUNT

25-50 PREPAID SAMPLE BAGS
$4.50 / SAMPLE

51 OR MORE PREPAID SAMPLE BAGS
$4.00 / SAMPLE

TESTS REQUESTED
CHECK BOXES BELOW
1 STANDARD $5.00
2 ORGANIC MATTER $2.00
3 MANGANESE $2.00
4 ZINC $3.00
5 BORON $3.00
6 HEAVY METALS $17.00

COPY LETTERS AND NUMBERS FROM SOIL BAG IF MORE THAN ONE SOIL BAG, *LIST IN NUMERICAL ORDER.*

WRITE APPROPRIATE NUMBERS IN BOXES

USE CROP CODES FROM BACK PAGE

EXAMPLE ONLY

DO NOT WRITE IN THIS SPACE

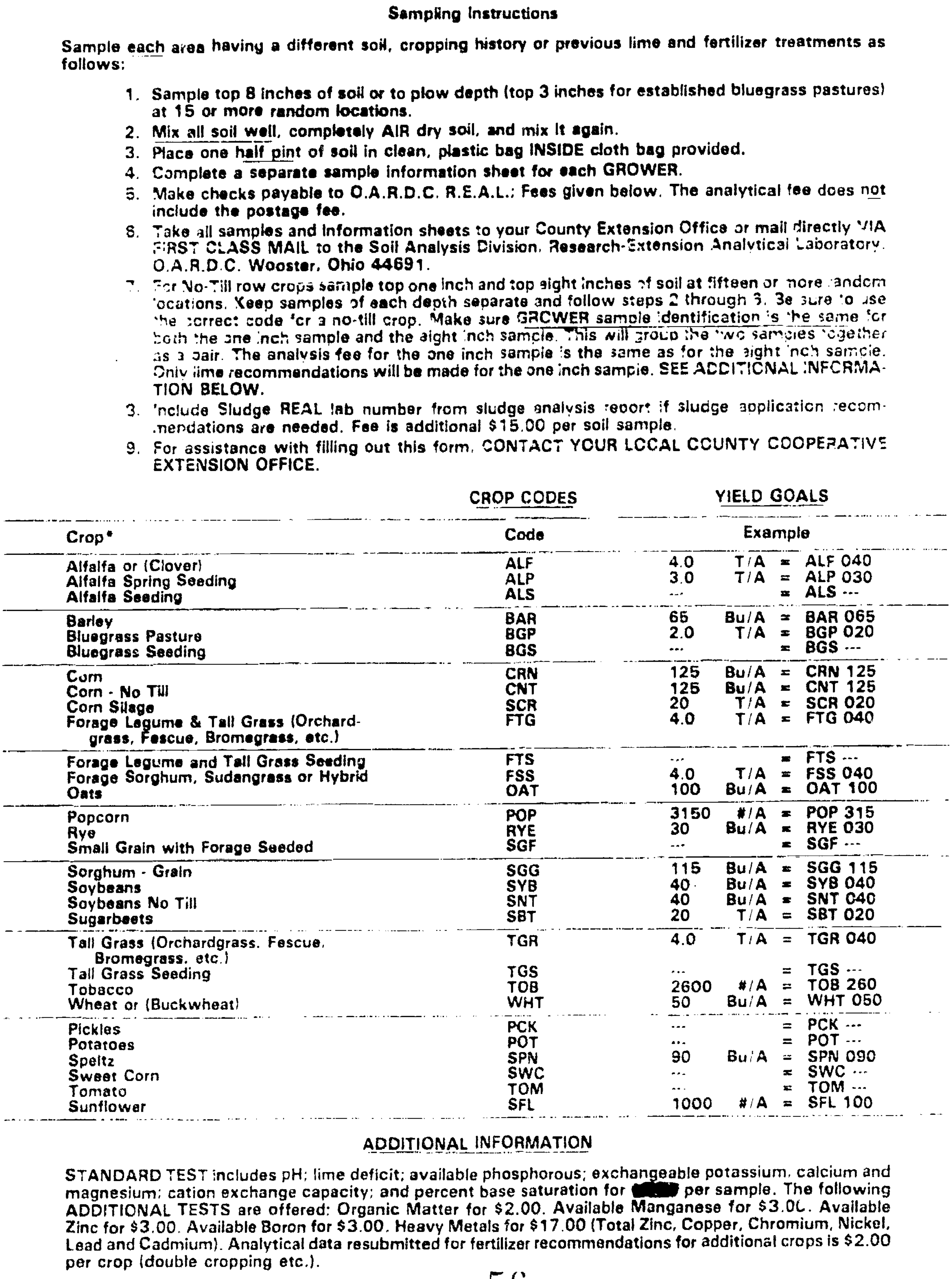
	GROWER SAMPLE IDENTIFICATION	ACRES REPRESENTED	LIME APPLIED LAST 2 YEARS (TONS A)	SAMPLING PLOWING DEPTH (INCHES)		LAST CROP	1ST CROP - YIELD GOAL CROP	YIELD GOAL	2ND CROP - YIELD GOAL CROP	YIELD GOAL	3RD CROP - YIELD GOAL CROP	YIELD GOAL	TESTS REQUESTED	SLUDGE R.E.A.L. LAB NUMBER (IF APPLICABLE)
WE99901	S3	050	040	08	2	CRN	CRN	150	SYB	040	CRN	150	☒1 ☒2 ☒3 ☒4 ☒5 ☒6	072
													☐1 ☐2 ☐3 ☐4 ☐5 ☐6	
													☐1 ☐2 ☐3 ☐4 ☐5 ☐6	
													☐1 ☐2 ☐3 ☐4 ☐5 ☐6	
													☐1 ☐2 ☐3 ☐4 ☐5 ☐6	
													☐1 ☐2 ☐3 ☐4 ☐5 ☐6	
													☐1 ☐2 ☐3 ☐4 ☐5 ☐6	
													☐1 ☐2 ☐3 ☐4 ☐5 ☐6	
													☐1 ☐2 ☐3 ☐4 ☐5 ☐6	

RETURN THIS SHEET; DO NOT PUT SHEET IN PLASTIC BAG WITH SOIL

REVISED 7 86

TO AVOID DELAY, SEND SAMPLES VIA FIRST CLASS MAIL, MAKE CHECKS PAYABLE TO: O.A.R.D.C. - R.E.A.L.

FIG. 50. Agronomic soil test form - front page (Courtesy Research Extension Analytical Laboratory, OARDC, Wooster, Ohio)



Sampling Instructions

Sample each area having a different soil, cropping history or previous lime and fertilizer treatments as follows:

1. Sample top 8 inches of soil or to plow depth (top 3 inches for established bluegrass pastures) at 15 or more random locations.
2. Mix all soil well, completely AIR dry soil, and mix it again.
3. Place one half pint of soil in clean, plastic bag INSIDE cloth bag provided.
4. Complete a separate sample information sheet for each GROWER.
5. Make checks payable to O.A.R.D.C. R.E.A.L.; Fees given below. The analytical fee does not include the postage fee.
6. Take all samples and information sheets to your County Extension Office or mail directly VIA FIRST CLASS MAIL to the Soil Analysis Division, Research-Extension Analytical Laboratory, O.A.R.D.C. Wooster, Ohio 44691.
7. For No-Till row crops sample top one inch and top eight inches of soil at fifteen or more random locations. Keep samples of each depth separate and follow steps 2 through 6. Be sure to use the correct code for a no-till crop. Make sure GROWER sample identification is the same for both the one inch sample and the eight inch sample. This will group the two samples together as a pair. The analysis fee for the one inch sample is the same as for the eight inch sample. Only lime recommendations will be made for the one inch sample. SEE ADDITIONAL INFORMATION BELOW.
8. Include Sludge REAL lab number from sludge analysis report if sludge application recommendations are needed. Fee is additional $15.00 per soil sample.
9. For assistance with filling out this form, CONTACT YOUR LOCAL COUNTY COOPERATIVE EXTENSION OFFICE.

CROP CODES		YIELD GOALS
Crop*	Code	Example
Alfalfa or (Clover)	ALF	4.0 T/A = ALF 040
Alfalfa Spring Seeding	ALP	3.0 T/A = ALP 030
Alfalfa Seeding	ALS	--- = ALS ---
Barley	BAR	65 Bu/A = BAR 065
Bluegrass Pasture	BGP	2.0 T/A = BGP 020
Bluegrass Seeding	BGS	--- = BGS ---
Corn	CRN	125 Bu/A = CRN 125
Corn - No Till	CNT	125 Bu/A = CNT 125
Corn Silage	SCR	20 T/A = SCR 020
Forage Legume & Tall Grass (Orchardgrass, Fescue, Bromegrass, etc.)	FTG	4.0 T/A = FTG 040
Forage Legume and Tall Grass Seeding	FTS	--- = FTS ---
Forage Sorghum, Sudangrass or Hybrid	FSS	4.0 T/A = FSS 040
Oats	OAT	100 Bu/A = OAT 100
Popcorn	POP	3150 #/A = POP 315
Rye	RYE	30 Bu/A = RYE 030
Small Grain with Forage Seeded	SGF	--- = SGF ---
Sorghum - Grain	SGG	115 Bu/A = SGG 115
Soybeans	SYB	40 Bu/A = SYB 040
Soybeans No Till	SNT	40 Bu/A = SNT 040
Sugarbeets	SBT	20 T/A = SBT 020
Tall Grass (Orchardgrass, Fescue, Bromegrass, etc.)	TGR	4.0 T/A = TGR 040
Tall Grass Seeding	TGS	--- = TGS ---
Tobacco	TOB	2600 #/A = TOB 260
Wheat or (Buckwheat)	WHT	50 Bu/A = WHT 050
Pickles	PCK	--- = PCK ---
Potatoes	POT	--- = POT ---
Speltz	SPN	90 Bu/A = SPN 090
Sweet Corn	SWC	--- = SWC ---
Tomato	TOM	--- = TOM ---
Sunflower	SFL	1000 #/A = SFL 100

ADDITIONAL INFORMATION

STANDARD TEST includes pH; lime deficit; available phosphorous; exchangeable potassium, calcium and magnesium; cation exchange capacity; and percent base saturation for [redacted] per sample. The following ADDITIONAL TESTS are offered: Organic Matter for $2.00. Available Manganese for $3.00. Available Zinc for $3.00. Available Boron for $3.00. Heavy Metals for $17.00 (Total Zinc, Copper, Chromium, Nickel, Lead and Cadmium). Analytical data resubmitted for fertilizer recommendations for additional crops is $2.00 per crop (double cropping etc.).

FIG. 51. Agronomic soil test form - back page *(Courtesy Research-Extension Analytical Laboratory, OARDC, Wooster, Ohio)*

6. *Crop(s) to be grown and the yield goal* - Figure 51 shows the coding system for reporting crop yield goals.
7. *Cropland in rotation* – List crops in the order they will be grown in the rotation. Begin with the last crop harvested - for example, corn-wheat-alfalfa.
8. *Permanent pasture*
9. *Lawn or other turf growth* – For example, golf courses
10. *Greenhouse crops to be grown*
11. *Garden or truck crops to be grown*
12. *Specific problems with the soil from which the representative sample was taken* – Provide any pertinent information - for example, landfill area or stunted crop growth.
13. *Test(s) desired* – These are listed on the form.

Note - The amount of livestock manure applied is not requested due to the wide variance in the way this product is handled on farms. If livestock manure is properly handled, it contributes to the soil nutrient supply. The degree of contribution depends on the amount applied. More information regarding livestock manure is provided in Chapter 4.

Available Soil Tests

The Research-Extension Analytical Laboratory provides the following soil testing services:

- Standard test
- Available manganese
- Available zinc
- Available boron
- Organic matter
- Heavy metals (discussed on page 62)

STANDARD TEST

The **standard test** provides the following information:

1. *Soil pH* – Gives the **active soil acidity** or the concentration of hydrogen ions in the soil solution
2. *Lime test index* – Gives the soil's **total acidity** - the soil solution's acidity *plus* the **reserve acidity** (concentration of hydrogen and aluminum ions on the exchange sites of clay and organic matter particles)
3. *Available phosphorus* – Gives the pounds of available phosphorus in the soil
4. *Exchangeable potassium* – Gives the pounds of potassium on the exchange sites of the soil's clay and organic matter particles. This potassium moves into the soil solution and can be immediately used by plants.
5. *Exchangeable calcium* – Gives the pounds of calcium on the exchange sites of clay and organic matter particles. This calcium is readily available for plant use.
6. *Exchangeable magnesium* – Gives the pounds of magnesium on the exchange sites of a soil. It is readily available for plant use.

7. *Cation exchange capacity (CEC)* – Measures the soil's capacity to hold exchangeable cations on the clay and organic matter particles. This capacity is given in milliequivalents (meq) per 100 grams of soil. (See Chapter 2 for an explanation of CEC.) A soil with a high CEC (e.g., 30 meq) can hold more cations of potassium, calcium, and magnesium than one with low CEC (e.g., 10 meq.) Also, a soil with a high CEC may be more acid because it can hold more acid-causing ions (hydrogen and aluminum).
8. *Percentage base saturation of Ca, Mg, and K* – Indicates the percentage saturation of the soil CEC by each of these elements. This ratio is considered when determining what type of lime should be applied and whether Mg should be added to the soil to prevent **grass tetany** (mineral imbalance) in ruminants.

AVAILABLE MANGANESE, ZINC, AND BORON

Shortages of manganese, zinc, and boron exist in some areas. Tests are available to detect shortages of these micronutrients.

ORGANIC MATTER CONTENT

This test determines the percentage of organic matter in a soil. This percentage is sometimes used to estimate the amount of available nitrogen.

NITROGEN CONTENT

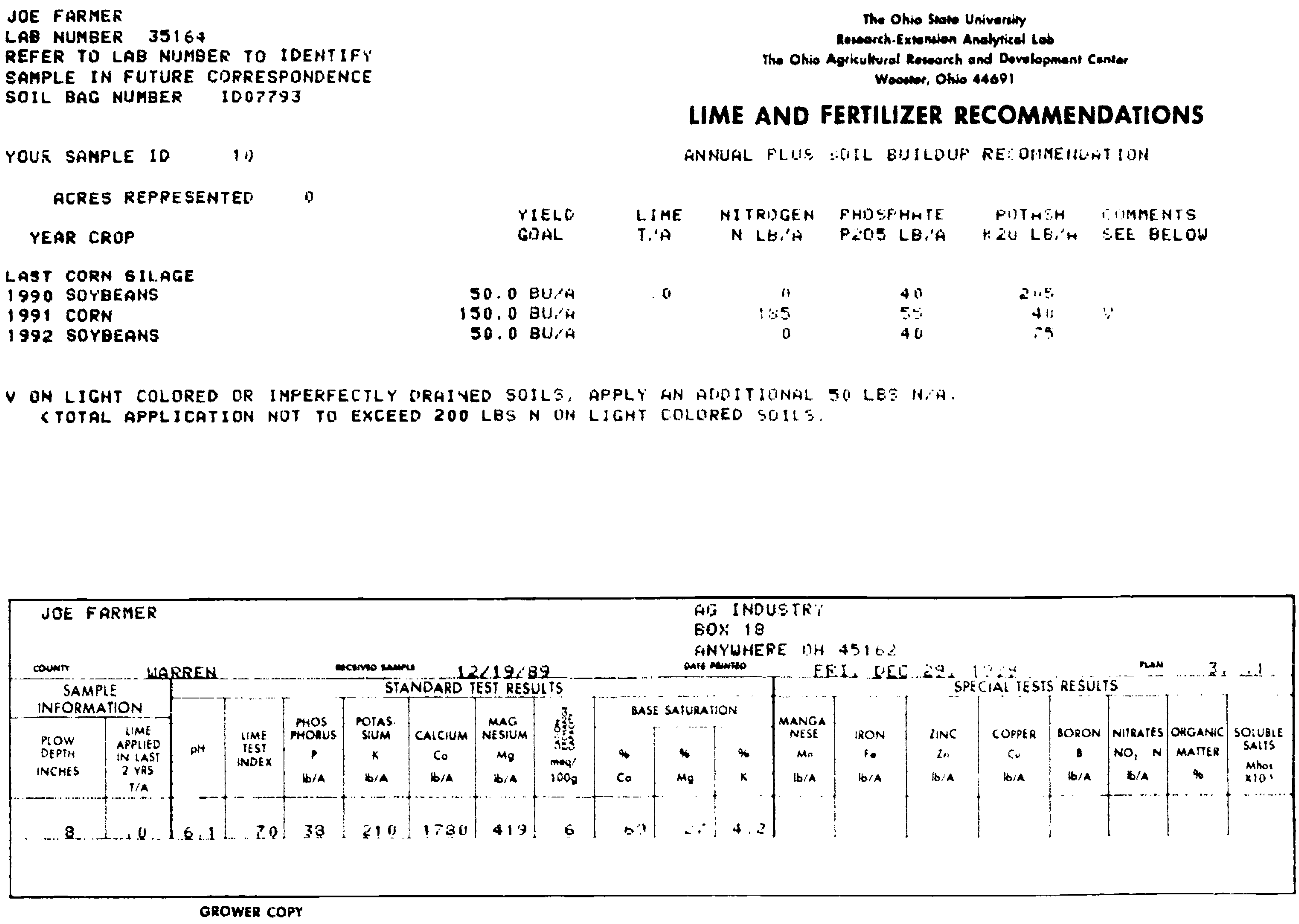
The nitrogen sources available for plant use are nitrates and ammonium. Nitrates (NO_3^-) are negatively charged; therefore, they do not attach to the clay soil particles. As a result they move in solution with the soil water. Ammonium (NH_4^+) is positively charged, but when the soil temperature rises above 50° F, ammonium rapidly changes to the nitrate form (NO_3^-). Any soil test made today for soil nitrogen content can have considerably different results six months from now. *Therefore, the Research-Extension Analytical Laboratory does not perform a soil test for nitrogen content.*

Interpreting Soil Test Reports

Figure 52 on page 52 shows a soil test report issued to a crop producer by the Research-Extension Analytical Laboratory. A great deal of information is included in this one-page report form. The upper right portion of the report form gives lime and fertilizer recommendations based on the soil test results. The crops to be grown and their yield goals are given in the left portion of the form, near the top.

SAMPLE IDENTIFICATION

There are several procedures used by soil analysis laboratories for sample identification. The first of these is the crop producer's **sample ID** (identification) which appears in the upper left portion of the report form, near the top. Each soil



JOE FARMER
LAB NUMBER 35164
REFER TO LAB NUMBER TO IDENTIFY
SAMPLE IN FUTURE CORRESPONDENCE
SOIL BAG NUMBER 1D07793

The Ohio State University
Research-Extension Analytical Lab
The Ohio Agricultural Research and Development Center
Wooster, Ohio 44691

LIME AND FERTILIZER RECOMMENDATIONS

YOUR SAMPLE ID 10

ANNUAL PLUS SOIL BUILDUP RECOMMENDATION

ACRES REPRESENTED 0

YEAR CROP	YIELD GOAL	LIME T/A	NITROGEN N LB/A	PHOSPHATE P2O5 LB/A	POTASH K2O LB/A	COMMENTS SEE BELOW
LAST CORN SILAGE						
1990 SOYBEANS	50.0 BU/A	.0	0	40	265	
1991 CORN	150.0 BU/A		185	55	40	V
1992 SOYBEANS	50.0 BU/A		0	40	75	

V ON LIGHT COLORED OR IMPERFECTLY DRAINED SOILS, APPLY AN ADDITIONAL 50 LBS N/A.
(TOTAL APPLICATION NOT TO EXCEED 200 LBS N ON LIGHT COLORED SOILS.

JOE FARMER

AG INDUSTRY
BOX 18
ANYWHERE OH 45162

COUNTY WARREN
RECEIVED SAMPLE 12/19/89
DATE PRINTED FRI, DEC 29, 1989
PLAN 3, 1

SAMPLE INFORMATION		STANDARD TEST RESULTS										SPECIAL TESTS RESULTS							
									BASE SATURATION										
PLOW DEPTH INCHES	LIME APPLIED IN LAST 2 YRS T/A	pH	LIME TEST INDEX	PHOSPHORUS P lb/A	POTASSIUM K lb/A	CALCIUM Ca lb/A	MAGNESIUM Mg lb/A	CATION EXCHANGE CAPACITY meq/100g	% Ca	% Mg	% K	MANGANESE Mn lb/A	IRON Fe lb/A	ZINC Zn lb/A	COPPER Cu lb/A	BORON B lb/A	NITRATES NO_3 N lb/A	ORGANIC MATTER %	SOLUBLE SALTS Mhos X10⁵
8	0	6.1	70	33	210	1730	419	6	69	[illegible]	4.2								

GROWER COPY

FIG. 52. Soil test report (*Courtesy Research-Extension Analytical Laboratory, OARDC, Wooster, Ohio*)

sample submitted for testing must have an identification code. To avoid confusion, each soil sample's identification code is different than identification codes assigned to other samples. Also, each soil sample submitted for testing is given a **laboratory number**. This number appears at the top left of the form. Finally, each soil sample is given a **soil bag number** which also appears at the top left of the form. The crop producer refers to this soil bag number when corresponding with the laboratory about the soil sample.

The following text explains each item appearing in the lower portion of the form in Figure 52.

SAMPLE INFORMATION

The following items are listed under "Sample Information" in Figure 52:

1. *Plow depth* – This information is needed to determine the amount of lime to recommend – for example, the deeper the plow depth, the more 'ime required.
2. *Lime applied during the last two years* – This helps determine how many tons of lime are needed.

ANALYTICAL RESULTS

The remainder of the information in the lower portion of the report form in Figure 52 gives analytical results obtained in the soil testing laboratory. Most of these results are obtained through complex chemical and mathematical procedures.

The following items appear under "Standard Test Results" in Figure 52.

Soil pH

Soil pH measures the soil's active acidity. As shown in Figure 53 on page 54, pH is measured by a single-digit number or a decimal. Figure 53 also shows the pH ranges in which different crop plants grow satisfactorily. A soil pH between 6.0 and 7.0 is best for growing most field crops on mineral soils.

Acid and alkaline ranges also appear in Figure 53. A pH of 7.0 is **neutral**: it is neither acid nor alkaline. Soils with a pH of above 7.0 are **alkaline**; soils with a pH below 7.0 are **acid**. Most soils in the humid, temperate, crop-growing areas of the Midwest tend to be acid or slightly acid. This is due to the removal of calcium, magnesium, and potassium by crops and leaching. A soil's parent rock also influences pH. Soils formed from sandstone and shale are naturally more acid than those formed from limestone.

SOIL ACIDITY AND NUTRIENT AVAILABILITY

Soil acidity affects the availability of some nutrients present in the soil. As shown in Figure 54 on page 55, when soil acidity increases, iron, aluminum, and manganese may become more available. In fact, they may become so abundant that they have a toxic (poisonous) effect on plants. Iron and manganese are needed in very small amounts by plants; however, too much of either has a harmful effect.

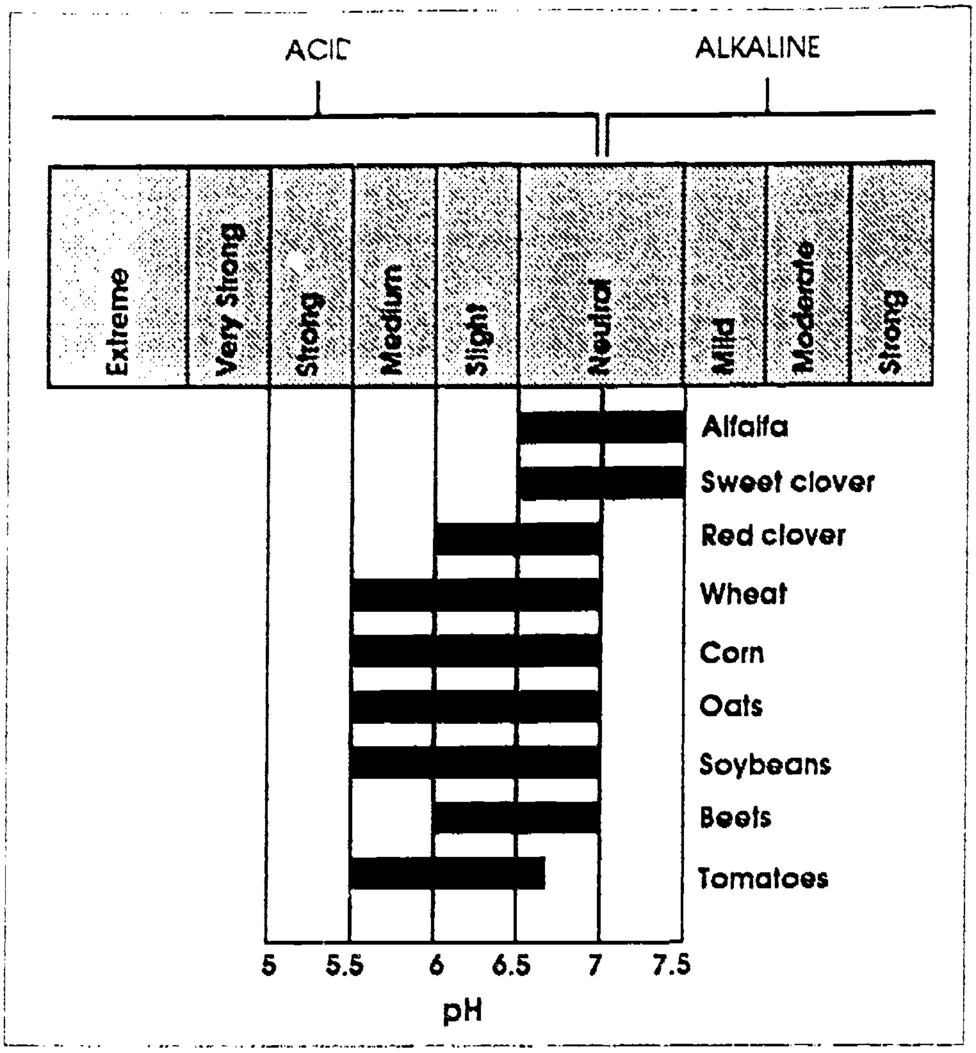


FIG. 53. The pH of a soil is indicated by a number between 0 and 14. Most crop plants grow best at a pH range of 5.5 to 7.5.

In acid soils, iron and aluminum may combine with the soil's phosphorus to form phosphate compounds. When this occurs, the phosphorus is no longer available to plants.

If the soil pH is above 7.0 (uncommon in the midwestern and southern states), boron, copper, zinc, and manganese become less available. If the pH rises above 7.5 due to an abundance of calcium, this calcium may combine with phosphorus to form phosphate compounds. This also makes phosphorus unavailable to plants.

LIME TEST INDEX

The **lime test index** appears in the second column under "Standard Test Results" (see Figure 52). This index is a two-digit number calculated by the soil testing laboratory and used to determine the soil's lime requirement. As shown in Table 11, the lower the lime test index number, the more lime required.

The lime test index number is determined by testing the following two acidity sources in the soil:

1. *Soil solution* – This contains the soil's **active acidity** sources.
2. *Clay and organic matter particles* – These are exchange sites and contain the soil's **reserve acidity**. The soil's active acidity is very small compared to the reserve acidity.

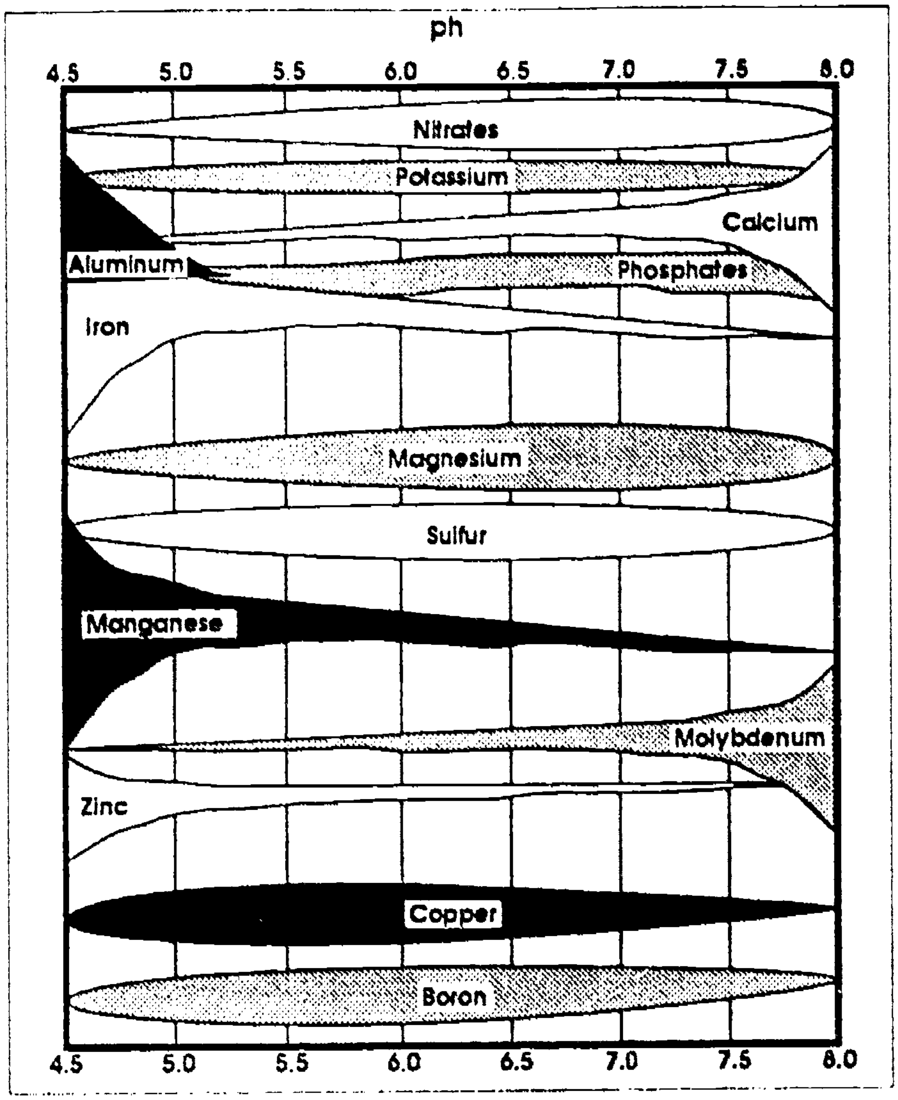


FIG. 54. Effect of soil pH on plant nutrient availability.

TABLE 11. Lime required to increase soil pH to four levels (T/A ag-ground limitation, TNP 90•, and 8-inch plow depth)*

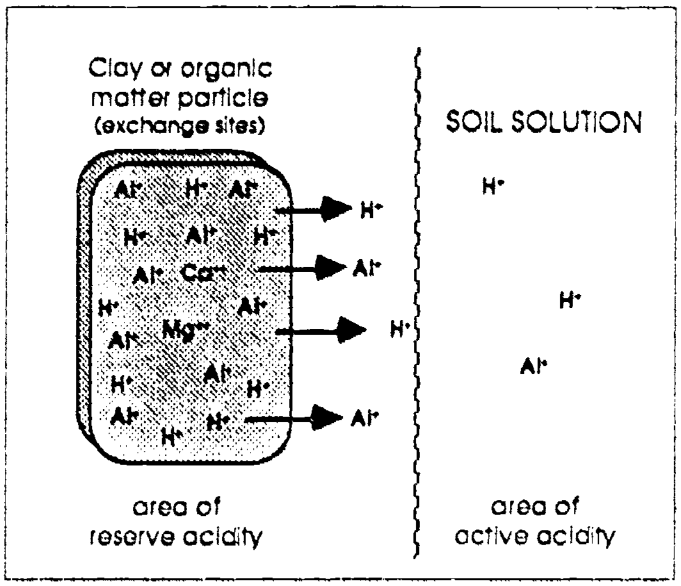
Lime Test Index	Mineral Soils (pH) 7.0	Mineral Soils (pH) 6.5	Organic Soils (pH) 6.0	Organic Soils (pH) 5.2
		tons of lime/acre		
68	1.4	1.2	1.0	0.7
67	2.4	2.1	1.7	1.3
66	3.4	2.9	2.4	1.8
65	4.5	3.8	3.1	2.4
64	5.5	4.7	3.8	2.9
63	6.5	5.5	4.5	3.5
62	7.5	6.4	5.2	4.0
61	8.6	7.2	5.9	4.6
60	9.6	8.1	6.6	5.1
59	10.6	9.0	7.3	5.7
58	11.7	9.8	8.0	6.2
57	12.7	10.7	8.7	6.7
56	13.7	11.6	9.4	7.3
55	14.8	12.5	10.2	7.8
54	15.8	13.4	10.9	8.4
53	16.9	14.2	11.6	8.9
52	17.9	15.1	12.3	9.4
51	19.0	16.0	13.0	10.0
50	20.0	16.9	13.7	10.5
49	21.1	17.8	14.4	11.0
48	22.1	18.6	15.1	11.6

*Adjust these values for material type, plow depth, and lime credit.

Figure 55 illustrates how the soil's reserve acidity can keep the soil solution's active acidity high even though very little lime is necessary to neutralize it. How much reserve acidity a soil has depends on the cation exchange capacity (CEC). A clay soil with a high cation exchange capacity has a higher reserve acidity than a sandy soil with a low cation exchange capacity. Research shows that a mineral soil with 20 percent moisture and a pH of 6 requires only 1/50 pound of agricultural ground limestone per acre to neutralize the active soil acidity; a pH of 5 requires 1/5 pound; and a pH of 4 requires only 2 pounds. To correct total soil acidity, limestone is applied in amounts of 1, 2 and even 6 tons per acre. The amount required depends on the lime test index number and the crop to be grown. These heavy applications are needed due to the large amounts of hydrogen and aluminum ions on the exchange sites (reserve acidity). This resistance to change in the soil's total acidity is called **buffering**.

Research shows that reserve acidity may be 1,000 times greater than active acidity on a sandy soil. However, reserve acidity may be 100,000 times greater than active acidity on a clay soil high in organic matter. The reason for this great difference is that a very sandy soil may have a cation exchange capacity of only 5; whereas, a clay soil high in organic matter can have a cation exchange capacity of 50 or more (see Table 4, Chapter 2). Thus, a clay soil with a high percentage of organic matter requires more lime than a sandy soil to correct the total acidity (see Figure 56).

FIG. 55. Lime application only temporarily corrects active acidity. Hydrogen and aluminum move from reserve acidity into the soil solution.



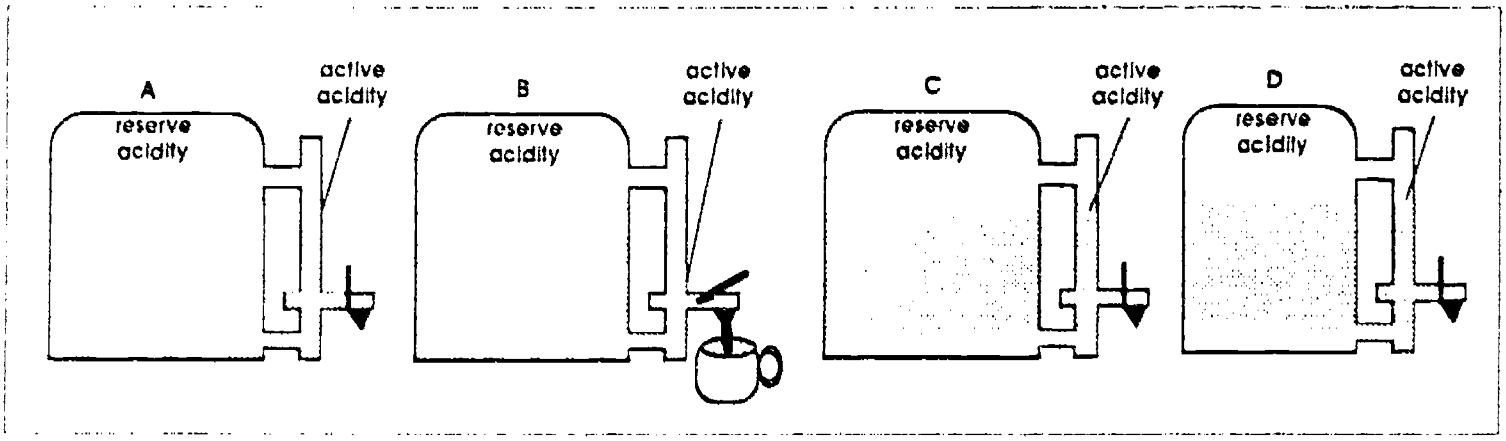


FIG. 56. Buffering can be compared to the action of this coffee dispenser. **A**: Indicator tube represents the soil solution's active acidity. It is small compared to the reserve acidity. **B** When a cup of coffee is removed from the dispenser, the level in the tube lowers. This represents the removal of hydrogen ions due to a small lime application. This only is temporary. **C**: When the valve is closed, the level in the indicator returns to almost the same level as shown in **A**. Likewise, the soil solution becomes acid again because the hydrogen ions move from the soil's reserve acidity into the soil solution. A sandy soil, represented by the smaller dispenser shown in **D**, has less reserve acidity and less resistance (buffering) to soil acidity change.

To sumarize, the **soil pH test** measures the soil's active acidity or alkalinity. It determines whether a soil is acid or alkaline. The **lime test index** (lime deficit or lime requirement) measures the soil's total acidity. As discussed earlier, Table 11 shows the relationship between the lime test index number and the amount of agricultural ground limestone needed to reach four different pH levels.

Available Phosphorus

The **available phosphorus** test results appear in the third column under "Standard Test Results" (see Figure 52). This number represents the soil's available phosphorus in pounds per acre. The amount of available phosphorus can vary a great deal from field to field, or even in samples from within the same field.

The crop to be grown determines the sufficiency of the amount of available phosphorus (see Figure 57). When the available phosphorus is at least 30 pounds per acre, corn and soybeans give almost 100 percent yield returns. However, wheat, oats, alfalfa, red clover, and sugar beets require a larger amount (see Table 12). These crops need 60 pounds of available phosphorus per acre. Nevertheless, a field showing 60 pounds of available phosphorus per acre still needs phosphorus-supplying fertilizer. This fertilizer must be applied to maintain the 60-pound level and replace the phosphorus that will be removed by the crop to be grown .

To summarize, the following factors must be considered when determining a soil's phosphorus needs:

1. Amount of phosphorus required by the crop to be grown
2. Amount of phosphorus required to reach the soil's desired available phosphorus level (soil buildup)

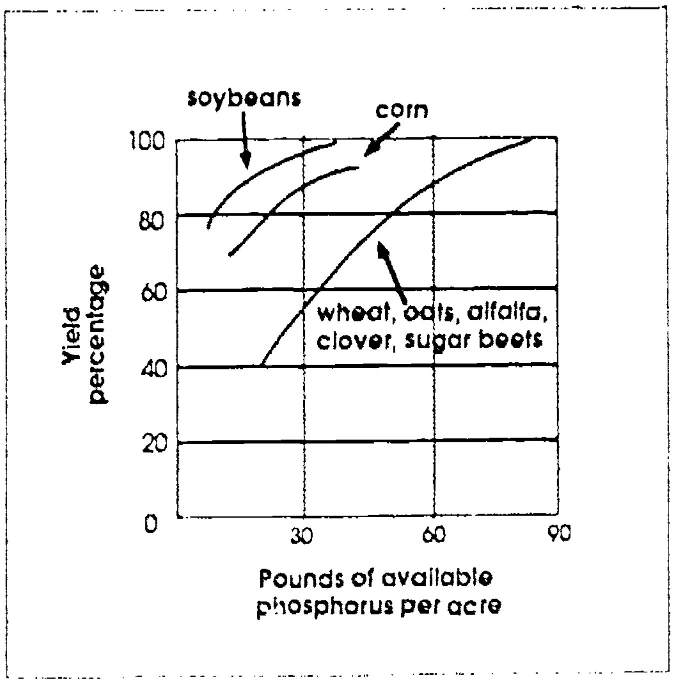


FIG. 57. Pounds of available phosphorus per acre and resulting yield percentages. *(Courtesy* Ohio Agronomy Guide, *1988)*

TABLE 12. Pounds of phosphate (P_2O_5) removed by various crops

Crop	P_2O_5 Removal
Corn (grain)	0.37 lb/bu
Corn (silage)	3.1 lb/T
Wheat (grain)	0.64 lb/bu
Wheat (straw)	0.09 lb/bu
Oats (grain)	0.25 lb/bu
Oats (straw)	0.15 lb/bu
Soybeans (grain)	0.80 lb/bu
Sorghum (grain)	0.39 lb/100 lb
Forage legume	13 lb/T
Sugar beets	2 lb/T
Tobacco	1.3 lb/100 lb

(Courtesy Ohio Agronomy Guide, *1988)*

Exchangeable Potassium

The **exchangeable potassium** test appears in the fourth column under "Standard Test Results" (see Figure 52). This test measures in pounds per acre the amount of potassium on the exchange sites of the soil's clay and organic matter particles. As noted earlier, when comparing the soil test results from field to field, the amount of exchangeable potassium may vary greatly. To determine whether the amount shown is adequate, the cation exchange capacity of the soil must be considered (see seventh column under "Standard Test Results," Figure 52). The higher the cation exchange capacity of a mineral soil, the greater the potassium-holding capacity. Thus, the cation exchange capacity of a soil is used to determine the amount of exchangeable potassium a soil should have. The following formula is used to calculate desirable exchangeable potassium levels:

5 x CEC + 220 = desirable soil test potassium level

Using the cation exchange capacity shown in Figure 52, the desirable potassium level can be determined:

$$(5 \times 6) + 220 = 250 \text{ pounds/acre potassium desired}$$

Because the potassium present in the sample reported in Figure 52 was 210 pounds per acre, and the desired potassium level was 250 pounds per acre, we can conclude that a potassium deficiency exists. In turn, the actual amount of potassium-carrying fertilizer to be applied depends on the following factors:

1. *Crop to be grown* – See Table 13 for the amount of potassium (in K_2O form) removed by different field crops.

2. *Soil's desired potassium level based on the cation exchange capacity of the soil* If potassium fertilizer is applied in the amount needed by the crop, plus is in excess of the desired level (calculated above), the oversupply may leach from the soil.

TABLE 13 Pounds of potash (K_2O) removed from the soil by various crops

Crops	K_2O Removal
Corn (grain)	0.27 lb/bu
Corn (silage)	9.00 lb/T
Wheat (grain)	0.36 lb/T
Wheat (straw)	0.91 lb/bu
Oats (grain)	1.00 lb/bu
Oats (straw)	1.00 lb/bu
Soybeans (grain)	1.40 lb/bu
Sorghum (grain)	0.39 lb/100 lb
Tallgrass and/or foliage legume	0.60 lb/T
Sugar beets	10 lb/T
Tobacco	8.3 lb/T

(Courtesy Ohio Agronomy Guide, 1988)

Exchangeable Calcium and Magnesium

Like the potassium test, the **exchangeable calcium and magnesium test** indicates the pounds per acre of these nutrients that are on the exchange sites of the soil's clay and organic matter particles. These test results appear in the fifth and sixth columns under "Standard Test Results" (see Figure 52). Calcium and magnesium are supplied to soil by applying limestone. This serves the following purposes regarding plant growth:

1. *Increases the amount of calcium and magnesium ions on the exchange sites of clay and organic matter particles* – Thus, more of the nutrients are available for plant use.
2. *Raises the soil's pH* – The acid-causing hydrogen and aluminum ions are reduced. As previously described in this chapter, most field crop plants do not grow well in acid soils (pH below 5.5 - see Figure 53). When a soil's pH is 6.0 to 7.0, there is usually an adequate amount of calcium and magnesium present for satisfactory plant growth.

It is important to remember that a certain calcium-magnesium **ratio** is needed in the soil. This is also true for magnesium and potassium. (Ratio is the relationship in amounts between two or more items, for example, between calcium and magnesium or between magnesium and potassium.) In other words, a balance among the three exchangeable nutrient elements - calcium, magnesium, and potassium - must be maintained in the soil for satisfactory plant growth. Figure 58 illustrates clay particles with desirable and undesirable calcium-magnesium and magnesium-potassium ratios.

CALCIUM-MAGNESIUM RATIO

For satisfactory plant growth, the amount of calcium in the soil should exceed the amount of magnesium. Use the following guidelines to determine if a correct ratio exists between calcium and magnesium:

1. *If the ratio is 1:1 or less the soil is not suitable for optimum plant growth* - This ratio indicates the amount of calcium is equal to or less than the amount of magnesium. There is one part calcium to one part magnesim. In this case, apply a low-magnesium limestone.

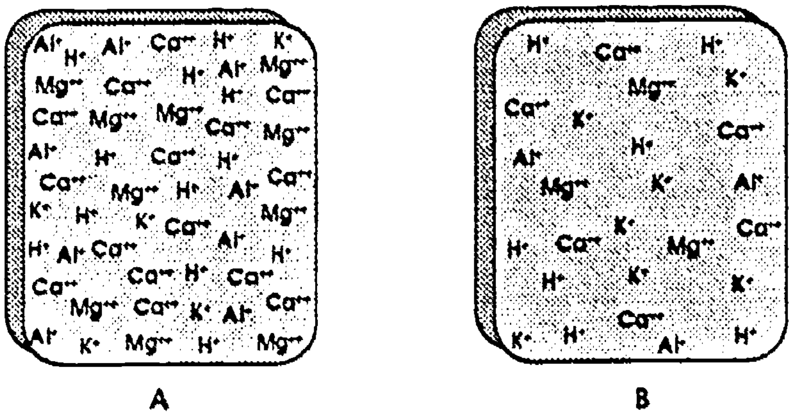


FIG. 58. A: Illustrates a clay particle with desirable ratios of calcium, magnesium, and potassium. The pH is satisfactory for crop production.
B: Illustrates an undesirable magnesium-potassium ratio. The pH is unsatisfactory for crop plant growth.

2. *If the ratio is above 10:1 the soil is not suitable for optimum plant growth* - This ratio indicates there are 10 or more parts calcium to one part magnesium. In this case, apply high-magnesium limestone.

3. *Satisfactory plant growth can be achieved within a wide range of calcium-magnesium ratios.*

MAGNESIUM-POTASSIUM RATIO

The ratio between the amounts of magnesium and potassium in the soil should be 2:1 – that is, there are two parts magnesium to one part potassium. However, the ratio between the two nutrients is usually greater than 2:1. On the other hand, a lesser ratio may result when a heavy bulk application of potassium-carrying fertilizer is applied and the pH of the soil is low (below 5.5). If the magnesium-potassium ratio is below 2:1, not enough magnesium is available for production of high-quality forage. Consequently, forage crops produced on low-magnesium soils and fed to livestock may cause grass tetany in cattle. (In this case it can cause *hypomagnesia* – a magnesium deficiency.)

DETERMINING CALCIUM-MAGNESIUM AND MAGNESIUM-POTASSIUM RATIOS

To determine calcium-magnesium and magnesim-potassium ratios, you need the **percent base saturation** of these nutrients. The soil testing laboratory calculates the percent base saturation by using the cation exchange capacity of the soil and the pounds of exchangeable nutrients per acre (from the soil test). The resulting values are listed in Figure 52 under "Standard Test Results" - columns 8 through 10. The base saturation of all three nutrients (Ca - 69%, Mg - 27%, K - 4.2%) fall within the ranges that can usually be expected. These ranges are the following:

- Calcium: 40 to 80 percent
- Magnesium: 10 to 40 percent
- Potassium: 1 to 5 percent

The calcium-magnesium ratio is determined by dividing the percent base saturation of calcium by the percent base saturation of magnesium. The ratio follows for the sample reported in Figure 52:

$$\frac{69}{27} = 2.56 \text{ or a } 2.56{:}1 \text{ calcium to magnesium ratio}$$

The magnesium to potassium ratio is calculated in the same manner.

$$\frac{27}{4.2} = 6.43 \text{ or a } 6.43{:}1 \text{ magnesium to potassium ratio}$$

Both of these ratios are satisfactory for proper plant growth.

Special Tests Results

MICRONUTRIENT TESTS FOR BORON, MANGANESE, AND ZINC

The micronutrient test results for boron, manganese, and zinc are given in pounds of available nutrient per acre. As described in Chapter 1, micronutrients are elements necessary for plant growth, but needed in very small amounts.

Fertilizer and liming practices can produce micronutrient deficiencies. For example, liming until the pH is above 7.0 can produce boron, manganese, and zinc deficiencies. Also, a pH below 5.0 may cause molybdenum, copper, and boron deficiencies. Zinc deficiencies can be caused by heavy and repeated applications of phosphorus fertilizers. Obviously, soil pH can indicate conditions possibly leading to micronutrient deficiencies. (Review Figure 54.)

The Research-Extension Analytical Laboratory conducts tests for the following three micronutrients. Their optimum levels are also given.

• Manganese	20 to 40 lb/A
• Boron	0.5 lb/A
• Zinc	3 lb/A

Use a soil test *and* a plant analysis to diagnose a suspected micronutrient deficiency. The soil test *detects* a micronutrient deficiency; the plant analysis *confirms* a suspected deficiency. Table 14 provides information regarding the soil types and crops in which micronutrient deficiencies are most likely to occur.

TABLE 14. Micronutrient deficiencies are most likely to occur in these soil types and crops.

Micronutrient	Soil Type	Crop(s)
Boron	Light-colored loams and sands	Alfalfa
Manganese	Lake bed soils	Soybeans, wheat
Zinc	Neutral, dark-colored loams and sands	Corn

ORGANIC MATTER TEST

The organic matter test gives the soil's organic matter content (percentage). (See Figure 52, "Special Tests Results.") Most mineral soils have an organic matter content ranging from 1.5 to 7 percent. The organic matter content of most light-colored soils is 1.5 to 3 percent; for dark-colored soils it is 3 to 7 percent. Mucks and peats (organic soils) may have an organic matter content as high as 90 percent.

SOLUBLE SALTS

A **soluble salts test** indicates the soil's salt concentration from both fertilizer and nonfertilizer sources. Salt water contamination of soil and excessive applications of fertilizer or manure can cause salt buildups. High salt concentrations can severely injure or even kill plants. Seedlings and young plants are particularly prone to salt injury. Table 15 is a guide for interpreting soluble salt levels.

TABLE 15. Soil and plant conditions indicating various soluble salt concentrations

Soil or Plant Condition	Soluble Salt Concentration mhos x 10 - 5/cm
Unfertilized, leached field soils	Less than 15
Well fertilized soil providing optimum plant growth	100 to 200
Salt-sensitive crop growth affected	Greater than 200
Severely injured plants	Greater than 300

Note: Values in table should be reduced by 1/2 for prolonged droughty conditions. Toxicity of a single salt, such as sodium chloride, is greater than an equivalent amount of a salt mixture.

(*Courtesy* Ohio Agronomy Guide, *1988*)

HEAVY METALS

The Research-Extension Analytical Laboratory can also conduct analyses that indicate the soil's total **heavy metal** concentration (e.g., copper, zinc, lead, nickel, chromium, and cadmium). Excessive heavy metal concentrations are undesirable because they may affect plant growth. In addition, certain heavy metals (e.g., lead, cadmium, and chromium) are toxic to both humans and animals.

Plant Analysis

WHAT IS PLANT ANALYSIS?

Plant analysis is a diagnostic method for determining the following:

1. Nutrient shortage
2. Nutrient excess
3. Nutrient imbalance

Do not use plant analysis as a substitute for soil testing; use it to supplement soil testing. Plant analysis verifies the availability of nutrients to plants.

Plant analysis is valuable because it provides more information for crop management. If used alone, it is not very valuable. However, when used with a soil testing program and growing-condition facts, it removes much of the guesswork involved in supplying correct amounts of nutrients.

To determine your level of crop management, carefully observe the growing conditions on your farm and answer the following questions:

1. Is an adequate soil testing program being followed on all crop production fields?
2. Are the soil test levels adequate for all fields tested?

3. Do any of these soil conditions exist?
   a. Limited moisture-holding capacity (droughty)
   b. Poor drainage (too wet)
   c. Compaction
   d. Low organic matter content
4. What kind and amount of fertilizer was used? How was it applied?
5. When was the crop planted?
6. What crop variety or hybrid was used?
7. What is the plant population (stand)?
8. Are there any insect, disease, or weed problems?
9. Is there adequate moisture?
10. Was the correct tillage system used for the field's soil conditions?

WHO PROVIDES PLANT ANALYSIS SERVICES?

The Ohio Cooperative Extension Service, The Ohio State University, and the Ohio Agricultural Research and Development Center jointly provide the Plant Analysis Program for Ohio crop producers. Many other states have similar laboratories operating as part of the land grant university research division. Private laboratories are also available to perform these services.

WHICH CROPS CAN BE ANALYZED?

The plant analysis laboratories typically accept field, vegetable, fruit, and ornamental crops for analysis. The following are examples of field crops accepted for analysis:

- Corn
- Grain sorghum
- Soybeans
- Wheat
- Oats
- Barley
- Forage grasses (timothy, fescue, bromegrass, and others)
- Alfalfa
- Clovers and other legumes
- Sugar beets
- Tobacco

After the plant sample is prepared, special laboratory instruments are used to conduct an analysis for the 13 nutrient elements (see Figure 59). These tests can be done in a very short time.

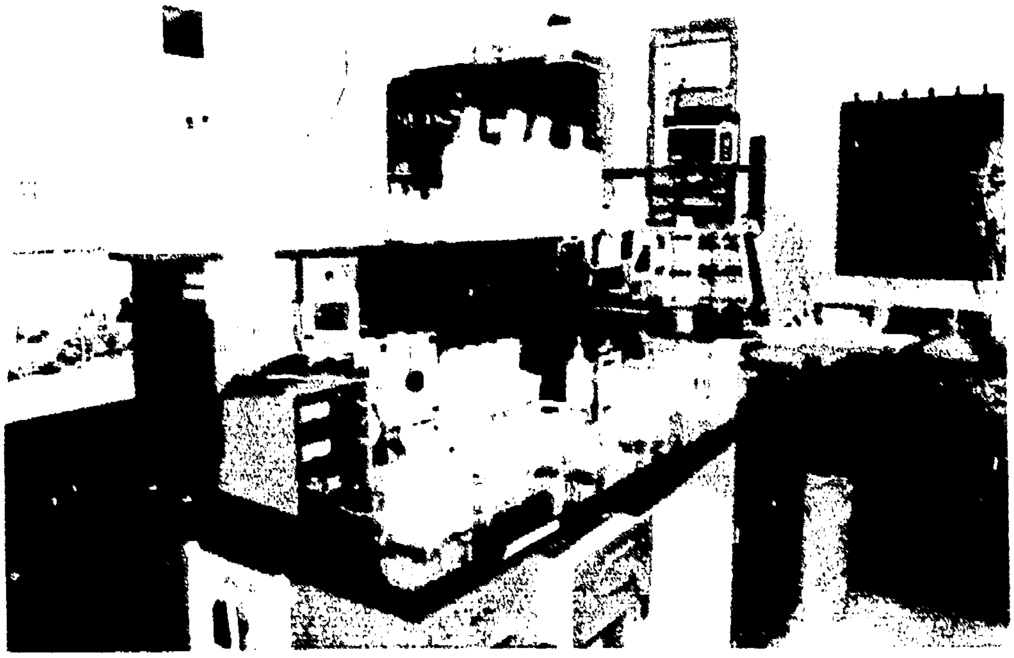


FIG. 59. A plant analysis laboratory

PROCEDURES FOR CONDUCTING A PLANT ANALYSIS

Conduct a plant analysis when unusual, unexplained growing conditions occur, or when you suspect a nutrient shortage or imbalance is affecting plant growth. However, remember that diseases, insects, pesticides, drought, and wet weather can also produce unusual growing conditions. If you decide to have a plant analysis done, carefully perform the following steps:

1. Take a plant sample.
2. Provide crop field information.
3. Interpret plant analysis reports.

Before taking a plant sample, obtain a mailing kit from your county cooperative extension service office. These kits contain instructions for taking the sample, envelopes for mailing the sample, and forms for recording important information regarding the crop and the field (see Figures 60 and 61).

The procedures described in this section are used for field crops. However, these are similar to the general procedures used for other crops (e.g., fruits, vegetables, and ornamentals).

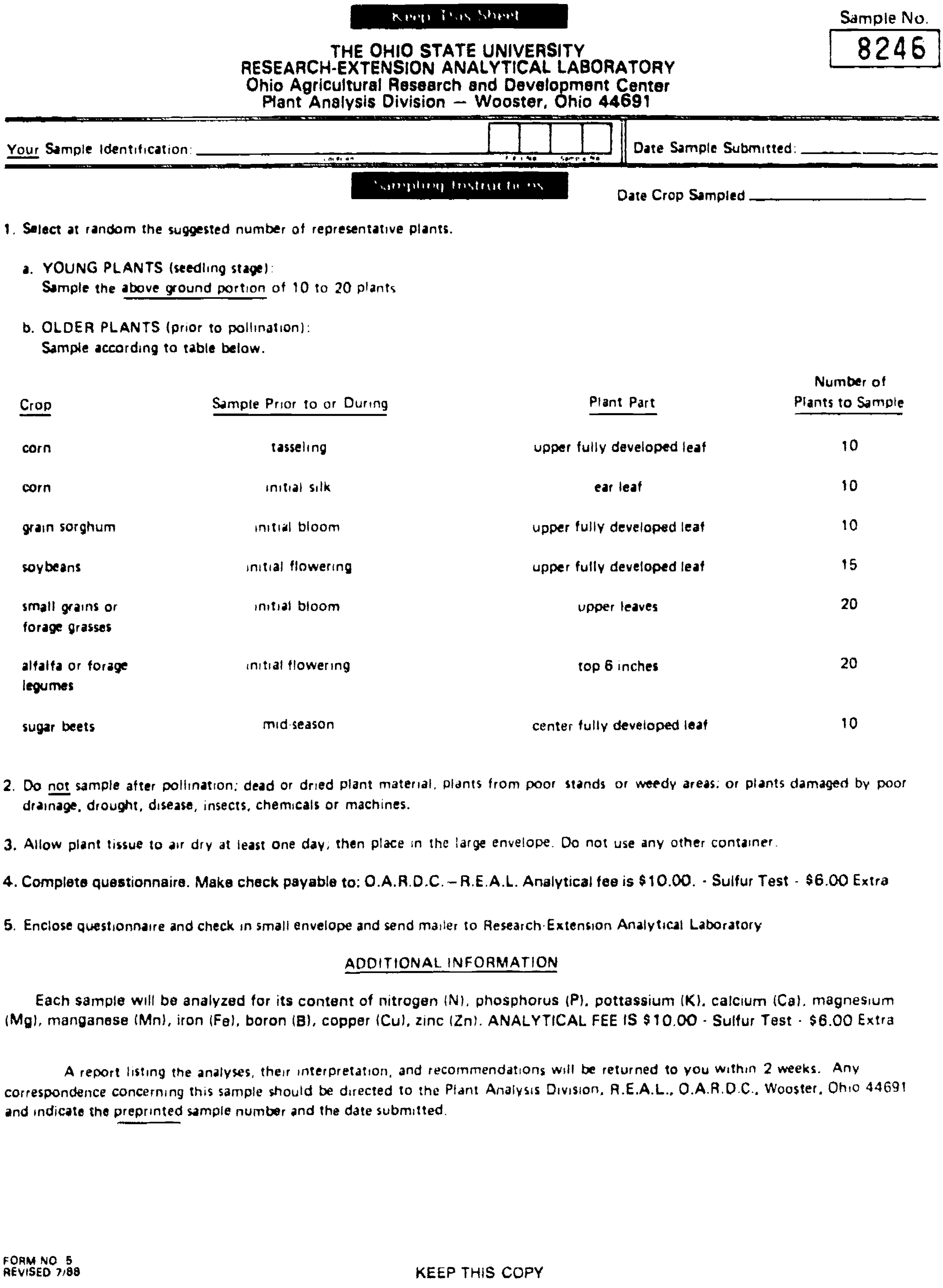
Obtaining a Plant Sample

Plants vary greatly in nutrient uptake during the growing season. Figure 62 on page 67 illustrates how nutrient uptake varies during the growth stages of corn. Therefore, sample crop plants at the growth stage recommended in the plant analysis questionnaire (Figure 60). For example, according to the sampling instructions, corn can be sampled during two growth stages. tasseling and initial silk. If corn is sampled before tasseling, the nutrient uptake of nitrogen, phosphorus, or potassium varies greatly from the uptake at tasseling. However, if it is necessary to take the plant sample at a growth stage other than the one recommended, report the growth stage on the plant analysis questionnaire (Figure 61). Also, since a one-plant sample may not be representative of field nutrient conditions, sample more than one plant. Figure 63 on page 67 shows a crop producer sampling the ear leaf on a corn plant at initial silk.

Providing Crop Field Information

As shown in Figure 61, much information is requested on a plant analysis questionnaire. Fill out this form as completely and accurately as possible. The more information the plant analysis laboratory personnel have, the more accurately they can diagnose the problem. Consequently, they can give better recommendations for correcting the condition. For example, a questionnaire providing the following information gives a clearer picture of the situation:

1. *Soil* – Coarse textured (sandy)
2. *Soil moisture last three weeks* – High (due to above-normal rainfall)
3. *Fertilizer applied* – Nitrogen (lb/A)
   150 broadcast - applied in spring
   20 row



Keep This Sheet

Sample No.
8246

THE OHIO STATE UNIVERSITY
RESEARCH-EXTENSION ANALYTICAL LABORATORY
Ohio Agricultural Research and Development Center
Plant Analysis Division — Wooster, Ohio 44691

Your Sample Identification: ______________________

Date Sample Submitted: ______________________

Sampling Instructions

Date Crop Sampled ______________________

1. Select at random the suggested number of representative plants.

   a. YOUNG PLANTS (seedling stage):
   Sample the above ground portion of 10 to 20 plants

   b. OLDER PLANTS (prior to pollination):
   Sample according to table below.

Crop	Sample Prior to or During	Plant Part	Number of Plants to Sample
corn	tasseling	upper fully developed leaf	10
corn	initial silk	ear leaf	10
grain sorghum	initial bloom	upper fully developed leaf	10
soybeans	initial flowering	upper fully developed leaf	15
small grains or forage grasses	initial bloom	upper leaves	20
alfalfa or forage legumes	initial flowering	top 6 inches	20
sugar beets	mid-season	center fully developed leaf	10

2. Do not sample after pollination; dead or dried plant material, plants from poor stands or weedy areas; or plants damaged by poor drainage, drought, disease, insects, chemicals or machines.

3. Allow plant tissue to air dry at least one day; then place in the large envelope. Do not use any other container.

4. Complete questionnaire. Make check payable to: O.A.R.D.C. – R.E.A.L. Analytical fee is $10.00. - Sulfur Test - $6.00 Extra

5. Enclose questionnaire and check in small envelope and send mailer to Research-Extension Analytical Laboratory

ADDITIONAL INFORMATION

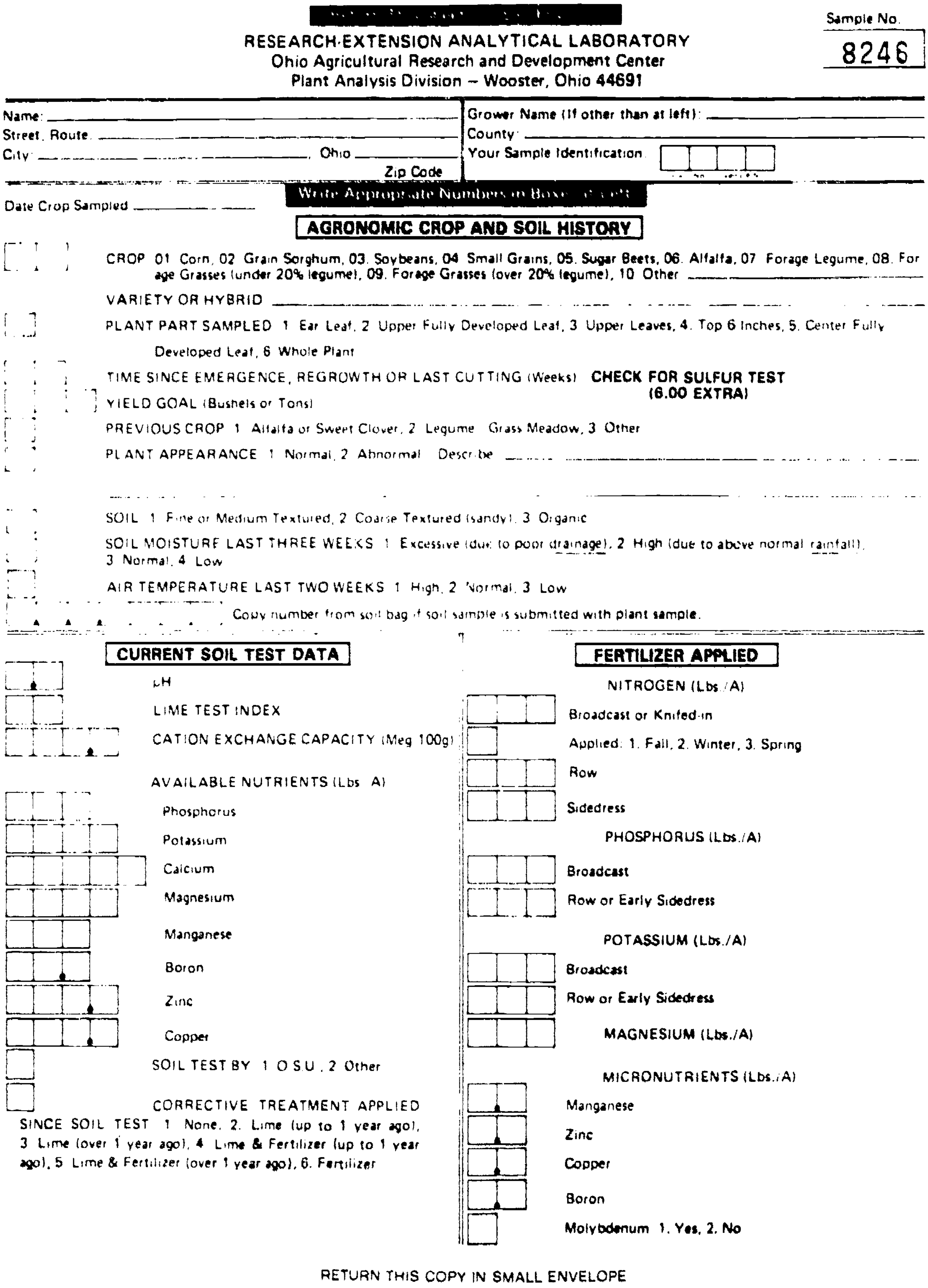
Each sample will be analyzed for its content of nitrogen (N), phosphorus (P), pottassium (K), calcium (Ca), magnesium (Mg), manganese (Mn), iron (Fe), boron (B), copper (Cu), zinc (Zn). ANALYTICAL FEE IS $10.00 - Sulfur Test - $6.00 Extra

A report listing the analyses, their interpretation, and recommendations will be returned to you within 2 weeks. Any correspondence concerning this sample should be directed to the Plant Analysis Division, R.E.A.L., O.A.R.D.C., Wooster, Ohio 44691 and indicate the preprinted sample number and the date submitted.

FORM NO. 5
REVISED 7/88

KEEP THIS COPY

FIG. 60. Plant analysis questionnaire – sampling instructions *(Courtesy Research-Extension Analytical Laboratory, OARDC, Wooster, Ohio)*



[illegible]

Sample No. 8246

RESEARCH-EXTENSION ANALYTICAL LABORATORY
Ohio Agricultural Research and Development Center
Plant Analysis Division – Wooster, Ohio 44691

Name: ______
Street, Route ______
City ______, Ohio ______ Zip Code

Grower Name (If other than at left): ______
County: ______
Your Sample Identification ☐☐☐☐

Date Crop Sampled ______

Write Appropriate Numbers in Boxes at Left

AGRONOMIC CROP AND SOIL HISTORY

☐☐ CROP 01 Corn, 02 Grain Sorghum, 03. Soybeans, 04 Small Grains, 05. Sugar Beets, 06. Alfalfa, 07 Forage Legume, 08. Forage Grasses (under 20% legume), 09. Forage Grasses (over 20% legume), 10 Other ______

VARIETY OR HYBRID ______

☐ PLANT PART SAMPLED 1 Ear Leaf, 2 Upper Fully Developed Leaf, 3 Upper Leaves, 4. Top 6 Inches, 5. Center Fully Developed Leaf, 6 Whole Plant

☐☐ TIME SINCE EMERGENCE, REGROWTH OR LAST CUTTING (Weeks) **CHECK FOR SULFUR TEST (6.00 EXTRA)** ☐

☐☐☐ YIELD GOAL (Bushels or Tons)

☐ PREVIOUS CROP 1 Alfalfa or Sweet Clover, 2 Legume Grass Meadow, 3 Other

☐ PLANT APPEARANCE 1 Normal, 2 Abnormal Describe ______

☐ SOIL 1 Fine or Medium Textured, 2 Coarse Textured (sandy), 3 Organic

☐ SOIL MOISTURE LAST THREE WEEKS 1 Excessive (due to poor drainage), 2 High (due to above normal rainfall), 3 Normal, 4 Low

☐ AIR TEMPERATURE LAST TWO WEEKS 1 High, 2 Normal, 3 Low

☐☐☐☐☐☐☐ Copy number from soil bag if soil sample is submitted with plant sample.

CURRENT SOIL TEST DATA

☐☐ pH
☐☐ LIME TEST INDEX
☐☐☐☐ CATION EXCHANGE CAPACITY (Meq 100g)

AVAILABLE NUTRIENTS (Lbs A)

☐☐☐☐ Phosphorus
☐☐☐☐ Potassium
☐☐☐☐☐ Calcium
☐☐☐☐ Magnesium
☐☐☐ Manganese
☐☐☐ Boron
☐☐☐☐ Zinc
☐☐☐☐ Copper
☐ SOIL TEST BY 1 O.S.U., 2 Other
☐ CORRECTIVE TREATMENT APPLIED SINCE SOIL TEST 1 None, 2. Lime (up to 1 year ago), 3 Lime (over 1 year ago), 4 Lime & Fertilizer (up to 1 year ago), 5 Lime & Fertilizer (over 1 year ago), 6. Fertilizer

FERTILIZER APPLIED

NITROGEN (Lbs./A)

☐☐☐ Broadcast or Knifed-in
☐ Applied: 1. Fall, 2. Winter, 3. Spring
☐☐☐ Row
☐☐☐ Sidedress

PHOSPHORUS (Lbs./A)

☐☐☐ Broadcast
☐☐☐ Row or Early Sidedress

POTASSIUM (Lbs./A)

☐☐☐ Broadcast
☐☐☐ Row or Early Sidedress
☐☐☐ MAGNESIUM (Lbs./A)

MICRONUTRIENTS (Lbs./A)

☐☐ Manganese
☐☐ Zinc
☐☐ Copper
☐☐ Boron
☐ Molybdenum 1. Yes, 2. No

RETURN THIS COPY IN SMALL ENVELOPE

FIG 61 Plant analysis questionnaire – crop and soil history, soil test data, and fertilizer applied
(Courtesy Research-Extension Analytical Laboratory, OARDC, Wooster, Ohio)

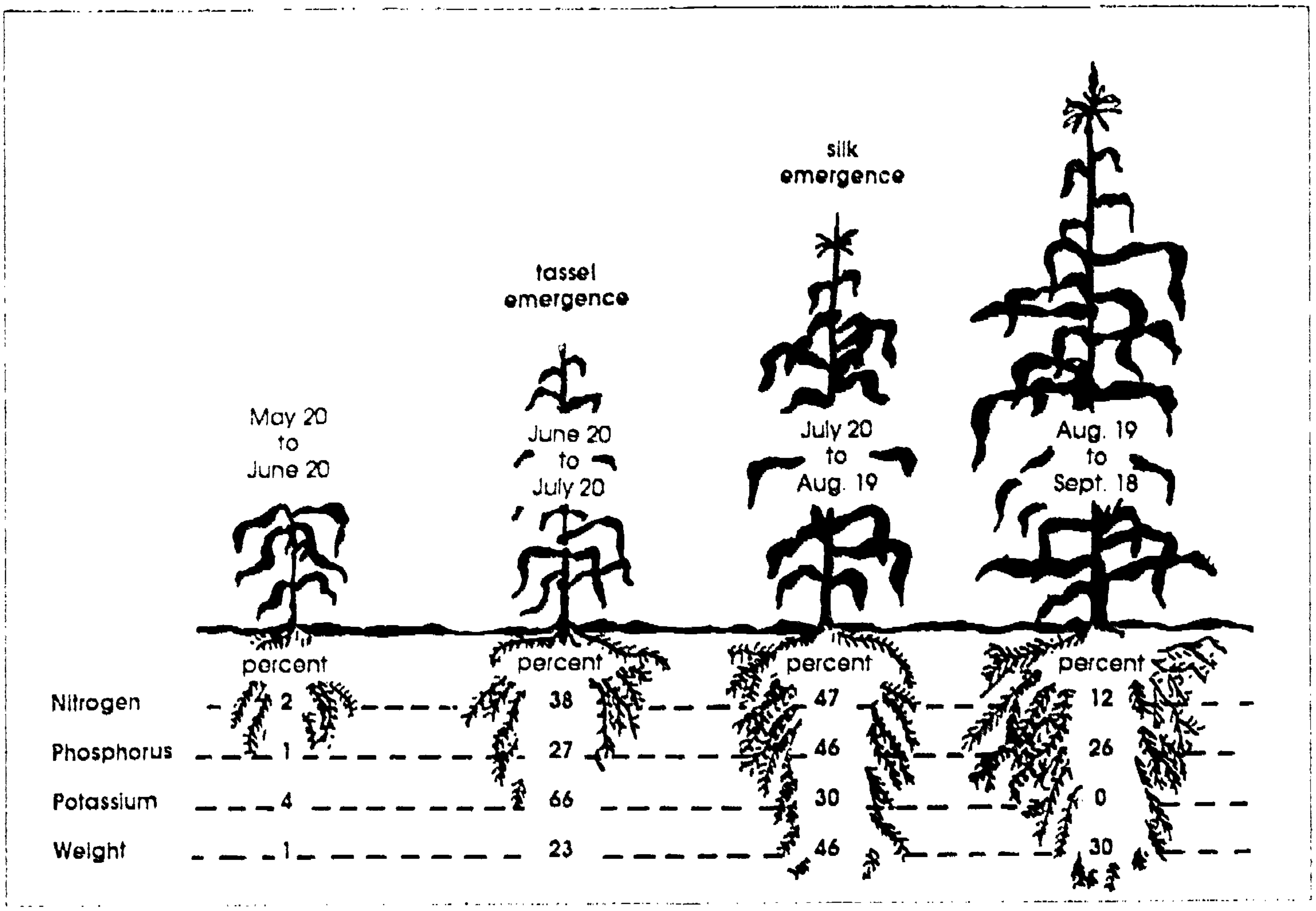
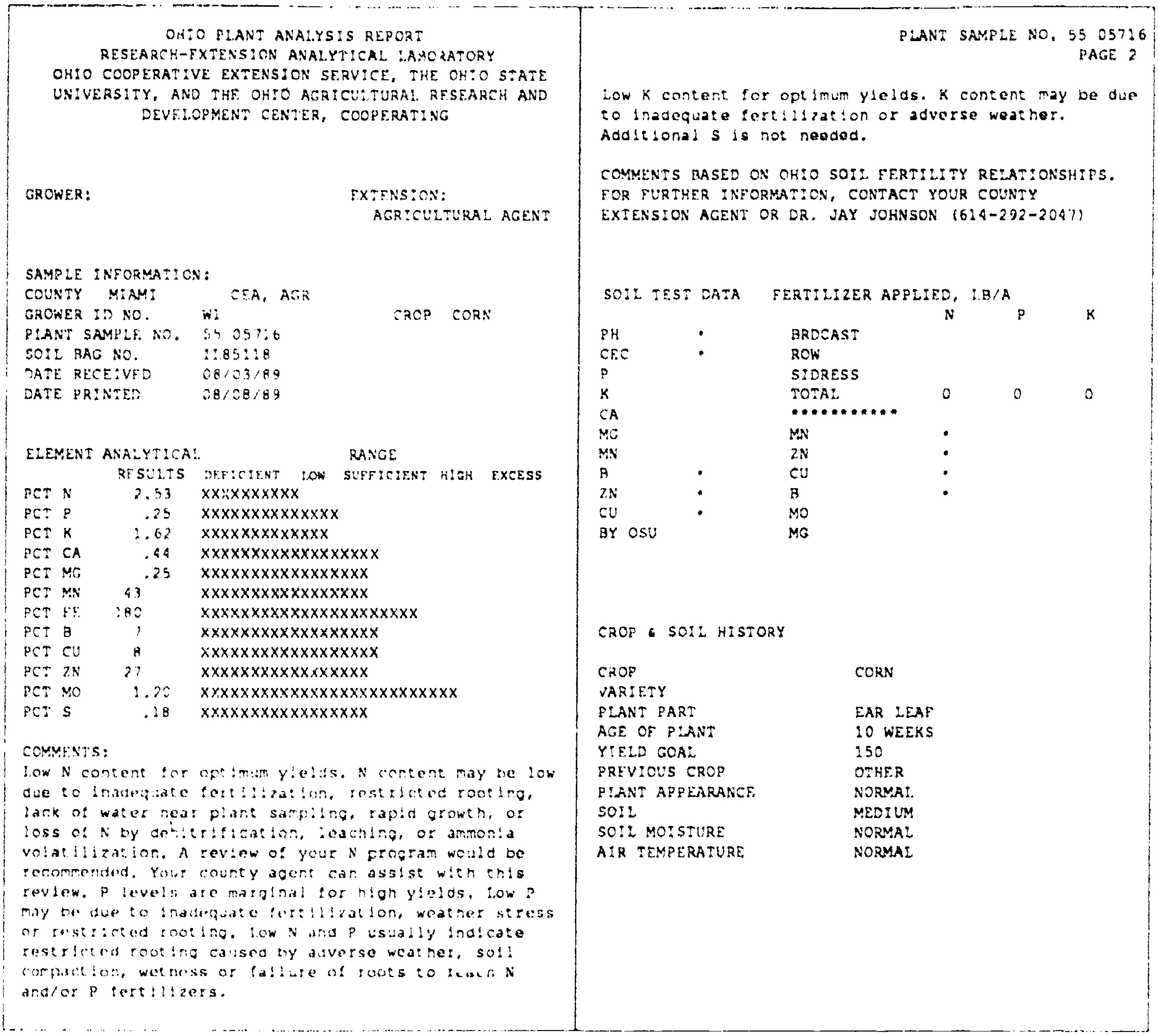


FIG. 62 This illustration shows the plant's weight gain and percentage of nutrient uptake at various growth stages. By the final stage, the plant has achieved final weight and about 100 percent of its nutrient uptake.

FIG. 63. Sample corn ear leaves at the start of silking. Send these samples for plant analysis. *(Courtesy C.R. Fridline)*

Using this information plus the rest of the questionnaire, plant analysis personnel are able to reach the following conclusions:

1. The analysis confirmed a suspected nitrogen deficiency.
2. The cause: Much of the nitrogen, in nitrate form, had leached through the coarse-textured soil due to heavy rainfall.



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             OHIO PLANT ANALYSIS REPORT
       RESEARCH-EXTENSION ANALYTICAL LABORATORY
  OHIO COOPERATIVE EXTENSION SERVICE, THE OHIO STATE
  UNIVERSITY, AND THE OHIO AGRICULTURAL RESEARCH AND
          DEVELOPMENT CENTER, COOPERATING


GROWER:                             EXTENSION:
                                      AGRICULTURAL AGENT


SAMPLE INFORMATION:
COUNTY   MIAMI        CEA, AGR
GROWER ID NO.     W1                   CROP  CORN
PLANT SAMPLE NO.  55 05716
SOIL BAG NO.      1185118
DATE RECEIVED     08/03/89
DATE PRINTED      08/08/89


ELEMENT ANALYTICAL                 RANGE
        RESULTS  DEFICIENT  LOW  SUFFICIENT HIGH  EXCESS
PCT N      2.53  XXXXXXXXXX
PCT P       .25  XXXXXXXXXXXXXX
PCT K      1.62  XXXXXXXXXXXXX
PCT CA      .44  XXXXXXXXXXXXXXXXXX
PCT MG      .25  XXXXXXXXXXXXXXXXX
PCT MN    43     XXXXXXXXXXXXXXXXX
PCT FE   180     XXXXXXXXXXXXXXXXXXXXXX
PCT B      7     XXXXXXXXXXXXXXXXXX
PCT CU     8     XXXXXXXXXXXXXXXXXX
PCT ZN    27     XXXXXXXXXXXXXXXXX
PCT MO     1.20  XXXXXXXXXXXXXXXXXXXXXXXXXX
PCT S       .18  XXXXXXXXXXXXXXXXX

COMMENTS:
Low N content for optimum yields. N content may be low
due to inadequate fertilization, restricted rooting,
lack of water near plant sampling, rapid growth, or
loss of N by denitrification, leaching, or ammonia
volatilization. A review of your N program would be
recommended. Your county agent can assist with this
review. P levels are marginal for high yields. Low P
may be due to inadequate fertilization, weather stress
or restricted rooting. Low N and P usually indicate
restricted rooting caused by adverse weather, soil
compaction, wetness or failure of roots to reach N
and/or P fertilizers.
```

```
                                PLANT SAMPLE NO. 55 05716
                                                   PAGE 2

Low K content for optimum yields. K content may be due
to inadequate fertilization or adverse weather.
Additional S is not needed.

COMMENTS BASED ON OHIO SOIL FERTILITY RELATIONSHIPS.
FOR FURTHER INFORMATION, CONTACT YOUR COUNTY
EXTENSION AGENT OR DR. JAY JOHNSON (614-292-2047)


 SOIL TEST DATA   FERTILIZER APPLIED, LB/A
                                    N      P      K
PH         •         BRDCAST
CEC        •         ROW
P                    SIDRESS
K                    TOTAL          0      0      0
CA                   •••••••••••
MG                   MN             •
MN                   ZN             •
B          •         CU             •
ZN         •         B              •
CU         •         MO
BY OSU               MG



CROP & SOIL HISTORY

CROP                       CORN
VARIETY
PLANT PART                 EAR LEAF
AGE OF PLANT               10 WEEKS
YIELD GOAL                 150
PREVIOUS CROP              OTHER
PLANT APPEARANCE           NORMAL
SOIL                       MEDIUM
SOIL MOISTURE              NORMAL
AIR TEMPERATURE            NORMAL
```

FIG. 64. Sample report from the Plant Analysis Laboratory *(Courtesy Ohio Cooperative Extension Service)*

Interpreting Plant Analysis Reports

After the plant analysis has been conducted, a detailed report is given to the crop producer. In the case shown in Figure 64, the laboratory performed analyses for 12 elements. The analytical results for nitrogen, phosphorus, potassium, calcium, and magnesium are given in percentages; the results for manganese, iron, boron, copper, zinc, molybdenum, and sulfur are given in parts per million (PPM). Table 16 lists the sufficiency ranges of 11 elements for corn, soybeans, alfalfa, wheat, and sugar beets.

The plant analysis report form places the element content in one of the following concentration ranges: **deficient, low, sufficient, high,** or **excess.** In Table 17 each range is defined in terms of plant appearance and crop yield. In Figure 64 nitrogen

TABLE 16. Sufficiency ranges for corn, soybeans, alfalfa, wheat, and sugar beets*

	CORN	SOYBEANS	ALFALFA	WHEAT	SUGAR BEETS
Element	**Ear Leaf Sample at Initial Silk**	**Upper Fully Developed Leaf Sampled During Initial Flowering**	**Top Six Inches Sampled During Initial Flowering**	**Upper Leaves Sampled During Initial Bloom**	**Center Fully Developed Leaf Sampled in Mid-season**
			PERCENT (%)		
N	2.76 - 3.50	4.25 - 5.50	3.76 - 5.50	2.59	3.01 - 4.50
P	0.25 - 0.50	0.26 - 0.50	0.26 - 0.70	0.21 - 0.50	0.26 - 0.50
K	1.71 - 2.50	1.71 - 2.50	2.01 - 3.50	1.51 - 3.00	2.01 - 6.00
Ca	0.21 - 1.00	0.36 - 2.00	1.76 - 3.00	0.21 - 1.00	0.36 - 1.20
Mg	0.16 - 0.60	0.26 - 1.00	0.31 - 1.00	0.16 - 1.00	0.36 - 1.00
			PARTS PER MILLION (PPM)		
Mn	20 - 150	21 - 100	31 - 100	16 - 200	21 - 150
Fe	21 - 250	51 - 350	31 - 250	11 - 300	51 - 200
B	4 - 25	21 - 55	31 - 80	6 - 40	26 - 80
Cu	6 - 20	10 - 30	11 - 30	6 - 50	11 - 40
Zn	20 - 70	21 - 50	21 - 70	21 - 70	19 - 16
Mo	—	1.0 - 5.0	1.0 - 5.0	0.03 - 5.0	0.15 - 5.0

*Sufficiency ranges used by the Research-Extension Analytical Laboratory, OARDC, Wooster, Ohio.

TABLE 17. Definitions of various nutrient concentration ranges

Range	**Definition** (plant appearance and crop yield)
Deficient	Plants show obvious symptoms of nutritional deficiency.
Low	Plants are normal in appearance, but responsive to fertilization with the low-testing nutrient.
Sufficient	Plants are normal in appearance and have adequate concentrations of this nutrient for the highest yields.
High	Plants are normal in appearance and high yields are expected. However, concentrations of this nutrient are higher than normally expected.
Excess	Yield is significantly reduced by an overabundance of this nutrient.

(N), phosphorus (P), and potassium (K) are present in low amounts; molybdenum (Mo) is present in a high amount. The remaining eight elements are present in sufficient amounts. Comments and recommendations for correcting unsatisfactory conditions are also given in the plant analysis report. Probable causes of these conditions are listed in Table 18 on page 70.

TABLE 18 Possible causes of low and high nutrient levels as determined by plant analysis

Nutrient	Cause of Low Nutrient Level	Cause of High Nutrient Level
Nitrogen (N)	Inadequate nitrogen fertilizer Low soil phosphorus level	Excessive application of nitrogen fertilizer Shortage of another nutrient
Phosphorus (P)	Low soil phosphorus level Inadequate phosphorus fertilization Poor drainage Low soil pH	High soil phosphorus level Excessive application of phosphate fertilizer
Potassium (K)	Low soil potassium level Inadequate potassium fertilization Heavy application of nitrogen fertilizer	High soil potassium level Excessive application of potash fertilizer
Calcium (Ca)	Low soil pH Low soil calcium level High soil potassium or heavy application of potassium fertilizer	Old plant tissue Dead or diseased tissue
Magnesium (Mg)	Low soil pH Low soil magnesium level High soil potassium or heavy application of potassium fertilizer	Old plant tissue Dead or diseased tissue
Manganese (Mn)	Low soil availability Associated with neutral, alkaline, peat, or muck soils	Low soil pH Heavy applications of phosphorus and/or nitrogen fertilizer on acid/organic matter soils Soil or dust contamination
Iron (Fe)	High soil pH	Soil or dust contamination Zinc deficiency
Boron (B)	Low soil availability Associated with alkaline, sandy, or low organic matter content soils	Improper application of boron fertilizer
Copper (Cu)	Low soil availability Associated with peats, mucks, or upland light-colored soils	Contamination from pesticide sprays or contact with brass equipment
Zinc (Zn)	Low soil availability Associated with sands, exposed subsoils, mucks, peats, and soils high in pH and available phosphorus	Contamination from brass or galvanized equipment Old, dead or diseased tissue
Molybdenum (Mo)	Low soil availability Associated mainly with acid soils, pH below 5.5	Potassium deficiency High soil pH
Aluminum (Al)	This is not an essential nutrient, so it cannot be deficient	Soil or dust contamination Poor drainage Low soil pH

Practical Application

■ The following activities should help you become proficient in determining fertility needs through soil testing. Check the box when the item is completed.

1. Selecting yield goals

Resources

- Aerial photograph of farm
- Graph paper (1/8 or 1/10 scale)
- Unlined white paper
- Scale with 1/8 and 1/10 divisions
- *Ohio Agronomy Guide* (current issue) or similar reference
- Soil survey report (If your county does not have a published report, a neighboring county may have a report listing your soil types.)

Procedure

☐ Using aerial photographs, draw farm boundaries to scale.
☐ Draw field boundaries to scale.
☐ Draw creeks, swampy areas, and ponds.
☐ Record soil types, erosion, and slope symbols. Include boundaries for each.
☐ Record field acreages and assign each field an identification number.
☐ Prepare a crop yield goal record for each field to be sampled. (Use form on page 72.)
☐ Determine and record soil type names for each field to be sampled.
☐ Determine cropping sequence for each field to be sampled.
☐ For each soil type, select a yield goal for the crop to be grown.

2. Taking a soil sample of a field(s)

Resources

- Outline map of each field to be sampled (from activity 1 above)
- Soil probe, soil auger, or spade
- Clean pail (one to two gallons, preferably plastic)
- Paper or plastic bags (one for each area to be sampled)
- Marking pen

Procedure

☐ On each field's outline map, mark each area with a soil sample identification number.
☐ Mark plastic or paper bags with identification numer (from outline map).
☐ Take at least 15 cores (samplings) per area.
☐ Avoid each field's unusual areas (e.g., fence rows, dead furrows, turn rows, and locations of previous lime or fertilizer spills).

Yield Goal Determination

Field No. ____________

Total acres ____________

Crop ____________

SOIL CHARACTERISTICS			SOIL TYPE		ACRES	POTENTIAL CROP YIELD		YIELD GOAL
Characteristic	Map Symbol	Characteristic of Area	Map Symbol	Soil Type of Area	Acres of Each Soil Type	Units per Acre	Potential for Each Soil Type (Units/A x Acres)	
Soil texture								
Slope								
Erosion								
Natural drainage								
Soil origin								
Soil texture								
Slope								
Erosion								
Natural drainage								
Soil origin								
Soil texture								
Slope								
Erosion								
Natural drainage								
Soil origin								
Soil texture								
Slope								
Erosion								
Natural drainage								
Soil origin								

Practical Application (continued)

3. Preparing and submitting soil sample

Resources

- Clean paper, plywood, or masonite on which to dry samples
- Short pieces of wood (one- or two-inch) or cardboard for separating samples
- Clean pail (one to two gallons, preferably plastic)
- Clean, one-cup container for each sample to submitted
- Record of field, soil type, yield goal, and previous lime and fertilizer applications

Procedure

☐ Spread samples on clean, prepared surface. Separate each sample and mark with identification number.

☐ Allow samples to air dry.

☐ Crush any clods or lumps present in each sample.

☐ Mix each sample thoroughly.

☐ Collect one pint of each soil sample; place each in original bag marked with sample identification number.

☐ Deliver sample(s) to county extension service office or other soil testing laboratory.

☐ Provide required information regarding sampled field.

☐ Select tests to be made.

4. Interpreting soil test reports

Resources

- Soil test report for sampled field(s)
- *Ohio Agronomy Guide* (current issue) or similar reference
- Notebook and pen

Procedure

☐ Using soil test reports for a field or soil area, determine how satisfactory the standard and special test results are. (If you need help, refer to "Interpreting Soil Test Reports" in this chapter.)

Practical Application (continued)

■ The following activities should help you develop proficiency in determining fertility needs through *plant analysis*. Check the box as the item is completed.

5. Collecting plant tissue and sending specimens to laboratory

Resources

- Plant analysis mailing kit (This includes sampling directions.)
- Large paper or plastic bag for collecting plant tissue

Procedure

☐ Select plant part according to crop type and growth stage. (See directions in plant analysis mailing kit.)

☐ Select plant tissue for the recommended number of plants.

☐ Complete the plant analysis questionnaire (included in plant analysis mailing kit)

☐ Mail plant tissue and questionnaire to plant analysis laboratory.

6. Interpreting plant analysis results

Resources

- Plant analysis report for a field (preferably reports for several fields showing different nutrient deficiencies)
- Notebook and pen

Procedure

☐ Using the form on page 75, record information from the plant analysis report form(s). Make recommendations for correcting the problem(s).

KEY TERMS

■ Following is a list of important terms found in this chapter. Can you define them?

acid soil
active acidity
alkaline soil
base saturation
buffering
field map
field trials
lettering system
neutral
numbering system
pH range
plant analysis
parent rock
ratio
reserve acidity
soil acidity
soil auger
soil cores
soil map
soil pH
soil origin
soil probe
soil sample
soil testing
soluble salts
sufficiency levels
total acidity

Soil Test Item	Amount (from report)	EVALUATION		
		Poor	Fair	Good
pH				
Lime test index				
Available phosphorus				
Exchangeable potassium				
Exchangeable calcium				
Exchangeable magnesium				
Cation exchange capacity				
% base saturation calcium				
% base saturation magnesium				
% base saturation potassium				
Magnesium				
Zinc				
Boron				
Organic matter				
Calculate the following (not on report):				
Calcium-magnesium ratio				
Magnesium-potassium ratio				

Nutrient	Amount from Analysis Report (% or PPM)	Recommended Sufficiency Range	Suggestions for Correcting Problem
Example: *Zn*	*16 ppm*	*20 - 70 ppm*	*Apply zinc fertilizer with starter or plow-down fertilizer*
N			
P			
K			
Ca			
Mg			
Na			
Mn			
Fe			
B			
Cu			
Zn			
Mo			
Al			

Chapter 4

Nutrient Sources

Introduction

In order to correctly select and apply fertilizer and lime, you must know something about plant nutrient sources. For example, it is important to know that nutrients can be easily lost from the soil or changed to forms unavailable to plants. This knowledge helps you make appropriate decisions when correcting nutrient shortages in the soil.

Since many nutrients have several different sources, you must also know that one nutrient source may react differently in the soil than another source of the same nutrient. For example, nitrogen in *nitrate* form (NO_3^-) does not attach to the soil's clay and organic matter particles because the nitrate is negatively charged. For this reason, nitrate is highly soluble in the soil solution (water) and moves with the soil solution. Thus, nitrate can easily leach from the soil. On the other hand, nitrogen in the *ammonium* form (NH_4^+) is positively charged and attaches itself to the soil's clay and organic matter particles. It does not leach from the soil. However, when the soil temperature reaches 50° to 55° F (10.08° to 12.88° C) or above, ammonium nitrogen rapidly changes to nitrate nitrogen. This is one reason why it is important to know about nutrient sources when selecting and applying fertility nutrients.

OBJECTIVES

After studying this unit, you should be able to do the following:

- Develop a nutrient loss prevention plan for livestock manure used for fertilizer. This plan includes
  - Calculating the amounts of nutrients available from livestock manure.
  - Calculating possible nutrient losses from the livestock manure.
- Plan a field cropping sequence to increase nitrogen content in a crop-growing program for legume crops. This plan includes
  - Calculating the approximate amount of nitrogen produced per acre by the different legume crops.
  - Listing the conditions most suitable for nitrogen fixation by legume plants.

- List the important functions of organic matter in the soil (i.e., livestock manure and crop residues).
- Select a suitable green manure crop(s) to provide erosion protection and improve the soil's nutrient and organic matter content. This procedure includes
  - Listing the approximate amount of organic matter supplied by green manure crops.
  - Listing the cultural requirements of green manure crops (e.g., planting times, lime, fertilizer, and similar requirements).
- Select the most suitable commercial fertilizer by considering the soil conditions (e.g., soil test, texture, slope, and drainage) and crops to be grown. This procedure includes
  - Listing the important nutrient sources of nitrogen, phosphorus and potassium from commercial fertilizers.
  - Listing the nutrient sources of micronutrients from commercial fertilizers.
- Select the liming materials that are most suitable for supplying calcium. Do this by considering the soil conditions (e.g., soil test, texture, slope, and drainage) and crops to be grown. Repeat this procedure to select the nutrient source most suitable for supplying magnesium.

SCIENCE CONCEPTS

This chapter covers the following science concepts:

- Plant nutrient movement through the soil is a result of chemical reactions or physical forces (such as water movement).
- The chemical and physical characteristics of both the soil and environment in which plant growth occurs determine plant nutrient availability.
- A variety of sources – including both organic and inorganic substances – provide plant nutrients.
- Soil particles carry electrical charges (either positive or negative) that attract and hold nutrients.
- The nitrification process changes the chemical composition of nitrogen in the soil, thus influencing nitrogen availability to plants.
- The carbon-to-nitrogen ratio of dead plant material determines the degree to which this material is converted to organic matter or carbon dioxide and water.
- Symbiotic relationships exist between commonly grown legume crops and certain bacteria found in the soil.
- Volatilization can be illustrated by the denitrification process.
- The electrical charge of potassium ions (K^+) results in a large percentage of potassium in the soil being unavailable for plant use.

Nutrient Losses from the Soil

Different plant nutrients react with and move in the soil in different ways. Applying an adequate amount of a nutrient-supplying material does not guarantee that all of it will be available to the plant when needed. Therefore, it is important to understand the following:

- If nutrients - in a form available to plants - are applied to the soil they may become unavailable before the plants can use them.
- Nutrients can be lost from the soil before being used by plants.
- Nutrients can be lost from the soil through leaching (see Figure 65).
- Nutrients can be lost from the soil through erosion (see Figure 66).
- Nitrogen is often lost through **denitrification** – the breakdown of nitrates in the soil.

In addition to nutrient loss, the following soil conditions influence nutrient availability:

- Soil temperature
- Soil water content
- Soil pH
- Soil texture
- Nutrient imbalance (an overabundance of one nutrient, a deficiency of another)
- Topography (slope of the land)

How these conditions affect nutrient availability and nutrient loss are explained in the following text.

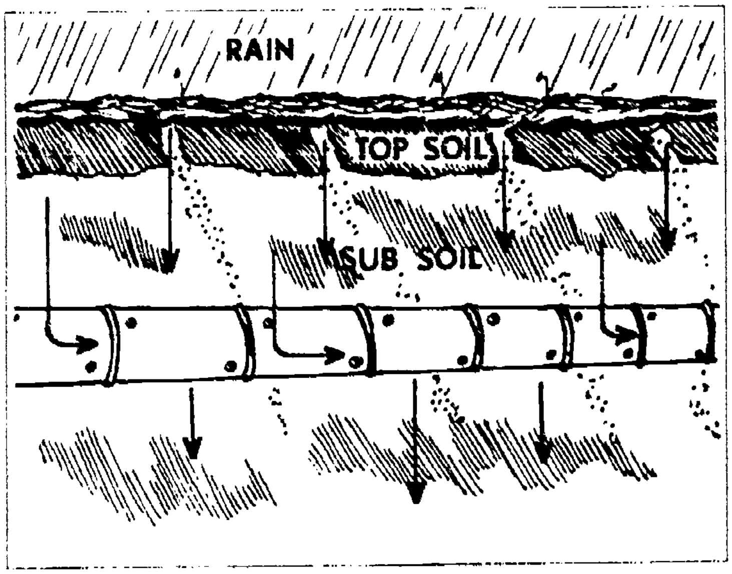


FIG. 65. Nutrients can be lost from the soil through leaching. If rainfall is heavy or frequent, nutrients move into the drainage system and beyond plant root range. *(Courtesy Ohio Cooperative Extension Service)*

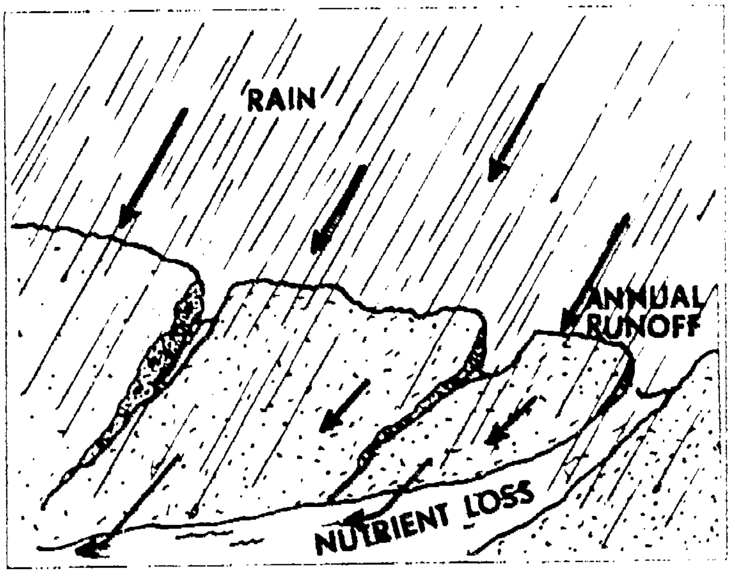


FIG. 66. Nutrients can be lost from the soil through erosion.

Nutrient Sources

In general, nutrients are supplied to plants by the following:

1. *Soil*
    - Minerals
    - Organic matter
2. *Other sources*
    - Animal manures
    - Crop residues
    - Green manure crops
    - Nitrogen fixation by legumes
    - Commercial fertilizers
    - Lime

Many soils cannot supply enough nutrients to meet planned yield goals. When this happens, fertilizer, lime, manure, and crop residues can be used to supply the nutrients needed to meet crop requirements.

SOIL MINERALS

As described in Chapter 2, the decomposition of the rock (parent material) from which the soil was formed produces the mineral part of the soil. With the exception of the nutrient nitrogen, all of the nutrients required by plants are found in the soil minerals. Although the most important nutrients (e.g., phosphorus and potassium) are found in abundance in most soils, the breakdown of these minerals into an available form is a slow process.

ORGANIC MATTER

In addition to supplying nutrients for plant growth, organic matter has many other important functions in the soil.

Organic Matter: Its Function in the Soil

1. *Organic matter is a reservoir of chemical elements (nutrients) for plant growth.*
    - Organic matter particle ions carry a negative (-) electrical charge. Thus, they attract and hold the positively (+) charged nutrient ions of magnesium, calcium, potassium, and nitrogen (ammonium, NH_4^+).
    - Most of the nitrogen in the soil's plow layer is found in the organic matter.
    - From 10 to 75 percent of the soil's phosphorus can be found in organic matter.
    - Other nutrients, such as sulfur, are contained in organic matter.

2. *Organic matter provides an energy source for soil organisms.*
    - Soil organisms require organic matter for growth and development.
    - As soil organisms grow, develop, and eventually die, plant nutrients become available.
    - When the amount of organic matter decreases, the number of soil organisms also decreases.

3. *Adequate organic matter improves the physical properties of soil.*
    - Soil with adequate organic matter is loose; air can move freely through this soil. As a result, respiration takes place. Respiration is required for plant growth, but plant roots need a continual supply of oxygen for this process to take place. Oxygen is also required to change some materials to available nutrients.
    - Loose soil also permits water to enter and move in the soil. Thus, the soil's water-holding capacity increases and more water is available for plant use.
    - Organic matter increases the soil's ability to resist erosion. The soil's pore spaces become larger and make the soil more granular. If pore spaces become smaller, the soil becomes dense and compact. When this occurs, water enters the soil slowly and surface runoff increases.
    - When organic matter is lost from soil, the soil tends to become hard, compact, and cloddy. Little space is left to hold air and moisture.

4. *Organic matter affects tillage operations of soils.*
    - Soil structure breakdown occurs more often in heavily tilled soils. However, soils containing more organic matter have a slower structural breakdown and are easier to till.

Nitrification

Organic matter is the soil's nitrogen "storehouse." Almost all the soil's nitrogen is part of the organic matter. Therefore, when organic matter decomposes, nitrogen is released and changes to forms available for plant use. This process is called **nitrification**. Some chemical fertilizer sources of nitrogen must go through nitrification before becoming available for plant use. If nitrogen is not in the ammonium (NH^+) or nitrate (NO_3^-) form, it is not available to plants. For example, animal manure, crop residues, and chemical fertilizers (urea and anhydrous ammonia) must go through nitrification before releasing nitrogen. Figure 67 on page 82 shows the following steps that transform unavailable nitrogen to available nitrogen:

1. **Ammonia** is the first chemical formed as organic nitrogen materials (manure, crop residues, and urea) start to decompose.
    - Ammonia (NH_3) is a colorless, pungent (strong-smelling) gas composed of nitrogen and hydrogen. It does not carry an electrical charge; therefore, it is *neutral* (neither positive nor negative). Ammonia is also very water soluble. It can be converted to a liquid by subjecting it to cold temperatures or by pressurizing ammonia gas.

- As Figure 67 illustrates, ammonia and ammonium do not require oxygen for formation. Ammonia is produced by the action of bacteria on organic matter materials (manure and crop residue) and urea. Under most soil conditions, bacterial action quickly changes ammonia (NH_3) to ammonium (NH_4^+). These processes take place without air (oxygen). Continued soil bacterial action changes ammonium to nitrite (NO_2^-) and then to nitrate (NO_3). These processes require air in the soil and soil temperature to be above 50° to 55° F (10.08° to 12.88° C). In other words, ammonia and ammonium formation can take place in a wet soil with very little air present. However, soil organisms (bacteria) are required for organic matter decomposition and the consequent ammonia formation.

2. Then, under most soil conditions, ammonia (NH_3) rapidly picks up a hydrogen ion (H^+) and forms **ammonium** (NH_4^+). If this does not occur, the ammonia escapes into the atmosphere. This is why an ammonia odor can be sometimes be detected near a fermenting manure pile.

3. Next, ammonium ions (NH_4^+) attach to the soil's clay and organic matter particles and are held as exchangeable nutrients. However, when soil temperatures reach 50° to 55° F (10.08° to 12.88° C) or above, these ammonium ions convert to **nitrites** (NO_2^-) (also known as *nitrous acids*) and then to **nitrates** (NO_3^-) – the largest source of plant nitrogen.
   - Nitrate formation requires the proper temperature and presence of bacteria and oxygen. Therefore, a water-saturated soil prevents nitrate formation due to a lack of oxygen in the soil air.

The opposite of nitrification is **denitrification** - the breakdown of nitrates in the soil. When denitrification occurs, nitrates are lost from the soil. This process is described in detail later in this chapter (see *Commercial Fertilizers*).

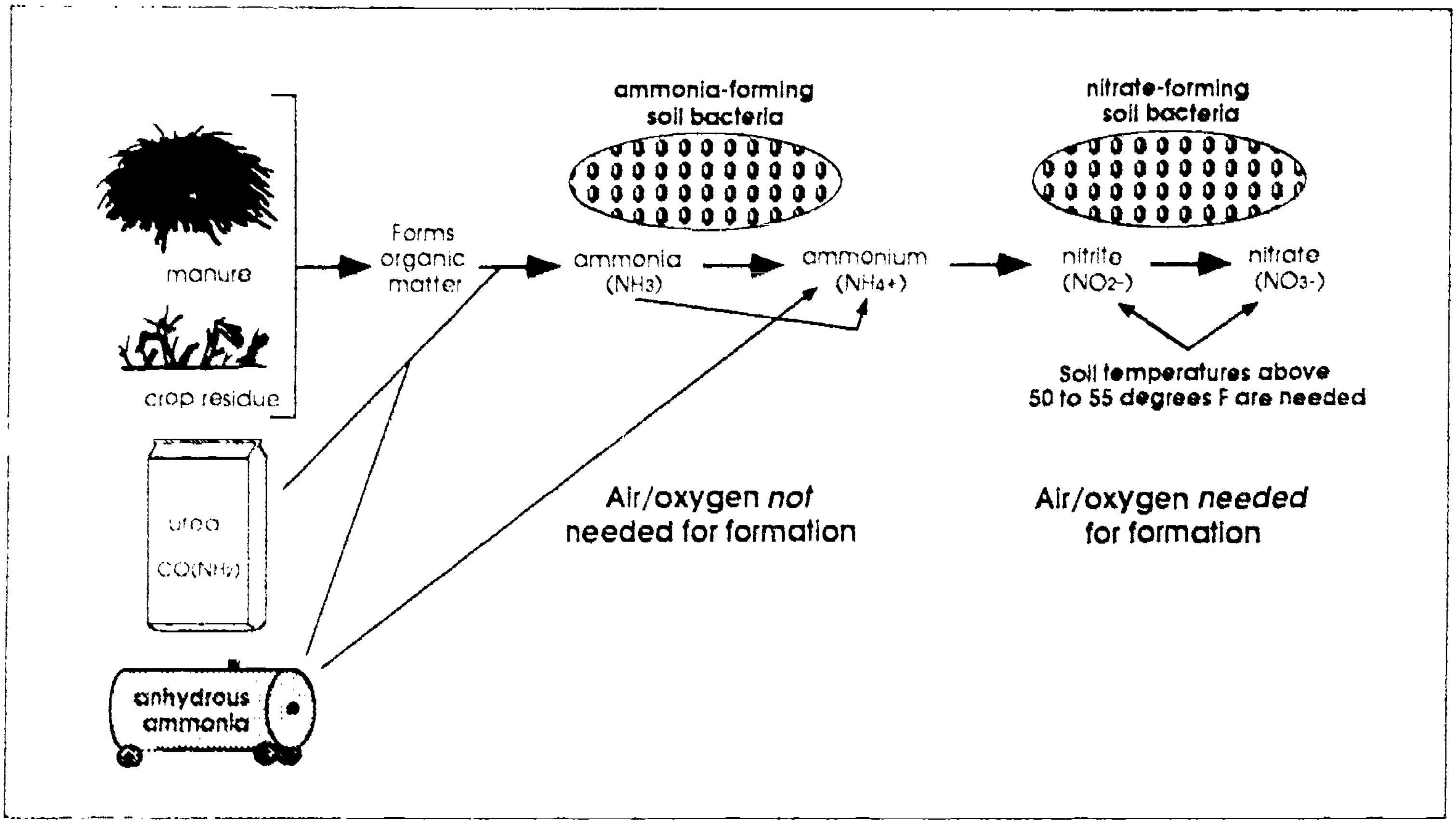


FIG. 67. The steps in the formation of ammonia and ammonium.

Humus

Most of the soil's stable organic matter is **humus**. This material remains after the major portion of animal manure and crop residues has decomposed. Humus decomposes slowly, thus holding nutrients in an unavailable form.

In contrast, fresh, green, crop residues, such as alfalfa or clover plants, decompose rapidly in the soil when plowed under. Therefore, nutrients from this source are readily available for plant use.

SOURCES OF ORGANIC MATTER

Sources of soil organic matter include the following:

1. Animal manure
2. Crop residues
3. Green manures

Animal Manure

Animal manure (excrement) is an important byproduct of livestock farms. When properly handled and applied to cropland, animal manure supplies organic matter and plant nutrients.

NUTRIENT CONTENT OF ANIMAL MANURE

Farm-produced animal manure varies in the amount of nitrogen, phosphorus, and potassium it contains due to the following factors:

1. Animal type and age
2. Animal feed ration
3. Bedding type and amount
4. Manure storage method

To illustrate the differences these variables can make, Table 19 on page 84 lists different animal manures, handling systems, and the approximate pounds of three nutrients they provide. Both liquid and solid manures are reviewed.

Figure 68 on page 84 shows the percentages of nutrients that livestock receive from feed, plus the amounts of plant nutrients and organic matter returned to the soil from manure.

TABLE 19. Pounds of fertilizer nutrients in animal waste with various handling systems and livestock*

Type of Livestock	Handling System	NUTRIENT P_2O_5	K_2O	Total N
Liquid Manure			***Lb/1,000 Gallons Raw Waste***	
SWINE	Liquid pit	27	19	36
	Oxidation ditch	27	19	24
	Lagoon	2	4	4
BEEF CATTLE	Liquid pit	27	34	40
	Oxidation ditch	18	29	28
	Lagoon	9	5	4
DAIRY CATTLE	Liquid pit	18	29	24
	Lagoon	4	5	4
POULTRY	Liquid pit	36	96	80
Solid Manure			***Lb/Ton Raw Waste***	
SWINE	Without bedding	9	8	10
	With bedding	7	7	8
BEEF CATTLE	Without bedding	14	23	21
	With bedding	18	26	21
DAIRY CATTLE	Without bedding	4	10	9
	With bedding	4	10	9
SHEEP	Without bedding	11	26	18
	With bedding	9	25	14
POULTRY	Without litter	48	34	333
	With litter	45	34	56
	Pit (compost)	64	45	68

*Adapted from *Utilization of Animal Wastes as Fertilizer.* Bulletin ID 101, Purdue University, West Lafayette, IN.

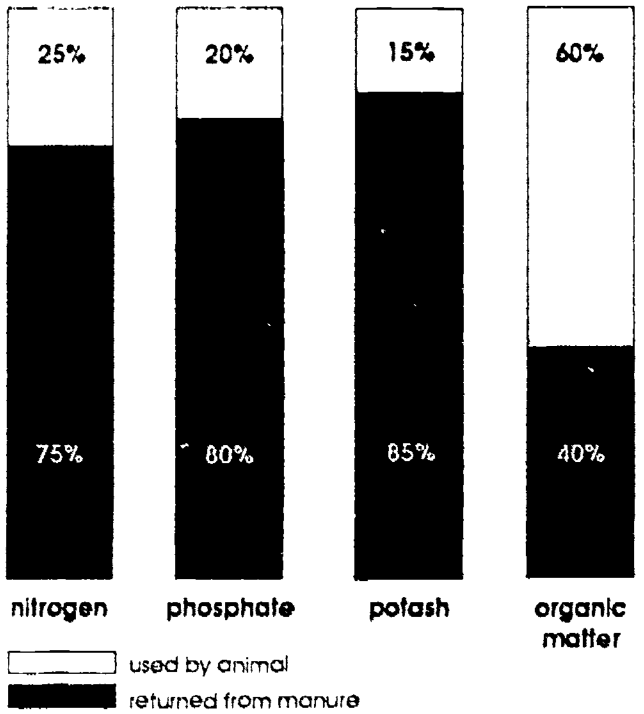


FIG. 68. Graphic representation of the amounts of nutrients used from feed by livestock and the amounts returned to the soil from manure.

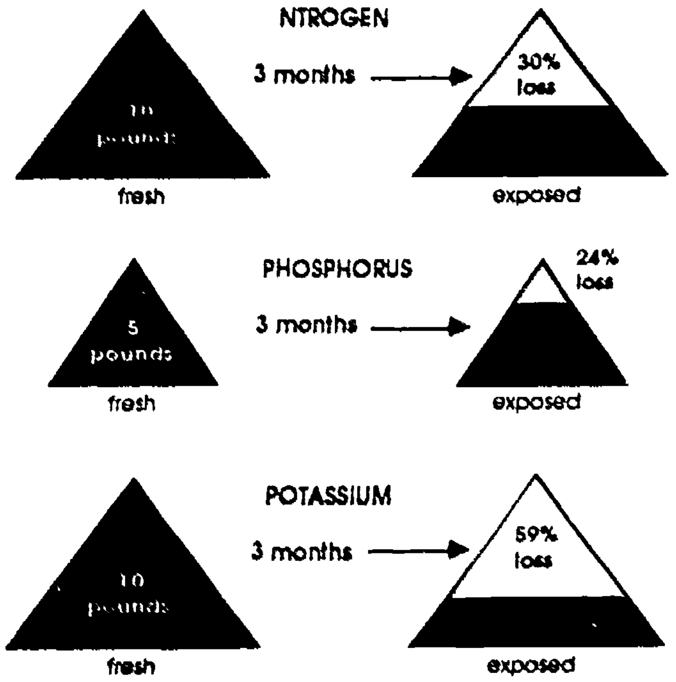


FIG. 69. Graphic representation of nutrient losses when manure is exposed to weathering action for three months.

NUTRIENT LOSSES FROM ANIMAL MANURE

Figure 69 represents improper manure handling and the resultant nutrient losses. This manure was left in an open barnyard from January through March. Consequently, it lost 30 percent of its nitrogen, 24 percent of its phosphorus, and 59 percent of its potassium.

Losses from the Liquid Part of Manure

As shown in Figure 70, the liquid portion of animal manure, which is mostly urine, contains 40 percent of the total nitrogen, 6 percent of the phosphorus, and 60 percent of the potassium. Therefore, if the liquid part of one ton of manure is lost, 40 percent of the plant nutrients available in that manure would be lost as well. The nutrients from the liquid part of manure are lost unless enough bedding is used to absorb the liquid. In addition to the liquid absorbed by the bedding, the bedding itself also contains plant nutrients (see Table 20).

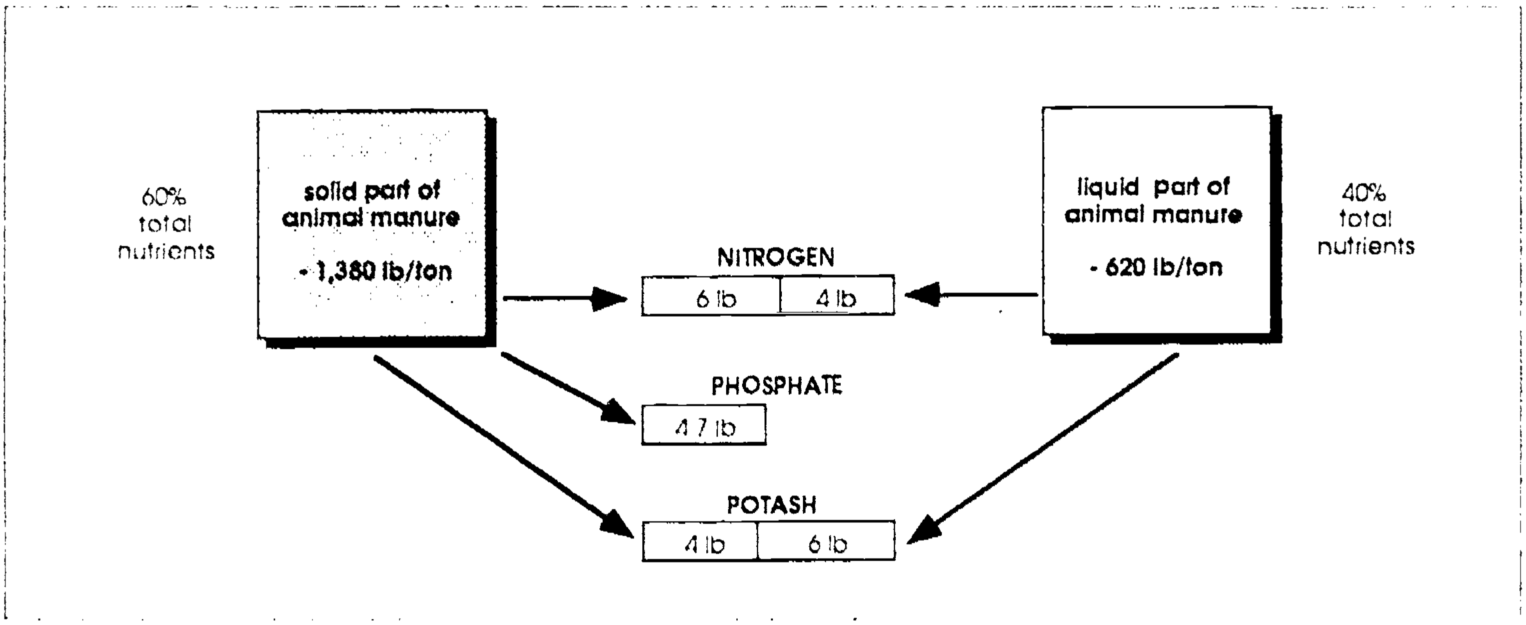


FIG. 70. Forty percent of the total plant nutrients are in the liquid part (mostly urine) of animal manure (fresh animal excrement before any bedding has been added). The liquid part contains 40 percent nitrogen, 6 percent phosphorus, and 60 percent potassium. *(Adapted from Ohio Cooperative Extension Service data.)*

TABLE 20. Absorption qualities and nutrient content of bedding materials.

Material	Pounds of Material Required to Absorb 100 Pounds of Liquid	COMPOSITION OF MATERIALS (Pounds per Ton - Air Dried) Nitrogen N	Phosphates P_2O_5	Potash K_2O
Wheat straw	45	11	4	20
Oat straw	35	12	4	26
Chopped straw	20 - 30	—	—	—
Cornstalks (shredded)	25 - 35	15	8	18
Sawdust	25	4	2	4
Wood shavings	25 - 45	4	2	4

Losses from the Solid Part of Manure

Losses from the solid part of manure can also be considerable. Following are ways in which nutrients can be lost:

1. Since potassium contained in the solid part of manure is water soluble, rainfall can leach additional potassium from the manure.
2. Nitrogen contained in the solid part of manure is in organic form. Therefore, as manure ferments and decomposes, ammonia is formed and escapes into the air (see Figure 67).
3. If manure is not applied to fields shortly after production, but allowed to decompose in exposed areas, available organic matter is lost (see Figure 71).
4. Some nutrients are lost if manure is applied to a field, not plowed under, and left exposed to the elements.
5. Applying manure on frozen fields also allows nutrients to be washed away when the ground thaws. This is particularly a problem on sloping fields.

PRACTICES TO PREVENT MANURE NUTRIENT LOSS

Use the following manure handling practices to prevent nutrient losses:

1. Use enough bedding to absorb the liquid (see Table 20).
2. As manure is produced, add superphosphate at the rate of 30 to 50 pounds per ton of manure for the following reasons:
   - Animal manure provides only about 5 to 45 pounds of phosphorus per ton; therefore, the addition of superphosphate makes manure a better balanced source of nutrients.
   - When added to manure, superphosphate combines with nitrogen-forming compounds to prevent ammonia formation. Thus, ammonia does not escape into the air.
3. Spread manure as quickly as possible after it is produced (see Table 21). If manure must be stored, place it in a covered shed and compact it to keep air out. It can also be stored in a liquid pit, oxidation pit, or lagoon.

When using any manure handling system, prevent fresh water contamination by keeping the residues from groundwater, runoff water, and streams.

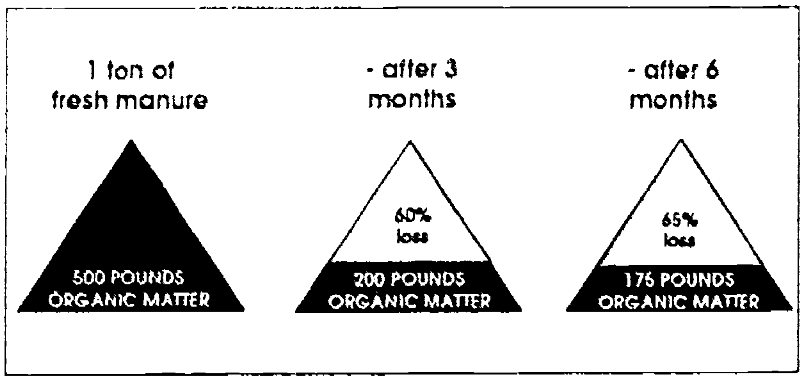


FIG. 71. Graphic representation of the effects of weathering on the organic matter content of one ton of manure. *(Adapted from Ohio Cooperative Extension Service data.)*

TABLE 21. Nutrient losses from manure

Management Practice	Percent Actually Returned to the Soil N	P	K
Spread daily (all liquid saved)	75	100	100
Open barn lot - 3 months	50	75	40
Open barn lot - 6 months	30	60	20

Crop Residues

Crop residues are those parts of the crop remaining in fields after harvest. Depending on the crop produced, these residues can include stalks, straw, leaves, or roots. In grain production (e.g., corn) all the plant parts (except the grain) can be plowed under or worked into the soil. In forage production, the roots may be the only part remaining in the field.

ORGANIC MATTER AND NUTRIENT SUPPLIES FROM CROP RESIDUES

Crop residues are the most important source for maintaining or increasing the soil's organic matter content. In addition, crop residues supply valuable nutrients. The types and amounts of these nutrients are determined by the crops grown. For example, a cropping sequence of alfalfa for three years, corn for one year, and small grains for one year could supply approximately 15,000 pounds (7.5 tons) of organic matter, 60 pounds of nitrogen, 40 pounds of phosphorus, and 100 pounds of potassium. Table 22 gives the total weights and nitrogen percents in the root systems of various crops.

Table 23 gives the approximate amounts of primary nutrients supplied by various crop residues. For instance, 60 pounds of nitrogen is supplied by alfalfa grass residue as compared to -30 pounds from corn or small grain residue (stalks or straw).

TABLE 22. Pounds of roots and nitrogen percents from legume and grass plant roots*

		Amount per Acre	
Crop	**Time of Sampling**	**Weight of Roots**	**Percent Nitrogen**
Red clover	Average of 48 dates and growth stages	1,000	2.2
Alfalfa	Late fall, seeding year	1,270	2.8
Alfalfa	Late fall, first-year hay	2,680	2.3
Alfalfa	Late fall, second-year hay	3,400	2.3
Sweet clover	November, seeding year	2,640	3.6
Sweet clover	July, year after seeding	800	1.7
Soybeans	Pods well filled and 3,800 pounds of tops	550	1.5
Timothy	December unfertilized	4,180 **	1.7
Timothy	December fertilized	6,080 **	2.1
Bluegrass	Old sod	6,770 **	2.1
Ryegrass	Sown in corn and sampled following spring	6,000 **	0.7

**Data adapted from Ohio Agricultural Research and Development Center.*
**Includes all underground parts as well as true roots.

TABLE 23. Estimated amounts of nutrients supplied per acre from plowing under different residues*

Kind of Residue	**Pounds N Supplied**	**Pounds P_2O_5 Supplied**	**Pounds K_2O Supplied**
Alfalfa grass	60	20	60
Clover grass	30	20	30
Mostly grass	10	10	10
Stalks or straw	-30	10	30

**Ohio Agricultural Research and Development Center data*

CARBON-NITROGEN RATIO OF CROP RESIDUES

Carbon-nitrogen ratios of crop residues are shown in Table 24. For example, corn stalks have a ratio of 40 parts carbon to 1 part nitrogen; corn stalks and roots have a high carbon content. In contrast, alfalfa has a low carbon-to-nitrogen ratio of 12 to 1.

A low carbon-to-nitrogen ratio is preferable because residues with high ratios can be converted to organic matter only if enough nitrogen is present to decompose them. If sufficient nitrogen is not present, most of these residues are "burned up" and lost to the atmosphere as carbon dioxide and water. In turn, without this organic matter, additional nitrogen cannot be released (refer to Figure 67). In other words, it takes nitrogen to make nitrogen.

If crop residues are plowed into the soil, soil organisms (bacteria) feed on this new food supply and rapidly multiply. They decompose the crop residues into organic matter, and nitrogen is eventually released for crop plant use. However, in order for the soil organisms to multiply, the crop residues must contain a carbon-to-nitrogen content of 10 parts carbon to 1 part nitrogen. If this 10 to 1 ratio is not present in the crop residues, soil organisms use nitrogen present in the soil.

Green Manure Crops

A **green manure crop** is another source of organic matter and plant nutrients. In one respect, green manure crops and crop residues are similar: both are plowed under or worked into the soil. However, they differ in the following ways:

1. A green manure crop is grown specifically for soil improvement purposes; crop residues remain after a grain or forage crop is harvested.
2. Green manure crops are plowed under while still green and succulent; crop residues are often in a dry (dead) condition when plowed under.

TABLE 24. The carbon-nitrogen ratios of crop residues and the pounds of humus formed from these residues

Kind of Residue	Carbon-Nitrogen Ratio	Pounds of Residual Humus Formed*	Organic Matter Lost
Corn stalks	40 to 1	1,180	5,820
Straw	41 to 1	1,750	5,250
Rye (green stage turned under before heading)	33 to 1	2,300	4,700
Red clover	26 to 1	3,170	3,830
Alfalfa	12 to 1	3,500	3,500

Any of the above crop residues plus enough nitrogen to provide a 10-to-1 carbon-to-nitrogen ratio, gave approximately 3,700 pounds of humus and 3,300 pounds of organic matter.

*From the decomposition of 7,000 pounds of crop residue

Data adapted from Ohio Agricultural Research and Development Center information.

SELECTION OF SUITABLE GREEN MANURE CROPS

There are many crops and even weeds which are suitable as green manure when worked into the soil. In general, a green manure crop is desirable for the following reasons:

1. Establishes easily and grows rapidly.
2. Produces a large amount of succulent above-ground (top) growth and roots in a short time.
3. Provides complete ground cover in a short period of time, thus preventing erosion on sloping soils.
4. Grows on poor soils - Green manure crops are needed most on poor soils, for example, coarse-textured (sandy) soils and fine-textured (clay) soils with poor soil structure benefit greatly from green manure crops.

If possible, when selecting a green manure crop, consider legumes for their nitrogen-providing capabilities. As shown in Tables 22 and 24, legumes provide more nitrogen than non-legumes. The carbon-to-nitrogen ratio for alfalfa is 12 to 1 compared to a 40-to-1 carbon-to-nitrogen ratio for corn stalks. In spite of these facts, following are some disadvantages when using legumes as a green manure crop:

1. Legumes are often difficult to establish in fields with low soil fertility and low pH.
2. Legumes may be more valuable as livestock feed than as green manure.
3. Many legume seeds are expensive.
4. Some legumes do not fit into the cropping sequence at a time when they can be plowed under as green manure.

Table 25 lists crops often used for green manure and their growth characteristics.

TABLE 25. List of possible green manure crops and their growth characteristics

Crop	Time of Year to Establish	Will Grow Well on Low-fertility Soils	pH Requirement	Ease of Establishment	Amount of Material (tops-roots)	Rapid Ground Cover Growth
LEGUMES						
Alfalfa	Spring or summer	No	7	Fairly difficult	High	No
Sweet clover	Spring	Yes	7	Fairly easy	High	No
Red clover	Spring	Fairly well	6 to 6.5	Fairly easy	Fairly high	No
Soybean	Spring	Fairly well	6 to 6.5	Fairly easy	Fairly high	Fairly rapid
NON-LEGUMES						
Rye	Fall	Yes	5.5 to 6	Easy	High	Yes
Ryegrass	Spring or fall	Yes	5.5 to 6	Easy	Fairly high	Yes
Wheat	Fall	Yes	5.5 to 6	Easy	Fairly high	Yes
Corn	Spring	Fairly well	5.5 to 6	Easy	High	Yes

PROBLEMS WHEN USING GREEN MANURE CROPS

Even though green manure crops can add to the organic matter and nutrient content of a soil, they also can cause the following problems:

1. Non-legume crops may have a high carbon-to-nitrogen ratio which can reduce the available nitrogen in the soil. (See *Crop Residues* in this chapter.) Plowing under a heavy crop, such as rye or ryegrass, can result in nitrogen deficiency of the following crop. This usually happens when the green manure crop is plowed under late in the spring after considerable growth has occurred. This condition can be corrected by adding nitrogen fertilizer when the green manure crop is plowed under.

2. A green manure crop may deplete the soil moisture for the succeeding crop. This usually occurs under the following conditions:

   - The green manure crop has had heavy growth.
   - The green manure crop is plowed under in late or early spring.
   - Below normal rainfall occurs during the growing season.

In general, use green manure crops to improve soils with poor texture and low fertility, to maintain or increase the soil's organic matter content, and to provide soil cover to prevent erosion.

Nitrogen Fixation by Legumes

Legumes are important to agricultural production for the following reasons:

1. Legumes are a valuable source of livestock food – for example, hay, pasture, and silage.
2. Seeds produced by some legumes are a valuable source of food for humans and livestock.
3. When plowed under, legumes increase the soil's organic matter content by improving soil structure and tilth.
4. Extensive root systems and year-round growth of several legumes help prevent or reduce soil loss by erosion.
5. Legumes fix atmospheric nitrogen in the soil.

Table 26 lists legumes commonly grown in the midwestern states and their uses and values as nitrogen sources.

TABLE 26. Legume crops – their uses and values as nitrogen sources

Legume	Primary Use	Value as Source of N
Alfalfa	Hay - pasture	High
Red clover	Hay	Medium
Birdsfoot trefoil	Hay - pasture	Medium
Sweet clover	Green manure	High
Alsike clover	Hay	Low
White (ladino) clover	Pasture	Medium
Lespedeza	Pasture - hay	Low
Soybeans	Seed	Low
Garden beans, peas	Seed	Low

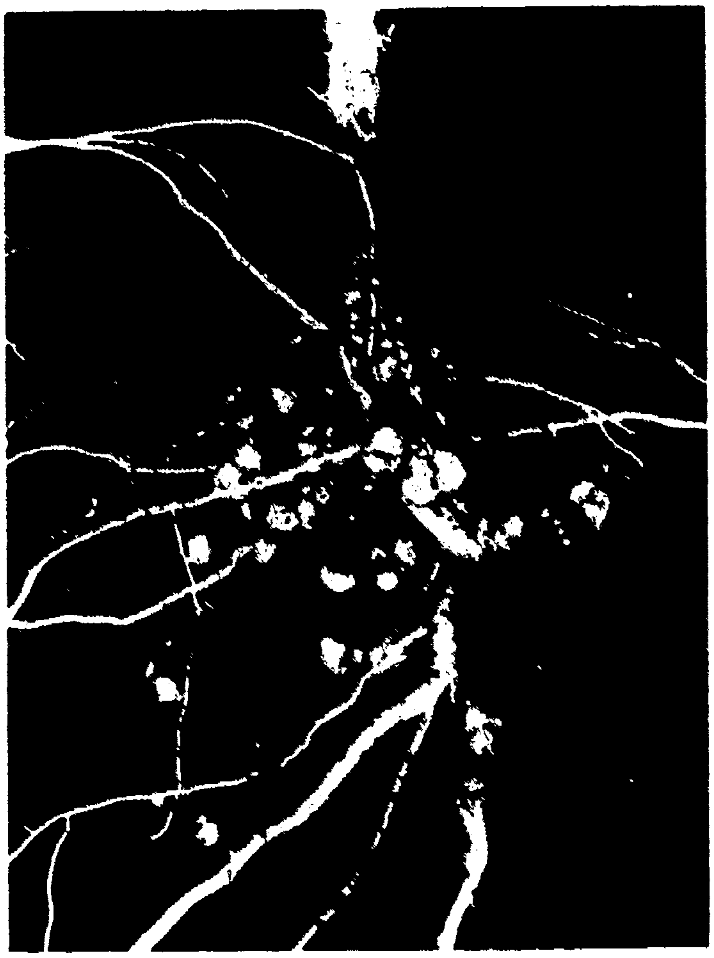


FIG. 72. The roots of this soybean plant show nodule formation.

Nodule Formation

Figure 72 shows **nodules** present on the roots of a legume plant. These nodules contain nitrogen-fixing bacteria called **rhizobia**. The legume plant and the rhizobia can live independently of each other. They both use the nitrogen available in the soil in the form of ammonium or nitrates. However, since neither the legume nor the rhizobia alone can convert nitrogen in the air to ammonia, a partnership must be formed. This partnership, which benefits both the legume plant and the rhizobia, is called **symbiosis**. When rhizobia are present, the legume plant can take nitrogen from the air and convert it to ammonia (NH_4). The ammonia then converts to ammonium (NH_4^+) and nitrates (NO_3^-). (Refer to Figure 67 on nitrification.) Why rhizobia are associated with only legumes is not known. Likewise, for unknown reasons certain disease-causing bacteria attack only specific plants.

The following steps occur during nodule formation:

1. The **root hairs** (filament-like extensions that absorb water and minerals) of legume plants secrete a nutritive substance that increases the number of nitrogen-fixing bacteria in the surrounding soil (see Figure 73-A).
2. In turn, these nitrogen-fixing bacteria produce a substance that will allow them to easily enter the root hairs.
3. Next, plant-produced growth regulators prepare the root hairs for the entrance of the nitrogen-fixing bacteria. As the root hairs curl, the bacteria enter the root hairs (see Figure 73-B). Nitrogen-fixing bacteria will enter *only* curled root hairs; however, they will not enter *all* the curled root hairs.
4. After the bacteria have entered the root hairs, an infection thread forms and grows through the root hair to the **cortex** (outer layer) of the root (see Figure 74-A).
5. The infection thread stimulates the tissue cells of the root cortex and causes them to rapidly divide.
6. After this rapid cell division, the bacteria are released from the infection thread. They increase in number and form **bacteriods** (several bacteria) that are held in groups by a membrane covering (see Figure 74-B). These bacteriods form a **nodule.**
7. If the bacteria is a type that can be used by the specific legume plant, nitrogen fixation occurs and a red pigment is visible inside the nodules. This red pigment is in the membrane surrounding the bacteriods. If nitrogen fixation occurs, the bacteria and legume plant are said to **be compatible** – that is, a partnership exists between the bacteria and the legume plant.

Factors Affecting Nitrogen Fixation

The following factors determine the amount of nitrogen fixation:

1. **Soil pH** – This affects the growth of nitrogen-fixing bacteria (rhizobia) in the soil. If the soil is very acid (pH of 4.5 to 5.5), heavier concentrations of hydrogen, aluminum, and manganese ions are present. These have a toxic effect on nitrogen-fixing bacteria and legume plants. In addition, the micronutrient molybdenum is required for nitrogen fixation. If the pH is low, molybdenum is unavailable.
2. **Legume species** – The plant species can also affect the amount of nitrogen fixation. A ten-year study in New York found the extent to which different legume species are able to fix nitrogen. Since alfalfa is able to fix more nitrogen than any of the other common species of crop legumes, it was given an index of 100. From these results, we can see that soybeans fix 58 percent less nitrogen than alfalfa (see chart below).

Crop	Percentage	Crop	Percentage
Alfalfa	100	Soybeans	42
Red clover	60	Hairy vetch	27
Alsike clover	50	Field beans	23

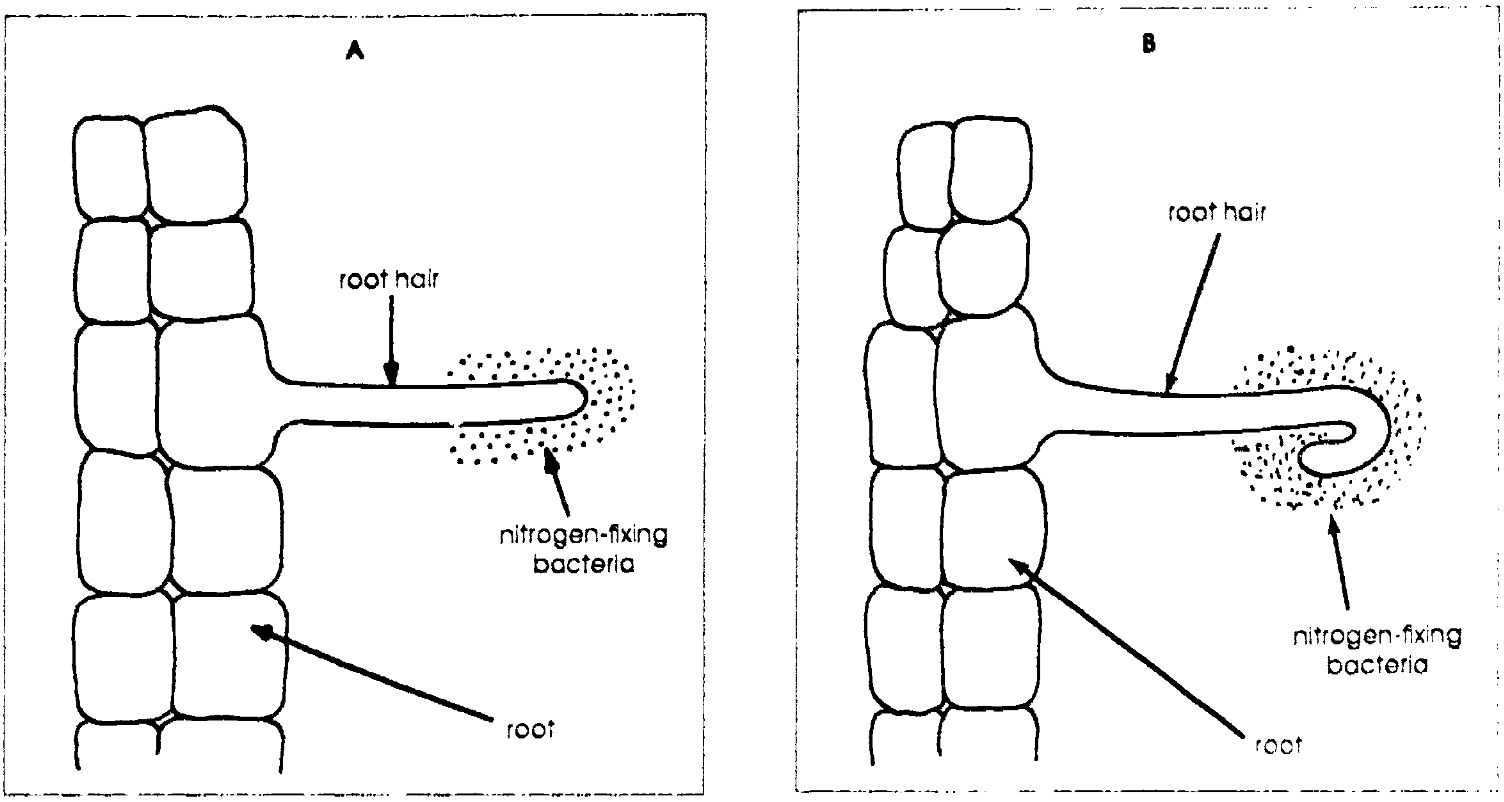


FIG. 73

A: The number of nitrogen-fixing bacteria increases around the root hairs of legume plants.
B: The nitrogen-fixing bacteria enter the root hairs as they begin to curl.

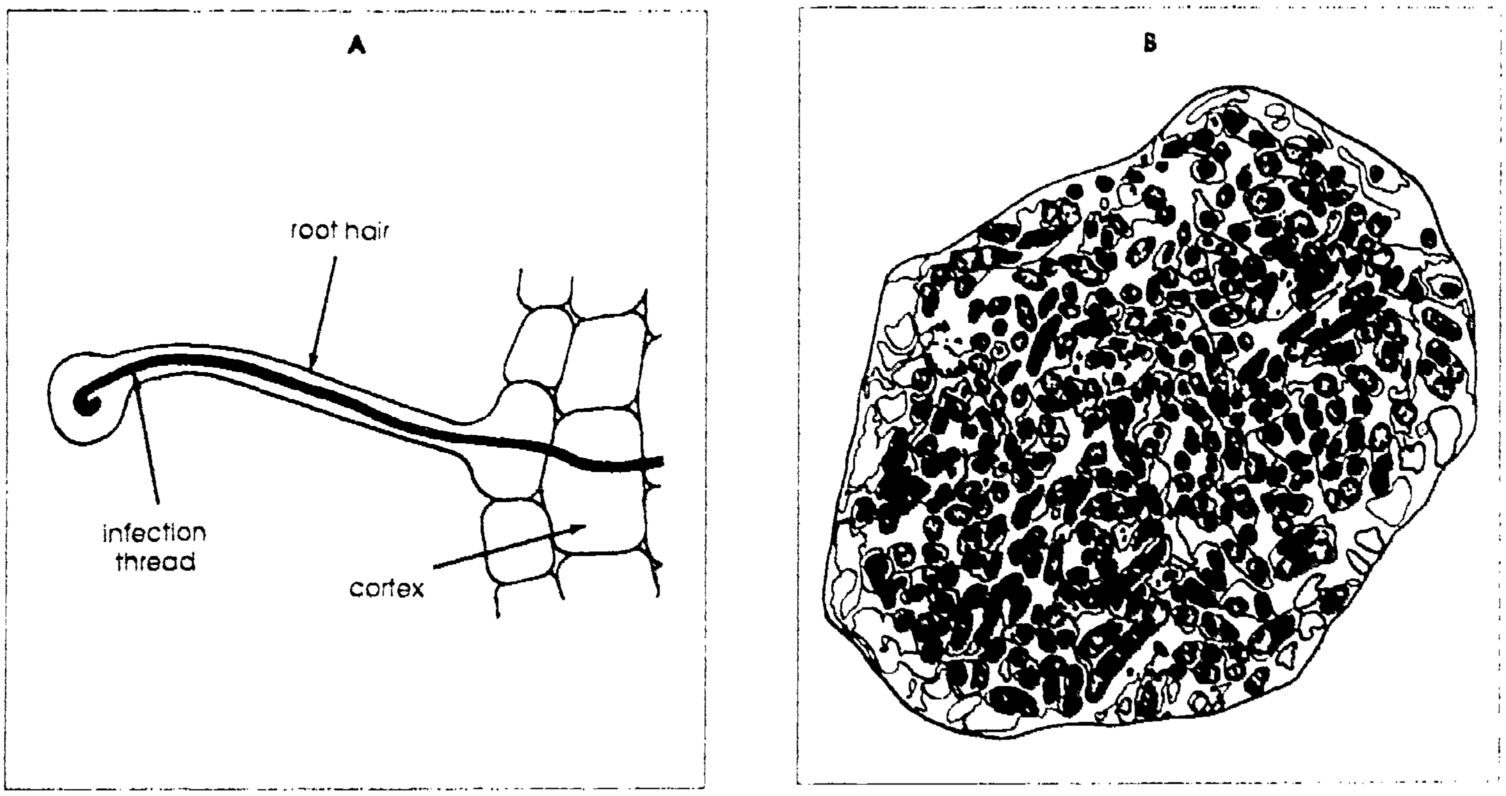


FIG. 74

A: After nitrogen-fixing bacteria enter the root hairs, an infection thread forms and grows through the root hair to the cortex. This infection thread stimulates the tissue cells of the cortex and causes them to rapidly divide.

B: Next, the bacteria are released from the infection thread; they multiply and form bacteriods.

3. **Bacteria preference** – Due to frequent contacts over long periods of time, certain legume species have developed preferences for certain strains of bacteria. As a result, the common crop legumes fall into eight cross-inoculation groups (see Table 27). To effectively provide the correct nitrogen-fixing bacteria (rhizobia) species, the crop producer must be familiar with this information. However, if legume crops have been grown successfully for several years in one location, introducing the specific inoculant is generally not necessary.

4. **Environmental factors** – Temperature, moisture, and sunlight also influence the amount of nitrogen fixation. These factors influence plant growth and bacterial growth, which then determine the amount of nitrogen fixation.

5. **Soil conditions** – Soil drainage, amount of compaction, texture, and structure also influence plant and bacterial growth which, in turn, affect nitrogen fixation.

6. **Nutrient supply** greatly influences the rate of nitrogen fixation. If adequate nitrogen is available in the soil, legume plants slow down nodule formation and nitrogen fixation. Therefore, if more nitrogen (fertilizer) is applied to legumes, less nitrogen is fixed by them. This is an important consideration in soybean production.

To produce 70-bushels-per-acre yields, soybeans require as much as 300 pounds of nitrogen. Research shows that neither nitrogen fertilization nor nitrogen-fixing bacteria alone can supply these needs. Nitrogen-fixing bacteria usually supply only 50 to 80 percent of the total nitrogen requirements of the plant. It has been established that each bushel of soybeans requires 1.7 pounds of nitrogen from the soil and 1.7 pounds of nitrogen fixed by the plant. However, on soils lower in organic matter, soybeans may be able to fix as much as 2.7 pounds of nitrogen per bushel of seed (80 percent of the nitrogen requirement). Other legumes react similarly. Therefore, to receive optimum yields, the legume producer must consider the soil conditions, environmental conditions, the species grown, and the availability of nutrients and nitrogen-fixing bacteria.

TABLE 27. Legume species and their inoculation groups

Legume Species	Inoculant Group
Alfalfa - sweet clover	I
Red, white (ladino), alsike and crimson clovers	II
Annual lespedeza, cowpeas, kudzu and lima beans	III
Garden peas, vetch and sweet peas	IV
Soybeans	V
Garden and pinto beans	VI
Lupines	VII
Birdsfoot trefoil	VIII

Commercial Fertilizers

Animal manures and crop residues can add plant nutrients; however, they usually do not supply enough to produce high crop yields. Commercial fertilizers are needed to produce high yields. In general, these fertilizers supply nitrogen, phosphates, and potash. Special fertilizers supply micronutrients, such as zinc or boron, but in most crop-growing situations additional micronutrients are not needed. Calcium and magnesium are usually supplied by lime.

NITROGEN FERTILIZER SOURCES

Nitrogen is an inert gas that comprises four fifths of the earth's atmosphere. With the exception of legumes, this vast source of nitrogen cannot be used by plants unless it combines with hydrogen or oxygen. This combination forms compounds that are available to plants.

Commercial fertilizers provide the following forms of nitrogen:

1. Nitrates
2. Ammonium
3. Synthetic organics
4. Natural organics

Nitrates

All nitrogen fertilizers have one thing in common: if they are not in nitrate form, they are converted to nitrates in the soil (see Figure 75). Ammonia and nitric acid are used in the manufacture of nitrate nitrogen.

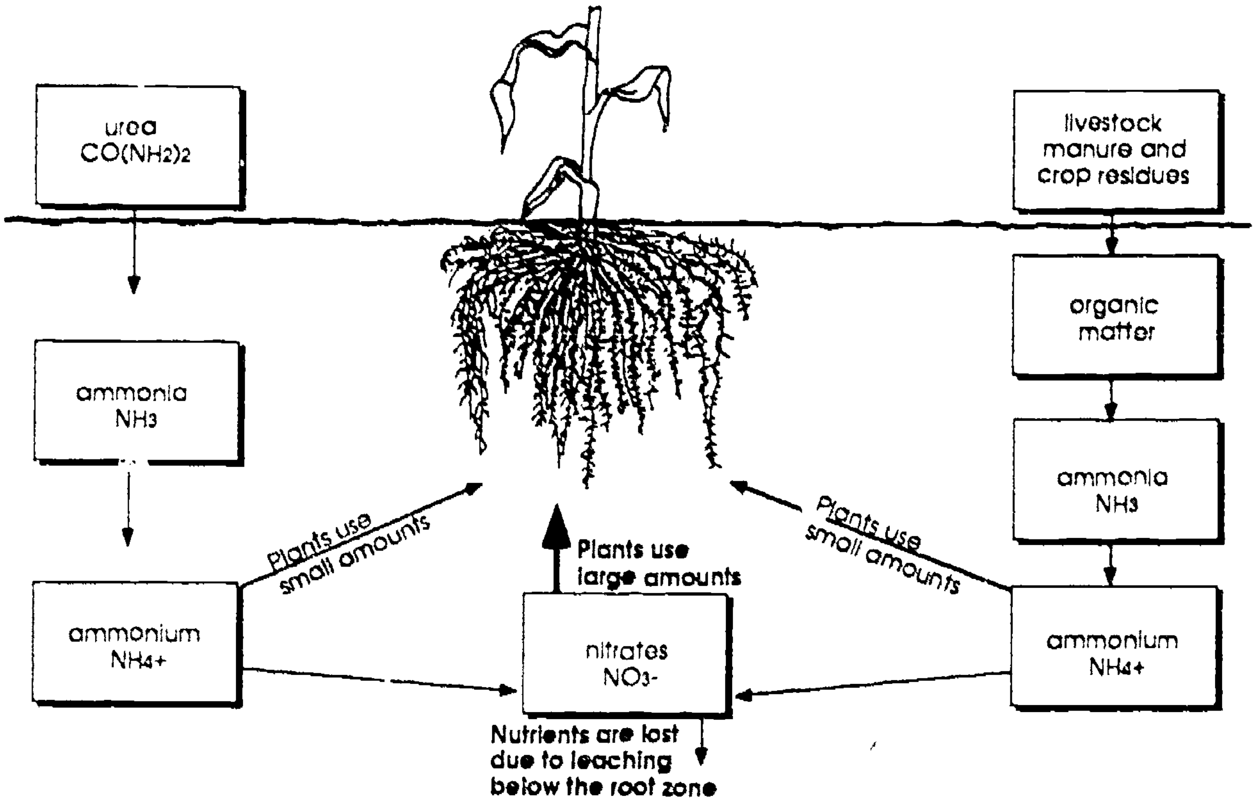


FIG. 75. All nitrogen sources have one thing in common: they are converted to nitrates in the soil. Plants use most of their nitrogen in this form.

NITRATE SOURCES

The following are commercial fertilizer sources of nitrate nitrogen:

- **Ammonium nitrate** contains 3.5 percent total nitrogen. Approximately 50 percent of this total nitrogen is in nitrate form.
- **Calcium nitrate** contains 15 percent nitrogen and 19 percent calcium. It also contains a very small amount of magnesium.
- **Potassium nitrate** contains 13 percent nitrogen and 44 percent potassium.
- **Nitrate of soda** is a natural source of nitrate nitrogen. It is mined in this usable form and does not require manufacture. Nitrate of soda contains 16 percent nitrogen.

NITRATE MOVEMENT IN THE SOIL

The nitrate ion (NO_3^-) carries a negative charge. This means it will not attach to the negatively charged ions of clay and organic matter particles. Thus, these negatively charged nitrate ions remain free and unattached in the soil. Since nitrates are easily dissolved in water, they become part of the soil solution (soil water) and move with it (see Figure 76). On the other hand, ammonium ions (NH_4^+) attach to the soil particles. The following are examples of conditions promoting nitrate movement in the soil:

1. If the growing season is dry, the soil water carries the nitrate nitrogen to the soil surface and deposits it.
2. With sufficient rainfall, nitrates move back into the soil with the soil solution and become available for plant use.
3. If rainfall is too heavy, one of the following situations may result, depending on the soil condition:
    - The nitrates in the drainage water move down and away from the crop root zone and are not available for plant use.
    - In poorly drained soils, denitrification may occur and the nitrates are not available for plant use.

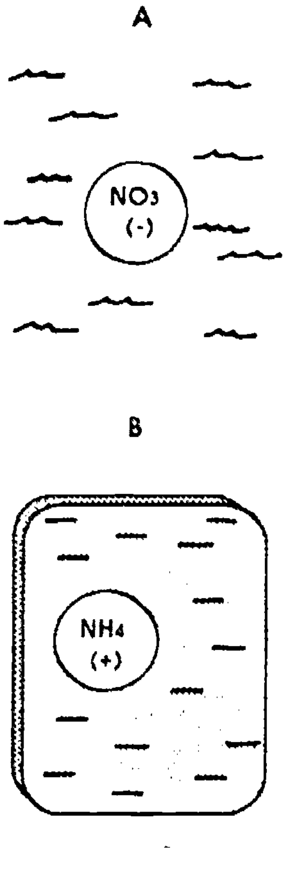


FIG 76 A Negatively charged ions do not attach to the soil particles and flow freely with the soil water B: Positively charged ammonium ions attach to the soil particles

DENITRIFICATION

Denitrification is an example of **volatilization** – the conversion of a solid to a gas. In this case, nitrate – a solid – is converted to atmospheric nitrogen – a gas. Denitrification favors warm, wet soils with large amounts of crop residues incorporated into the soil (plowed under). This process results from the following:

1. Certain soil organisms (bacteria) require oxygen in order to survive.
2. Under normal soil conditions, the soil pores contain air. Soil organisms obtain their oxygen from this air.
3. Under wet soil conditions the soil pores fill with water and displace the air (see Figure 77). The high water content of this soil prevents additional air from entering the soil. For this reason, the soil organisms must obtain their oxygen from nitrates (NO_3^-). During this process nitrates are converted to their natural gaseous state of nitrogen and oxygen (See Figure 78).

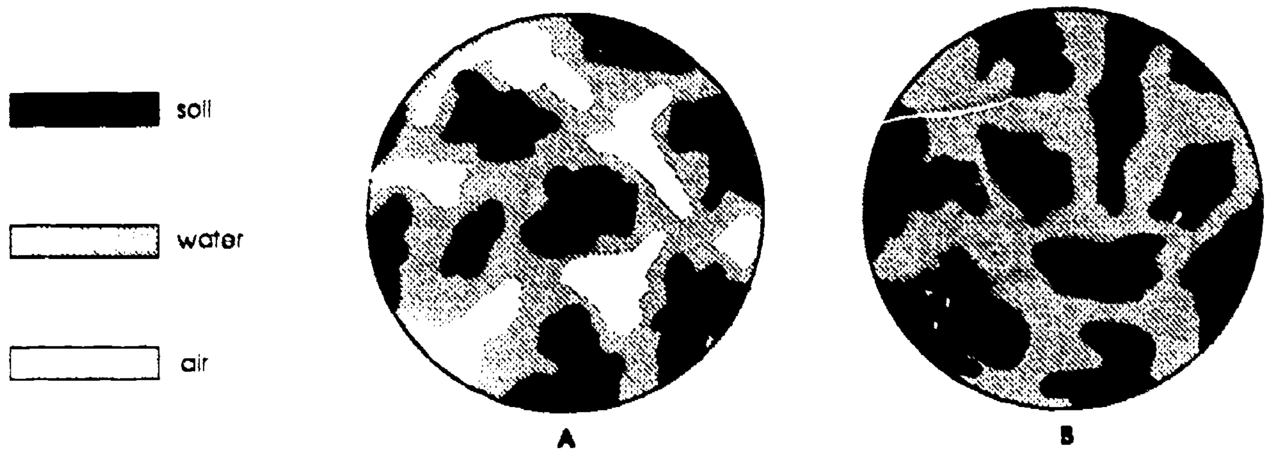


FIG. 77. **A**: These soil pores contain both air and water. **B**: These soil pores are completely filled with water that has displaced the air. Under these conditions, oxygen is lacking in the soil and nitrate nitrogen can be converted to gases.

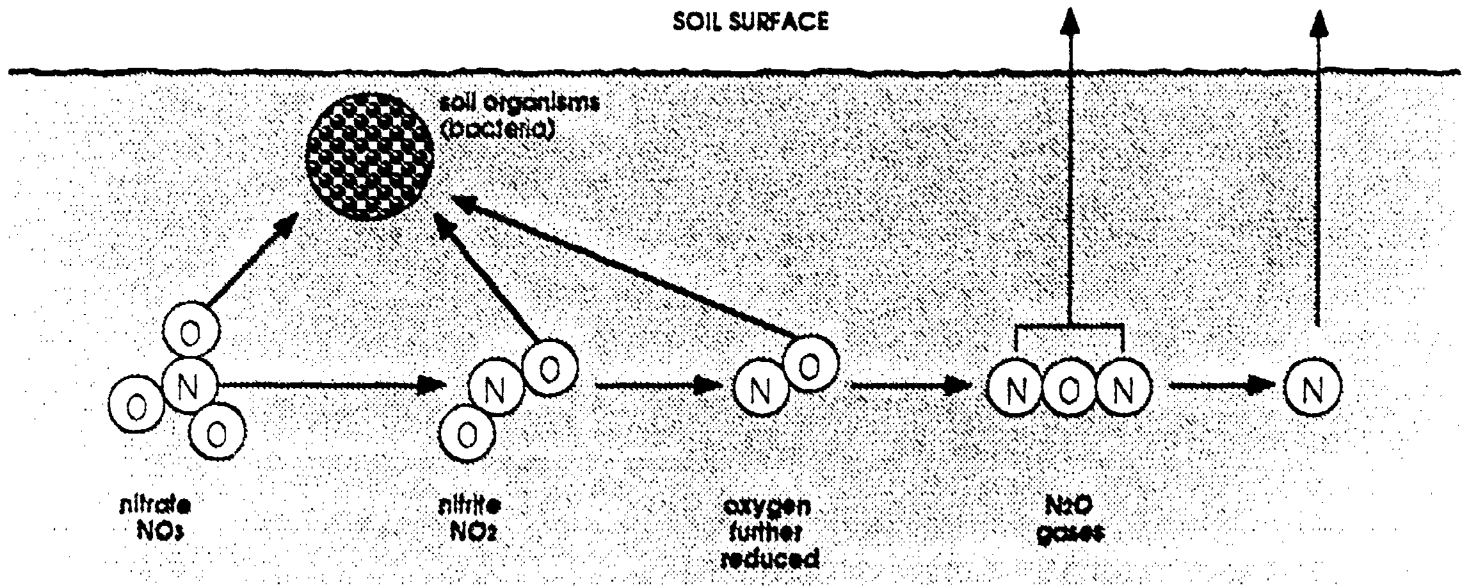


FIG. 78 Dentrification occurs in warm, moist soils having large amounts of crop residues plowed under. Soil organisms react with the nitrates (NO_3) in the soil and cause a lack of oxygen. These nitrates are then converted to a gas (NO_2) and leave the soil.

Even though nitrogen is supplied through urea and ammonium, it can be readily lost in warm, wet soils. Under these conditions, urea and ammonium convert very rapidly to nitrate.

AMMONIUM

The **ammonium** ion (NH_4^+) is positively charged: it will attach to the soil's clay particles. Since ammonium ions are "held" by clay particles, they move less in the soil than nitrates do. However, as mentioned above, ammonium is rapidly converted to nitrate when temperatures are warm (see Figure 79). This conversion from ammonium to nitrate form starts at 50° to 55° F (10.08° to 12.88° C) and rapidly accelerates when temperatures reach 70° F (21.28° C) or higher.

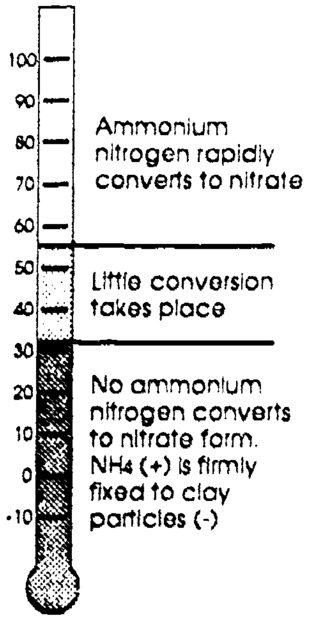


FIG. 79. As the temperature rises, ammonium ions convert to nitrate form.

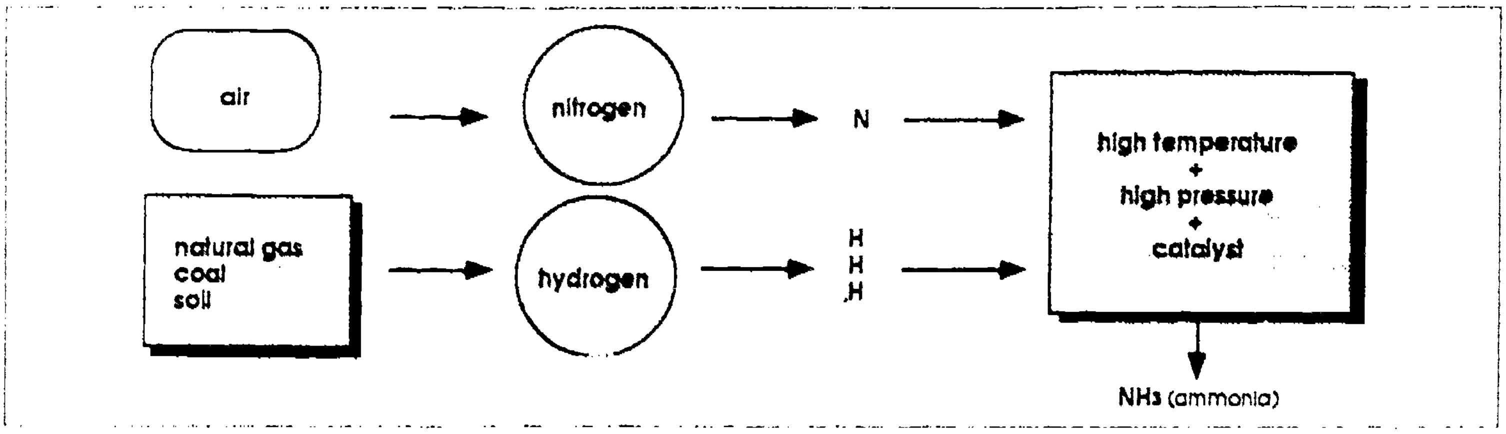


FIG. 80. The steps involved in ammonia (NH_3) production

Ammonium forms of nitrogen can be applied during late autumn or early spring when soil temperatures are below 50° to 55° F (10.08° to 12.88° C). At this time the soil bacteria needed for converting ammonium to nitrate are not very active and conversion does not occur.

Carriers of ammonium are ammonium sulfate, ammonium nitrate, and ammonium solutions (liquid forms).

Synthetic Organics

ANHYDROUS

Anhydrous ammonia (NH_3) -- ammonia without water – is the first compound produced in synthetic nitrogen fertilizer manufacturing. It is a lighter-than-air, colorless gas containing 82 percent nitrogen. Anhydrous ammonia is made by combining nitrogen from the air with hydrogen from natural gas, coal, or the soil (see Figure 80). This nitrogen-hydrogen bonding takes place when the two elements are exposed to high temperatures, high pressures, and a **catalyst** (substance that promotes the reaction). Anhydrous ammonia is injected directly into the soil using special equipment described later in Chapter 5.

Ammonia is used to produce other synthetic nitrogen materials such as urea.

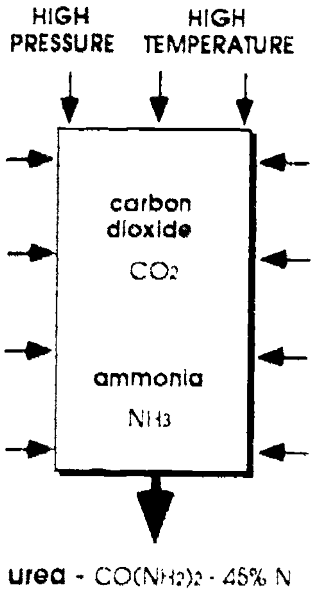


FIG. 81 Urea production

UREA

The synthetic nitrogen source, **urea**, is produced by combining carbon dioxide (CO_2) with ammonia under high pressures and high temperatures (see Figure 81). A large percentage of the commercial nitrogen fertilizer currently used is in the urea form.

Characteristics of Urea

The following are characteristics of urea:

1. It is a water-soluble material containing 45 percent nitrogen.
2. It converts to the ammonium form when applied to the soil. Therefore, its action in the soil is similar to ammonium.
3. Since urea must first convert to ammonium, it becomes available to plants more slowly than ammonium forms of fertilizer.

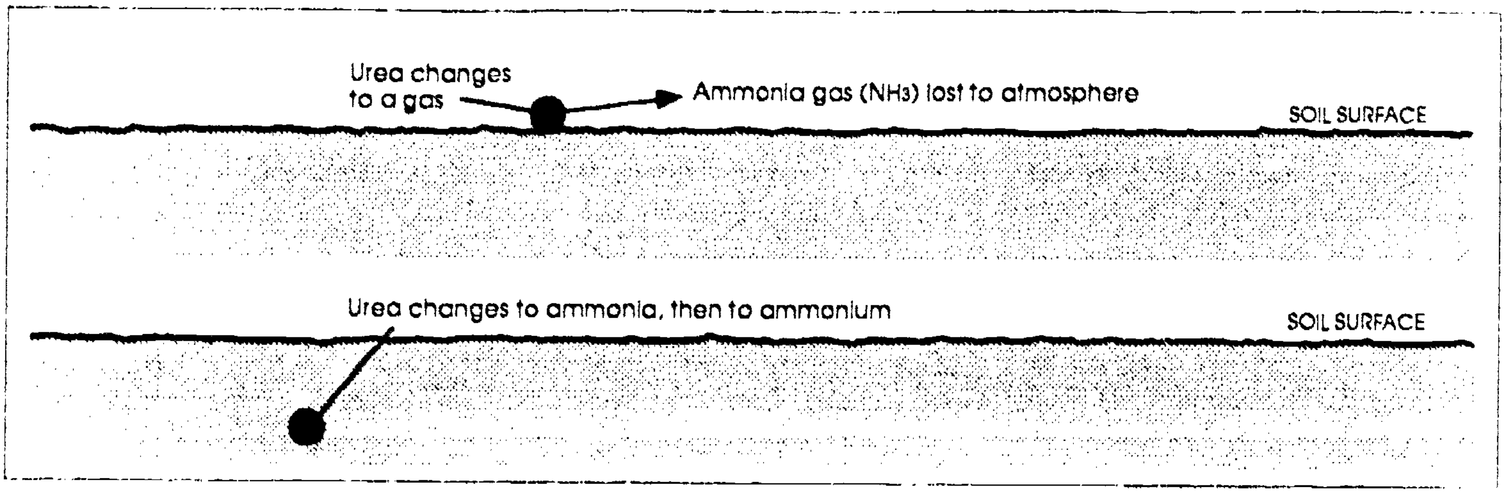


FIG. 82. During warm, moist conditions surface-applied urea may convert to ammonia gas and escape into the atmosphere. If urea is applied in the soil, it converts first to ammonia gas and then to ammonium before the gas can escape.

Urea Loss from the Soil

When urea is applied to the soil surface, it may be lost through *volatilization* – the process of changing a usable form of nitrogen to a gaseous form. The volatilization of urea occurs in the following steps:

1. Urea nitrogen is rapidly converted to ammonium carbonate under warm, moist conditions and in the presence of the **enzyme** urease. (An enzyme is a substance that causes a reaction to take place; it serves as a *catalyst.*)

2. In turn, ammonium carbonate – an unstable compound – rapidly breaks down into ammonia, carbon dioxide, and water (see Figure 82). If this occurs on the soil surface, ammonia gas escapes into the air. However, if this occurs in the soil, the ammonia quickly changes to ammonium and then to nitrate.

The amount of urea nitrogen lost from surface-applied urea sources may vary considerably, depending on the weather. If it rains soon after the urea is applied, most of the water-soluble urea moves into the soil.

CALCIUM CYANAMIDE

Another synthetic nitrogen material is **calcium cyanamide**. It is made by combining nitrogen gas with calcium carbide. As a nitrogen source, it is not as important for crop production as urea or anhydrous ammonia.

Natural Organics

Natural organics include both animal and plant byproducts, such as tankage, blood meal, linseed meal, and cottonseed meal. All of these natural organic products are high in protein content, but are usually too expensive to be used as commercial fertilizers. In addition, when natural organics are applied to the soil, they must be decomposed by microorganisms before the nitrogen is available. This decomposition changes the protein nitrogen into ammonia nitrogen.

PHOSPHORUS FERTILIZER SOURCES

Three phosphorus sources are **organic matter** (crop residues and manure), **soil minerals**, and **commercial fertilizers**. Most of the phosphorus used by plants is in the phosphate forms of HPO_4^- and $H_2PO_4^-$. Regardless of the source, plants absorb phosphorus in these same two forms. Whether the phosphate form is $H_2PO_4^-$ or HPO_4^- is determined largely by the soil pH. When the pH is alkaline (above 7), the phosphate form is mainly HPO_4^-. When the pH is moderately acid (slightly below 7), both HPO_4^- and $H_2PO_4^-$ are present. When the soil becomes strongly acid the phosphate form present is mostly $H_2PO_4^-$.

Water Solubility of Phosphorus Fertilizers

As with nitrates, phosphates are absorbed by plants mainly through the soil solution (see Figure 83). However, unlike nitrates, phosphates do not leach from the soil; they are not lost when phosphate compounds are broken down by soil organisms. Phosphorus forms are lost from the soil only through erosion. Therefore, if erosion is controlled, phosphorus reserves can be built up in the soil by applying large quantities of phosphorus fertilizers at one time.

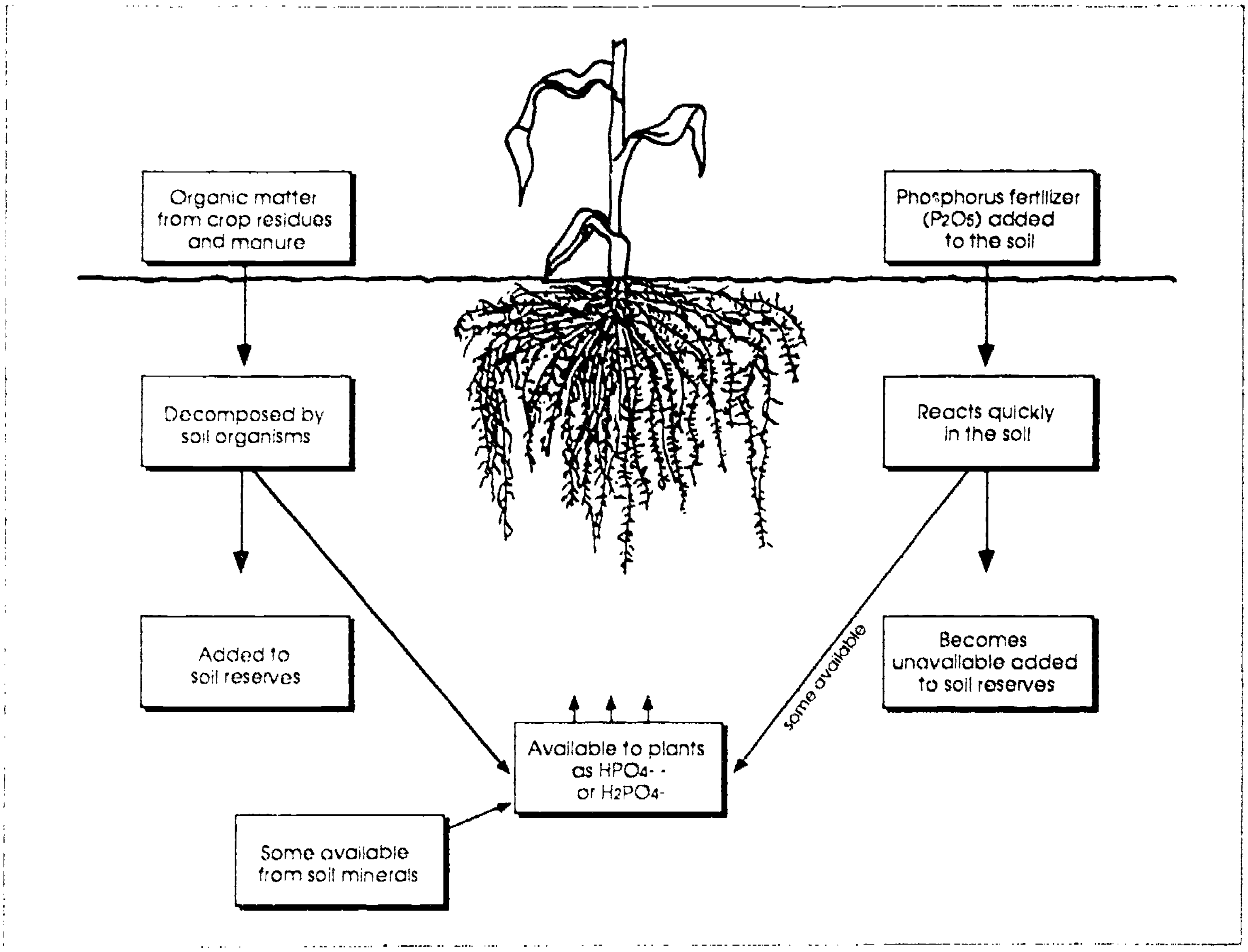


FIG. 83. Phosphorus is available to the plants through organic matter and commercial fertilizer. Plants absorb the phosphorus mainly through the soil solution.

In most soils, only a small amount of phosphate is available to plants at any one time – even if a highly water-soluble source (e.g., **superphosphate**) is applied. The reasons for this follow:

1. Water-soluble phosphorus forms can rapidly convert to insoluble forms in the soil. For example:
   - On acid soils, water-soluble phosphorus is converted to iron and aluminum phosphates, limiting phosphorus availability.
   - On neutral or alkaline soils, water-soluble phosphorus is converted to calcium phosphate, which is moderately soluble.
   - Phosphorus compounds are most soluble at a pH of 6.5. A variation in pH can cause the phosphorus to become insoluble.
   - When phosphorus fertilizers are applied to a soil, they diffuse (spread out) very little. Dissolved phosphorus usually diffuses no more than 1 1/2 inches from the fertilizer granules (see Figure 84).
2. When plant roots grow into zones of phosphorus fertilizer, they absorb the phosphates, lowering the phosphorus content of the soil solution. However, when this happens more solid phosphorus from the fertilizer granules enters the soil solution, restoring the soil's phosphorus content. This depletion/renewal process can take place as often as ten times a day. As plants grow, their root systems extend into new areas of phosphorus soil solutions and the process continues. Since phosphorus does not diffuse far from granule application sites, plant roots are able to find zones of available phosphorus.

Phosphate Rock

Phosphate rock is the ore used in the manufacture of phosphorus fertilizers. Phosphate rock is mined in Florida, Tennessee, South Carolina, Idaho, and Wyoming. The phosphorus in phosphate rock is combined with calcium and fluorine. In this form it has a very low degree of availability to plants. Therefore, during phosphorus fertilizer manufacture, phosphate rock is treated with sulfuric, phosphoric, or nitric acid. These treatments form more soluble, available phosphates.

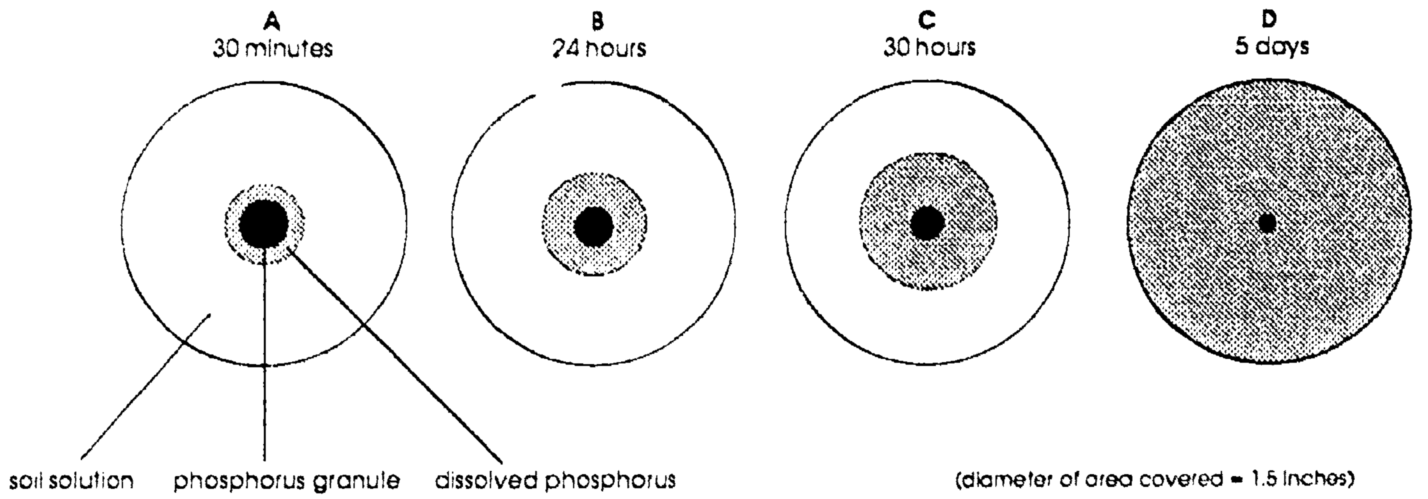


FIG. 84. The diffusion of dissolved phosphorus at various time intervals after application.

Rock Phosphate

Rock phosphate is unrefined phosphate rock ore sold as phosphorus fertilizer. It contains 34 percent phosphate (P_2O_5), but only 3 to 8 percent is in a form available to plants. Consequently, if rock phosphate is used as a phosphorus fertilizer source, it should be applied at 1,000 to 2,000 pounds per acre. These large amounts are necessary due to the low percentage of available phosphorus in rock phosphate.

Superphosphates

Superphosphates are the most common sources of phosphorus fertilizers. Two kinds of superphosphates are produced: ordinary superphosphate and concentrated superphosphate. Both kinds are 85 percent water soluble.

ORDINARY SUPERPHOSPHATE (20 percent P_2O_5)

Ordinary superphosphate is made by mixing rock phosphate with sulfuric acid. This converts most of the phosphorus to mono-calcium phosphate. Calcium sulfate (gypsum) is also formed. Fifty percent of ordinary superphosphate is comprised of calcium sulfate.

CONCENTRATED SUPERPHOSPHATE (45 percent P_2O_5)

Concentrated superphosphate fertilizers are often referred to as double or triple superphosphates due to their higher concentrations of P_2O_5. To produce concentrated superphosphate, phosphoric (and some sulfuric) acid is mixed with rock phosphate. Mono-calcium phosphate is the resulting phosphorus compound. No gypsum (calcium sulfate) is formed in this phosphoric acid/rock phosphate reaction; thus, a higher percentage of P_2O_5 is produced.

Concentrated superphosphate is the most widely used source of phosphorus in commercial fertilizers. It can be directly applied in dry form, mixed fertilizers, and bulk blends. A ton of concentrated superphosphate (45 percent P_2O_5) supplies as much phosphorus as 2 1/4 tons of ordinary superphosphate (20 percent P_2O_5). This has the following advantages:

1. Lower transportation costs
2. Less material to handle
3. Fewer bags or containers required for material storage

Calcium Metaphosphate (63 percent P_2O_5)

This source of phosphorus is made by treating rock phosphate with phosphorus oxide. (Phosphorus oxide is made from burning phosphorus in the smelting of phosphorus rock.) **Calcium metaphosphate** contains 63 percent P_2O_5 that is citrate soluble; only 1 percent is water soluble. Due to the low water solubility, this product is not suitable to use as starter fertilizer for row crops.

Calcium metaphosphate is used mainly as a bulk application to build soil reserves of phosphorus or as a topdressing for meadows and pastures.

Ammonium Phosphate (48 Percent P_2O_5)

Ammonium phosphate supplies two nutrients: nitrogen and phosphorus. In addition to containing 48 percent P_2O_5, it contains 11 percent nitrogen in ammonium form. Ammonium phosphate is manufactured by treating phosphoric acid with ammonia and then evaporating the solution. The phosphorus is highly water soluble.

This phosphate form is used in mixed fertilizers, in bulk blends, and as a dry, direct-application fertilizer.

Phosphoric Acid

There are two types of phosphoric acid: **ordinary phosphoric acid** (54 percent P_2O_5), and **superphosphoric acid** (70 percent P_2O_5).

Ordinary phosphoric acid is made by applying sulfuric acid to rock phosphate. This produces ordinary superphosphate. Phosphoric acid is also made through an electric furnace process. This produces phosphoric acid with fewer impurities.

Ordinary phosphoric acid is used in the following ways:

1. As a direct-application liquid fertilizer
2. In superphosphate fertilizer manufacture (phosphoric acid and rock phosphate)
3. In ammonium phosphate manufacture (ammonia and phosphoric acid)
4. In liquid mixed fertilizer manufacture
5. In superphosphoric acid manufacture (phosphoric acid is concentrated)

Superphosphoric acid is a concentrated form of regular phosphoric acid. It is produced by evaporating the water from ordinary phosphoric acid. Superphosphoric acid is used to manufacture liquid fertilizer mixtures because it keeps any solids present in the liquid fertilizer in suspension. (It is also used to make superphosphate fertilizers having a higher-than-normal phosphorus content.

Basic Slag (10 Percent P_2O_5)

Basic slag is a byproduct of steel manufacturing. In this process, iron ore and limestone are heated in a furnace. Iron ore impurities combine with the limestone and form slag. The amount of P_2O_5 in this slag depends on the amount of phosphorus in the iron ore. Slag generally contains 3 percent P_2O_5. Basic slag is used in a limited geographic area (e.g., near Birmingham, Alabama) and has limited use in crop production.

Bone Meal (25 Percent P_2O_5)

Bone meal is a good source of phosphorus for plants, but it is very expensive. Some bone meal is used in small packaged fertilizer products for flower growers, but most is used as livestock feed.

POTASSIUM FERTILIZER SOURCES (K)

There are several types of potassium fertilizers, and potassium is present in a number of chemical compounds in these fertilizers. The amount of potassium present in potassium fertilizers is usually measured and reported as the equivalent of K_2O, or potassium oxide. The letter "K" – the chemical symbol for potassium – comes from the German word "Kalium," meaning potassium. **Potash** is the word often used when referring to potassium fertilizer sources. The word "potash" comes from an old extraction method for potassium. This method involved leaching potassium salts from wood ashes in pots; the water was then evaporated. Remaining material or residue was referred to as "pot ashes."

Potassium, like phosphorus, comes from mineral ores. Potassium ore contains about 30 percent potassium oxide (K_2O). These mineral ores also contain magnesium and sodium. As a result, complex refining must be done to separate the potassium, magnesium, and sodium compounds. Some of the largest potassium mines are in the western United States and Canada. Unlike rock phosphate, potassium ore can be used almost directly as a plant nutrient without chemical changes.

Another potassium source is natural brine. Searles Lake in California and the Salduro Marsh in Utah are two important extraction sites. The brine at Searles Lake contains 3 percent potassium oxide; the brine at Salduro Marsh contains 2 percent. In contrast, ocean water contains about 0.04 percent potassium oxide.

How Potassium Reacts in the Soil

Potassium enters plants as positively charged (K^+) ions from the soil solution. On the other hand, potassium (K^-) is readily available from the negatively charged exchange sites of the clay and organic matter particles. The percentage of total potassium present in a soil in the exchangeable form is a very small part (1 to 2 percent) of the total potassium present in soil. Since potassium ions are absorbed on the negatively charged exchange sites of clay and organic matter particles, it does not leach from the soil. However, leaching will occur, to some extent, on coarse-textured soils with a low cation exchange capacity.

Potassium Chloride or Muriate of Potash (KCl)

Potassium chloride is also referred to as **muriate of potash** – muriate meaning chloride. Muriate of potash contains 60 to 62 percent potassium oxide (K_2). About 90 percent of potassium fertilizers sold are muriate of potash. They can be applied directly to the soil, used in mixed dry fertilizers, or bulk blended. Potassium chloride can also be used in liquid fertilizer formulations since it readily dissolves in water.

As Figure 85 shows, when fertilizer is applied to soil as muriate of potash (KCl), the positively charged K^+ ions are released from the exchange sites of the clay and organic matter particles. The negatively charged chlorine (Cl^-) ions tend to move out of the plant root zone in water percolating through the soil.

Potassium Sulfate (K_2SO_4)

Another potassium fertilizer source is **potassium sulfate.** This compound is a white salt that is 48 to 50 percent K_2O. Although potassium sulfate is more expensive than muriate of potash, on most crops it produces the same results. Potassium sulfate is mainly used on tobacco and potato crops. It also supplies sulfur – a secondary plant nutrient; however, sulfur is seldom in short supply in most soils.

As with muriate of potash, potassium sulfate can be applied directly to the soil, in mixed fertilizers, bulk blended, and in liquid fertilizer formulations.

Sulfate of Potash-Magnesia ($K_2SO_4 \cdot MgSO_4$)

Sulfate of potash-magnesia provides three nutrients: potassium, magnesium, and sulfur. It supplies 22 percent K_2O and 18 percent MgO (magnesium oxide). Sulfate of potash-magnesia is used for crop growing situations where all three nutrients (potassium, magnesium, and sulfur) are needed.

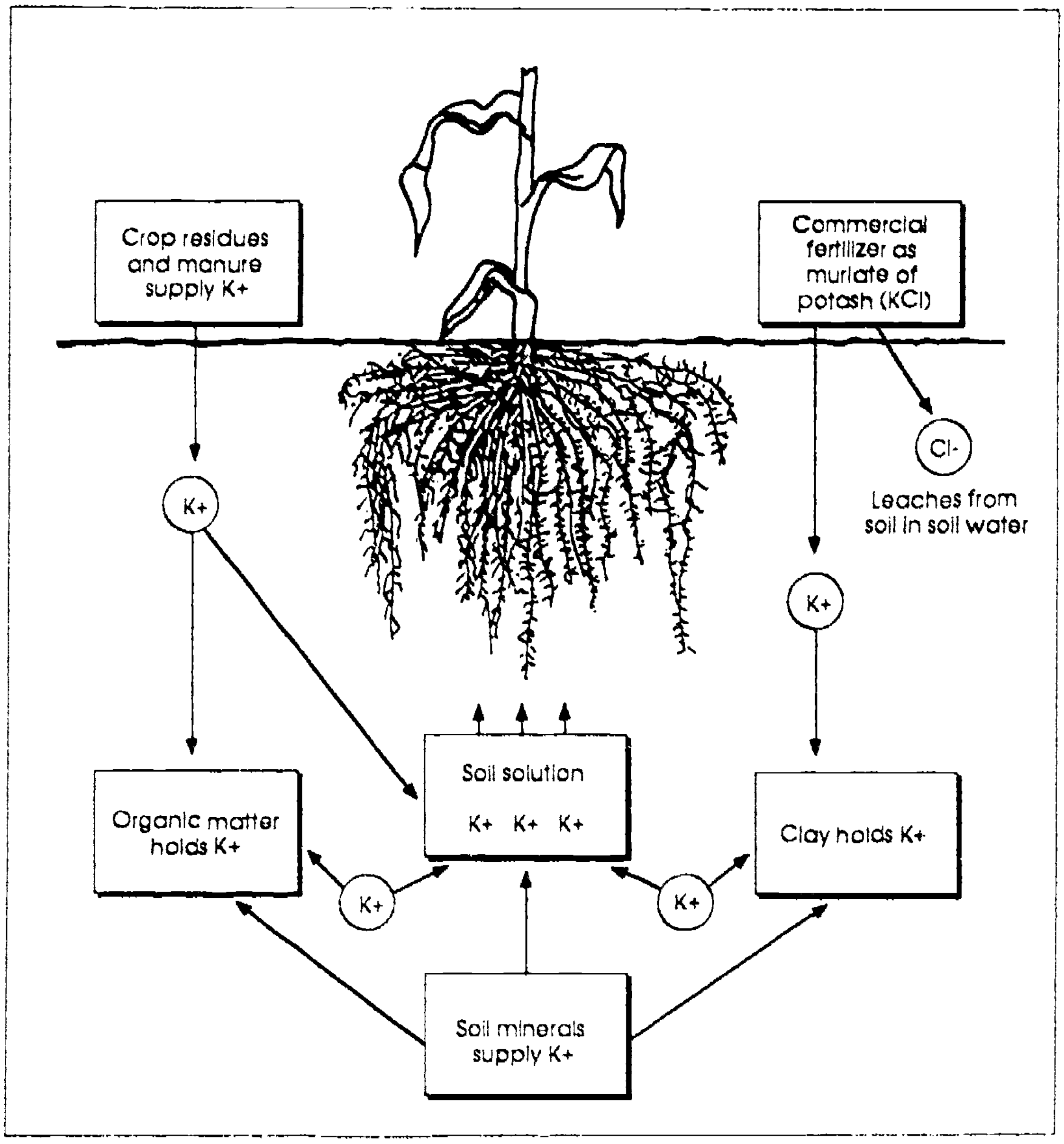


FIG. 85. When fertilizer is applied to soil as muriate of potash (KCl), the positively charged K$^+$ ions are released from the exchange sites of the clay and organic matter particles. The negatively charged chlorine (Cl$^-$) ions tend to move out of the plant root zone in water percolating through the soil.

Potassium Nitrate (KNO_3)

Potassium nitrate fertilizer supplies 44 percent K_2O and 14 percent nitrogen. It is readily soluble and well suited for use in liquid fertilizer solutions. Potassium nitrate is used with crops in which chlorine is undesirable, such as tobacco and potatoes. However, when used with corn and small grain crops, it has no advantage over other sources of potassium.

Potassium Metaphosphate (KPO_3)

Since **potassium metaphosphate** contains 55 percent P_2O_5 and 35 percent K_2O, it is a high-analysis fertilizer. Production of this product is very limited and used only under special situations.

CALCIUM SOURCES (Ca)

Calcium is one of the more abundant nutrients in the mineral part of the soil. The amount of calcium in a soil depends on the kind of rock from which the soil was formed. For example, soils derived from limestone are often high in calcium content. The main source of calcium is **calcitic limestone** ($CaCO_3$). Other lime materials that contain calcium are dolomitic limestone - $MgCO_3CaCO_3$, hydrated lime - $Ca(OH)_2$, and burnt lime - CaO.

Fertilizer materials supplying calcium are ordinary superphosphate (20 percent calcium) and calcium nitrate (19 percent calcium).

MAGNESIUM SOURCES (Mg)

Magnesium, although abundant in the earth, is usually not found in as large amounts in crop-producing soils as calcium is. Since magnesium is more soluble than calcium, it is more likely to leach out of the soil. Magnesium is supplied most easily to the soil by using dolomitic lime - $CaCO_3MgCO_3$. Fertilizer sources of magnesium include magnesium ammonium phosphate (10 percent magnesium), magnesium sulfate – epsom salt (17 percent magnesium), and potassium magnesium sulfate (11 percent magnesium).

SULFUR SOURCES (S)

A **sulfur** shortage in soils is usually not a problem for crop growth. In areas where coal or gas is burned, sulfur from this combustion is returned to the soil through rain. Fertilizer materials supplying sulfur are ammonium sulfate (23 percent sulfur), ordinary superphosphate (12 percent sulfur), magnesium sulfate (15 percent sulfur), potassium sulfate (17 percent sulfur), and potassium magnesium sulfate (22 percent sulfur).

MICRONUTRIENT SOURCES

Micronutrients are usually present in most soils at levels suitable for crop growth. However, in Ohio deficiencies of boron in alfalfa, of copper in corn and wheat, and of zinc in corn have been found. Magnesium deficiencies are also found in soybeans. When such deficiencies occur, it is usually necessary to apply compounds that supply the needed nutrients. Table 28 presents sources commonly used to supplement several micronutrients.

TABLE 28. Micronutrient sources and percent of nutrient supplied

Micronutrient	Source	Percent of Nutrient Supplied
Boron	Borax (sodium borate)	11 - 20%
Copper	Copper sulfate	25%
Copper	Copper oxide	75%
Iron	Iron sulfate	20%
Manganese	Manganese sulfate	24%
Manganese	Manganese oxide	48%
Zinc	Zinc sulfate	36%
Molybdenum	Sodium molybdate	40%

Practical Application

■ The following exercises or activities should help you determine the value of nutrient sources. They also review the selection of proper nutrient sources for specific crop-growing situations or conditions. Where appropriate, check the box as the item is completed.

1. Take a field trip to a livestock farm that uses efficient manure handling techniques. Obtain information from the farm owner regarding the following:

   ☐ Numbers and kinds of livestock
   ☐ Manure storage method(s)
   ☐ Manure hauling method(s)
   ☐ Amounts and kinds of bedding used
   ☐ Other manure-saving practices

2. Calculate the nutrients supplied from one ton of livestock manure produced on the farm.

Practical Application (continued)

Resources

- Pencil and notebook
- References on livestock and manure management
- Calculator (optional)

Procedure

- Inventory livestock (numbers and kinds).
- Inventory bedding (kinds and amounts).
- Estimate the amount of manure produced.
- Estimate the amount of nutrients lost by improper manure handling.
- Calculate the net amount of available nutrients produced from livestock manure.

Performance Checklist

☐ Calculated amount of manure produced (including bedding) for each kind of livestock.

☐ Calculated total nutrients available for the manure produced. Considered nutrient losses due to mishandling of manure.

☐ Calculated nutrients available in one ton of manure.

3. Calculate the nutrients supplied from crop residues for each field of the farm.

Resources

- Pencil and notebook
- Map of farm giving field numbers
- Cropping sequence and acres of each field
- References on amounts of crop residue supplied by different crops (Include material on the amount of nitrogen required to decompose residues with high carbon content.)
- Calculator (optional)

Procedure

- Prepare a table with the following information:
    1. Crop
    2. Approximate amount of residue produced at harvest
    3. Approximate amounts of nitrogen, phosphorus, and potassium supplied
- List cropping sequence of each field.
- List crop yields from each field.

Practical Application (continued)

Performance Checklist

☐ Calculated the amounts of nitrogen, phosphorus, and potassium supplied for each crop.

☐ Calculated the total amount and kind of residue supplied from each crop yield.

☐ Determined the amount of nitrogen fertilizer required to decompose high carbon residues (corn, stalks, straw).

4. Select a green manure crop for a field that needs improvement in nutrient and organic matter content.

Resources

- Pencil and notebook
- References regarding crops suitable for green manuring
- Soil test report of the field
- Soil map showing field slope and erosion
- Farm map giving cropping sequence

Procedure

- Prepare a use table for a green manure crop. Provide the following information:
    1. Crop
    2. Approximate amount of green material produced
    3. Approximate amounts of nutrients supplied
    4. Planting time
    5. Fertility and pH requirements

Performance Checklist

☐ Selected green manure crop based on cropping sequence.

☐ Selected green manure crop based on pH and soil fertility.

☐ Selected green manure crop that prevents erosion.

☐ Selected green manure crop that provides winter cover where needed.

Practical Application (continued)

5. Select a nutrient source(s) for supplying nitrogen, phosphorus, and potassium from commercial fertilizer.

Resources
- Pencil and notebook
- List of available fertilizer materials with chemical content
- Soil test of each field (cation exchange capacity needed)
- Soil map showing soil types
- Outline map of farm showing acres and cropping sequence

Procedure
- List the following soil test report results for each field: percent organic matter, available phosphorus, exchangeable potassium, and cation exchange capacity.
- List the crop to be grown.
- List possible times during the year when fertilizer could be applied.

Performance Checklist

☐ Selected nutrient sources of nitrogen based on the crop to be grown and the application time and method.

☐ Selected nutrient sources of phosphorus based on their solubility and the crop to be grown.

☐ Selected nutrient sources of potassium based on crop to be grown and application time.

6. Select the nutrient sources for calcium and magnesium from liming materials.

Resources
- Pencil and notebook
- List of available liming materials indicating their chemical contents
- Soil test of field(s)
- Cation exchange capacity and percent base saturation needed

Procedure
- Calculate calcium-magnesium and magnesium-potassium ratios from soil test report.
- List liming materials giving calcium and magnesium contents.

Performance Checklist

☐ Determined nutrient sources from liming materials for calcium and magnesium based on the percent base saturation (from soil test) and the calcium-magnesium ratio.

☐ Determined nutrient sources for magnesium based on the potassium-magnesium ratio.

KEY TERMS

■ Following is a list of important terms found in this chapter. Can you define them?

- ammonium nitrate
- ammonium phosphate
- anhydrous
- bacteriods
- basic slag
- bone meal
- calcitic limestone
- calcium cyanamide
- calcium metaphosphate
- calcium nitrate
- carbon-nitrogen ratio
- catalyst
- compatible
- concentrated superphosphate
- cortex
- crop residue
- denitrification
- enzyme
- green manure crop
- gypsum
- humus
- magnesium
- manure
- micronutrients
- muriate of potash
- natural organics
- nitrate
- nitrate of soda
- nitrification
- nitrite
- nitrogen fixation
- nodule
- ordinary phosphoric acid
- ordinary superphosphate
- organic matter
- phosphate
- phosphate rock
- phosphoric acid
- potash
- potassium metaphosphate
- potassium nitrate
- potassium sulfate
- rhizobia
- rock phosphate
- root hairs
- sulfate of potash-magnesia
- sulfur
- superphosphate
- superphosphoric acid
- symbiosis
- synthetic organic
- urea
- volatilization

Chapter 5

Fertilizer Selection

Introduction

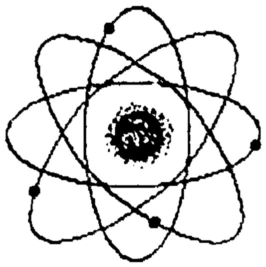
OBJECTIVES

After studying this unit, you should be able to do the following:

- Select the grade or analysis of fertilizer to use.
- Make conversions between the amount of phosphorus present in phosphate (P_2O_5) and elemental phosphorus (P).
- Make conversions between the amount of potassium present in potash (K_2O) and elemental potassium (K).
- Select the fertilizer ratio to use.
- Select the form of fertilizer to use.
- Calculate cost comparisons of fertilizer materials.

SCIENCE CONCEPTS

This chapter covers the following science concepts:



- The percentage of plant nutrients present in elemental form varies from fertilizer to fertilizer.
- Nutrients can be made available to plants as solids, liquids, or gases.
- Fertilizers can be compared by determining the value of the plant nutrients they contain.

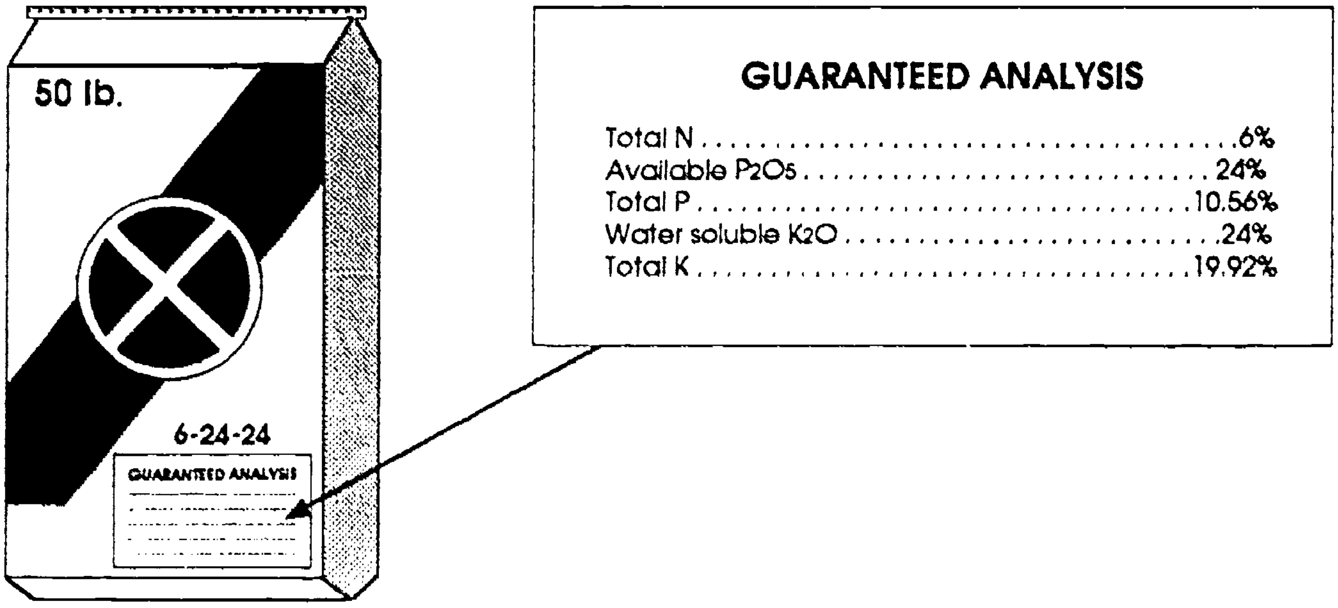
Fertilizer materials are sold in both dry and liquid formulations. They can be obtained in small amounts (bags) or in bulk quantities (in tanks, trucks, or wagons). It is important to remember that state and federal laws require the seller of fertilizer to guarantee the nutrient content to the buyer. This information is listed on the fertilizer bag or attached tag. Most states require that each bulk fertilizer sale, regardless of its form, have the following information on the invoice or delivery ticket:

1. Net weight of the fertilizer
2. Name and address of the fertilizer manufacturer or distributor
3. Grade and guaranteed analysis of the fertilizer (see Figure 86)

Base fertilizer selection, to some extent, on the soil test report. As described in Chapter 3, carefully conduct soil sampling and determine yield goals based on previous crops grown and the field's soil conditions. Also consider how much you are willing to spend for fertilizer materials.

Most soil test reports give the total amount of each nutrient recommended for application. These amounts are determined by the following:

1. Laboratory analysis of the soil sample
2. Crop to be grown
3. Yield goal
4. Previous crops grown on the field, for example:
    - If the previous crop grown was a sod crop containing more than 50 percent legume plants, less nitrogen fertilizer is needed.
    - If corn stalks or straw are plowed under, nitrogen can become temporarily unavailable. Thus, the soil test report usually recommends that higher rates of nitrogen fertilizer be applied.



GUARANTEED ANALYSIS

Total N	6%
Available P_2O_5	24%
Total P	10.56%
Water soluble K_2O	24%
Total K	19.92%

FIG. 86 Fertilizer packages give the guaranteed analysis of the fertilizer.

Analysis or Grade of Fertilizer Material

An important consideration when selecting fertilizer is its **analysis or grade.** When referring to liquid or solid fertilizer materials, analysis and grade have the same meaning: the percentage of material by weight.

The order in which a fertilizer's major nutrients are listed on the bag is the same throughout the United States. The analysis or grade is given as a set of three numbers. The first number gives the percent total nitrogen (N); the second number gives the percent available phosphate (P_2O_5 - phosphorus pentoxide); and the third number gives the percent soluble potash (K_2O - potassium oxide). For example, a 6-24-24 analysis or grade contains 6 percent nitrogen, 24 percent phosphorus pentoxide, and 24 percent potassium oxide (see label in Figure 86).

Since phosphorus pentoxide (P_2O_5) is known as *phosphoric acid* or *phosphate*, and potassium oxide (K_2O) is known as *potash*, the major nutrients are commonly referred to as nitrogen, phosphate, and potash. Consequently, if 200 pounds of a 6-24-24 fertilizer were applied per acre, it would provide 12 pounds of nitrogen (N), 48 pounds of phosphate (P_2O_5), and 48 pounds of potash (K_2O).

Elemental versus Oxide Forms of Fertilizer

As you may have previously noted, the amount of nitrogen in Figure 86 was stated as the equivalent of the **elemental** form; whereas, the amounts of phosphorus and potassium were stated as the equivalents of the **oxide** form: P_2O_5 – phosphate and K_2O – potash. Some manufacturers of fertilizer materials state the amounts of both the elemental and oxide forms of phosphorus and potassium. Stating these amounts in two different ways produces some confusion. To avoid this confusion, use the following as a guide:

Element Name	Element Symbol	Oxide Name	Oxide Symbol
Phosphorus	P	Phosphorus pentoxide or phosphate	P_2O_5
Potassium	K	Potassium oxide or potash	K_2O

At one time, nitrogen was stated as the amount of ammonia (NH_3). The law now requires the amount of nitrogen be stated as the equivalent of the elemental form. It is safe to assume that in the future, phosphorus and potassium will also be stated as the equivalent of the elemental form. The elemental form is a more realistic representation of the amount of a nutrient in fertilizer. This practice allows all three major plant nutrients to be measured on the same scale. However, until this practice is required throughout the United States, conversion factors must be used. To convert from elemental form to oxide form (or the reverse) use the following conversion factors:

1. One pound of phosphate (P_2O_5) = 0.44 pounds of phosphorus (P)
   One pound of phosphorus (P) = 2.3 pounds of phosphate (P_2O_5).
2. The percentage or amount of P multiplied by 2.3 = the amount of P_2O_5.
   The percentage or amount of P_2O_5 multiplied by 0.44 = the amount of P
3. One pound of potash (K_2O) = 0.83 pounds of potassium (K)
   One pound of potassium (K_2O) = 1.2 pounds of potash (K_2O)
4. The percentage or amount of K multiplied by 1.2 = the amount of K_2O
   The percentage or amount of K_2O multiplied by 0.83 = the amount of K

The scales in Figure 87 can also be used to convert from one form to the other. For example, if a fertilizer contains 20 pounds of P_2O_5, determine the elemental amount by using the phosphorus scale (see Figure 87 - scale A). On the right side of this scale find the number 20. Directly to the left on this scale is the number 8.8 This is the elemental amount of phosphorus: 8.8 pounds or 8.8 percent. Use the potassium scale in Figure 87 (side B) in the same manner.

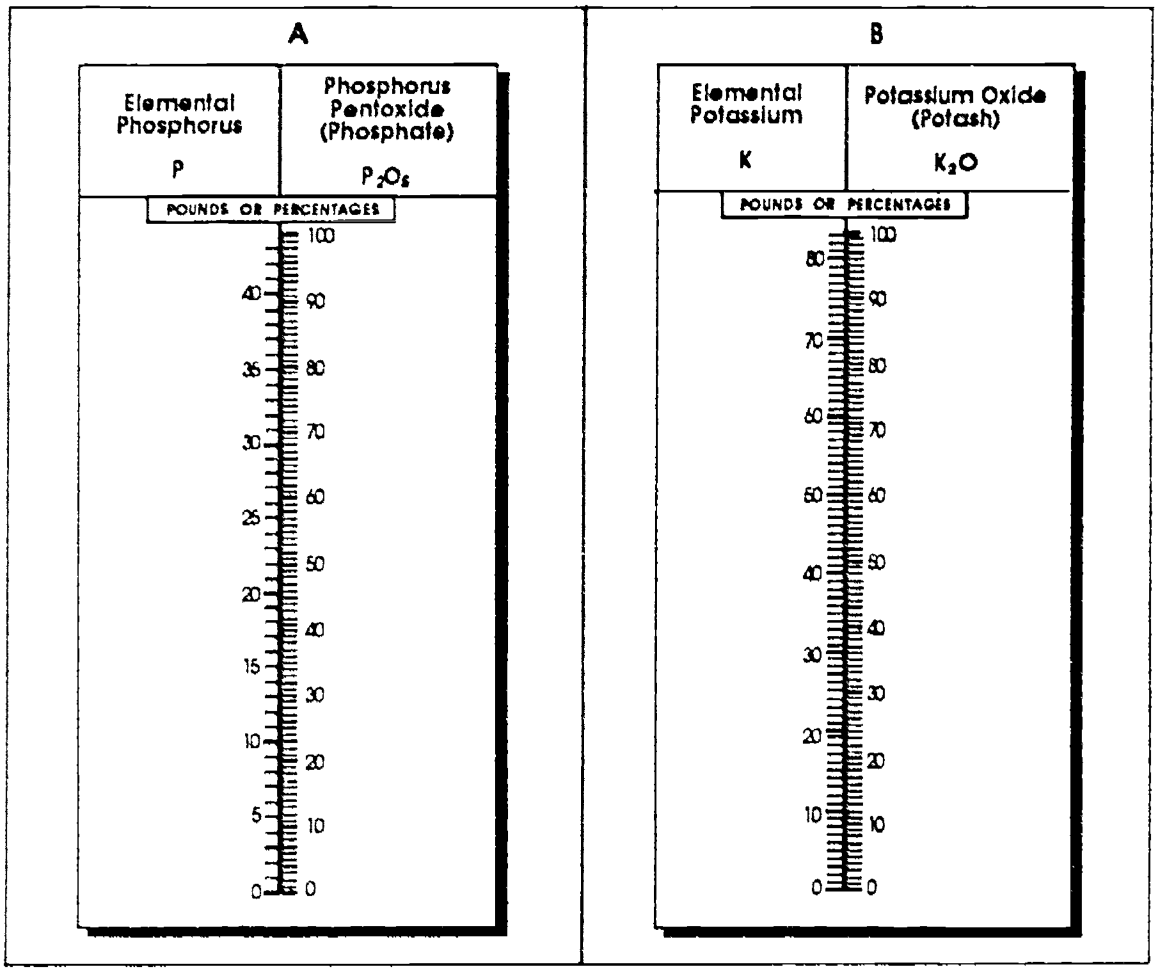


FIG. 87. Scales used for converting from the elemental form of phosphorus or potassium to the oxide form (or the reverse).

Table 29 provides elemental/oxide form equivalents for some common fertilizer grades.

TABLE 29. Comparison of some common fertilizer grades showing the amounts of PO_5 (oxide) and P (elemental) and amounts of K_2O (oxide) and K (element)

Fertilizer Grade OXIDE BASIS			Fertilizer Grade ELEMENTAL BASIS		
N	P_2O_5	K_2O	N	P	K
6	24	24	6	10.56	19.92
16	16	16	16	7.04	13.28
20	10	10	20	4.40	8.30
0	20	20	0	8.80	16.60
8	32	16	8	14.08	13.28
0	23	30	0	10.56	24.90

Fertilizer Carriers

One hundred pounds of 6-24-24 fertilizer contains 54 pounds of nitrogen, phosphorus, and potassium compounds that are available to plants (6 + 24 + 24 = 54 pounds). **Carrier material** makes up the remaining 46 pounds. This material is needed because the elements nitrogen, phosphorus, and potassium alone are not available to plants. They must combine with other elements to become plant nutrient sources. For example, if 6 pounds of nitrogen are from ammonium nitrate, then 33.5 percent of the material contains elemental nitrogen. The remainder of the material is oxygen from nitrates (NO_2) and hydrogen from ammonium (NH_4). If the phosphate (P_2O_5) source is ordinary superphosphate, it contains 20 percent phosphorus oxide or 8.8 percent elemental phosphorus. Since the chemical formula for ordinary superphosphate is $CaH_4 (PO_4)_2$, the carrier materials for phosphorus are calcium, hydrogen, and oxygen. With potassium, if the potassium-supplying material is muriate of potash (KCl), the carrier material is chlorine (Cl).

Most mixed fertilizers have an added **filler**. This filler balances the analysis or grade and can consist of several materials, such as lime sand or tobacco dust.

Fertilizer Ratios

The **fertilizer ratio** is the proportion of the three major nutrients present in fertilizer. A fertilizer grade or analysis of 6-24-24 states that the material contains 6 percent nitrogen, 24 percent available phosphate and 24 percent water-soluble potash. It also states that for each part of nitrogen, there are four parts each of phosphate and potash. To determine the ratio of a fertilizer grade, divide each of the numbers of the fertilizer grade by the smallest number of the grade. For example, in a 6-24-24 grade, 24 is divided by 6; thus giving the ratio 1:4:4.

As shown in Table 30, different grades can have the same ratio. For example, the grades 5-20-20 and 6-24-24 both have the same ratio: 1:4:4. Determining the fertilizer ratio is important when making cost comparisons. (Cost comparisons are discussed in more detail later in this chapter.)

TABLE 30. Fertilizer grades and their ratios

Fertilizer Grade			Ratio		
N	P_2O_5	K_2O	N	P_2O_5	K_2O
6	24	24	1	4	4
5	20	20	1	4	4
0	20	20	0	1	1
10	20	30	1	2	3
12	12	12	1	1	1
8	32	16	1	4	2

Fertilizer Forms

Fertilizers are available in three forms: **solid, liquid**, or **gas**. All three forms supply the needed plant food nutrients. Make cost comparisons when deciding which type of fertilizer to use.

LIQUID FERTILIZERS

Liquid fertilizers can contain only nitrogen or combinations of nitrogen, phosphate, and potassium. When applied in the same amounts (pounds of nutrients), liquid fertilizers have the same effect on plant growth as solid (dry) fertilizers.

Broadcasting (scattering over a broad area) does not require special equipment and is a common method of applying liquid mixed fertilizers. However, special equipment is needed if the crop producer wants to apply liquid fertilizer in the rows at planting time. Most companies supplying liquid mixed fertilizers also have equipment available for broadcasting.

Two types of liquid nitrogen fertilizers are typically available. These are **pressurized** solutions and **nonpressurized** solutions of aqua ammonia and nitrogen. They contain 21 to 49 percent nitrogen.

- *Nonpressurized* solutions are usually made from urea and ammonium nitrate (UAN) and contain 28 to 32 percent nitrogen. These solutions are typically broadcast onto the soil (see Figure 88).

- *Pressurized* liquid nitrogen solutions are knifed or injected into the soil at a depth of one to two inches. They can be applied before planting or sidedressed after the crop has been planted (see Figure 89). The nitrogen source in an ammonium nitrate solution is ammonia, also known as **free ammonia**. In other words, it can be easily lost from the solution unless injected into the soil where it is held by the soil's negative charges.

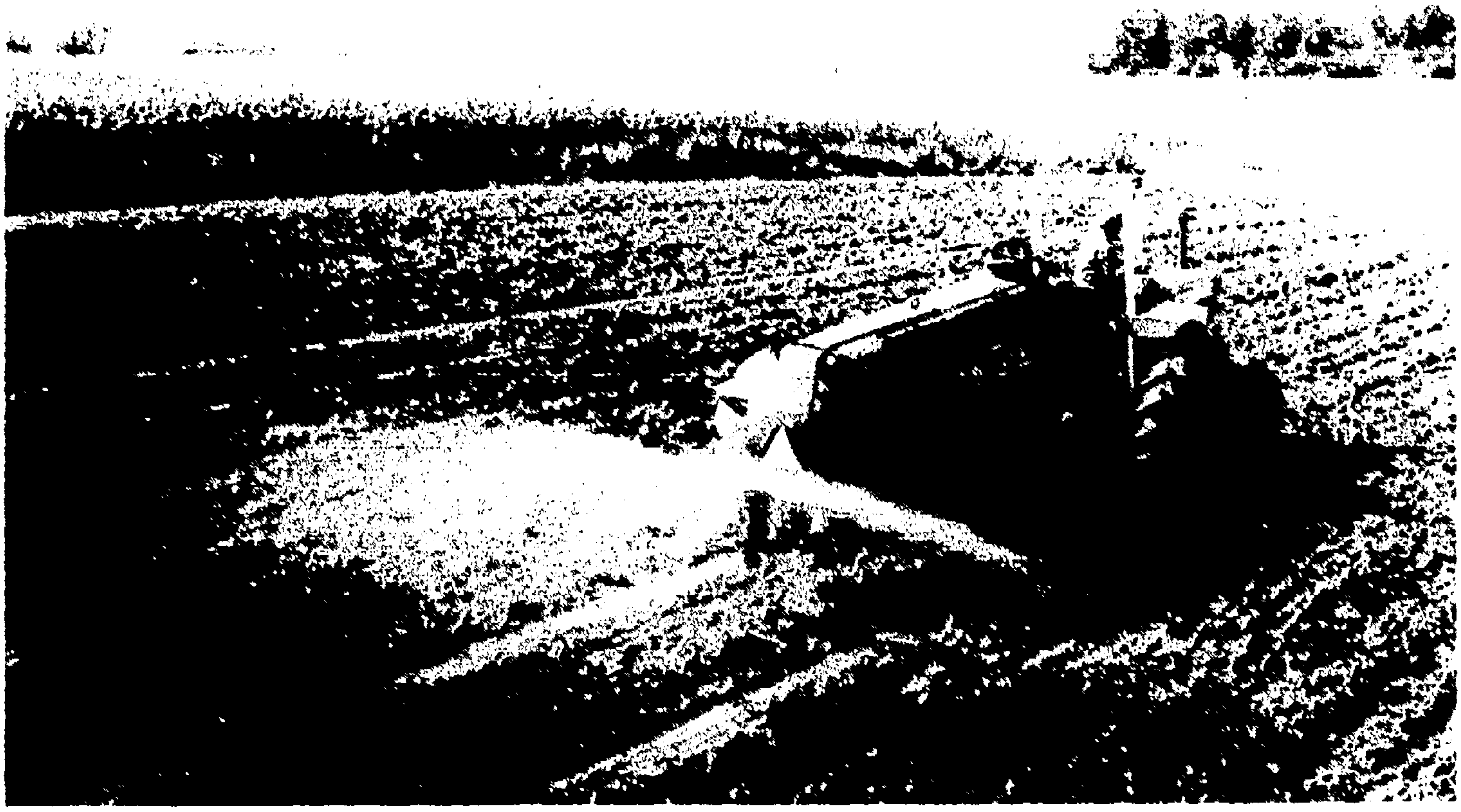


FIG. 88. Applying nonpressurized liquid fertilizer to the soil surface. *(Courtesy New Idea Farm Equipment Company)*

FIG. 89. Applying liquid fertilizer under pressure: material is knifed into the soil. *(Courtesy New Idea Farm Equipment Company)*

DRY FERTILIZERS

Much of the fertilizer used by crop growers is in **dry** form. Many varieties of dry fertilizer grades are available to the crop producer. Single analysis or **straight** (containing only one nutrient) fertilizers for nitrogen, phosphorus, and potassium are usually available. Examples are 45-0-0, which is urea and supplies nitrogen; 0-47-0, which is superphosphate and contains only phosphate; and 0-0-60, which is muriate of potash and contains only potassium.

Many of the dry fertilizers are **pelleted**. These fertilizers produce less dust when handled and are less likely to cake when exposed to moisture. They are free-flowing and promote uniform application. Figures 90 and 91 show common types of dry fertilizer spreaders.

GASEOUS FERTILIZERS

Anhydrous ammonia, a **gaseous** fertilizer, is an important source of nitrogen for fertilizing crop fields (see Figures 92 and 93). When compressed under high pressure anhydrous ammonia becomes liquid and is stored in tanks. As this liquid is applied to a field, it reverts to a gas. Consequently, anhydrous ammonia must be

FIG. 90. This air spreader is used to apply dry bulk fertilizer before plowing. *(Courtesy Countrymark, Inc., Derby Farm Center Site, Derby, Ohio)*

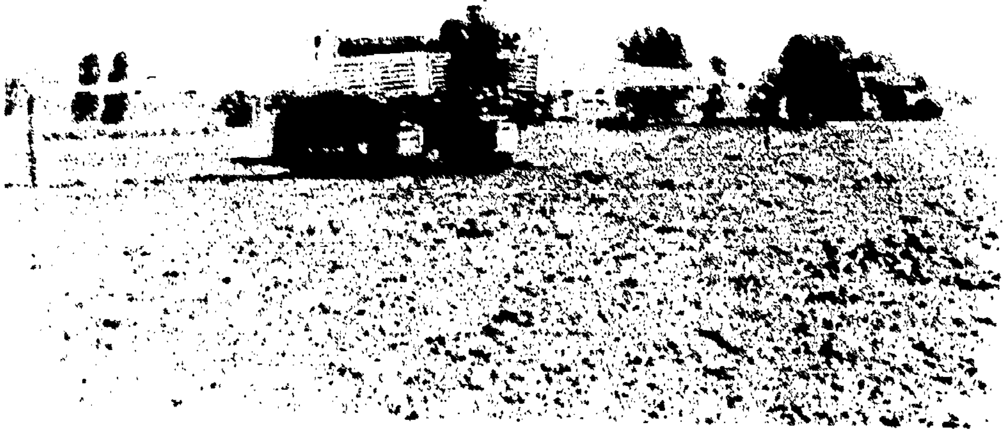


FIG. 91. This fan spreader is used to apply dry bulk fertilizer before plowing. *(Courtesy Terra International, Inc., Covington, Ohio)*

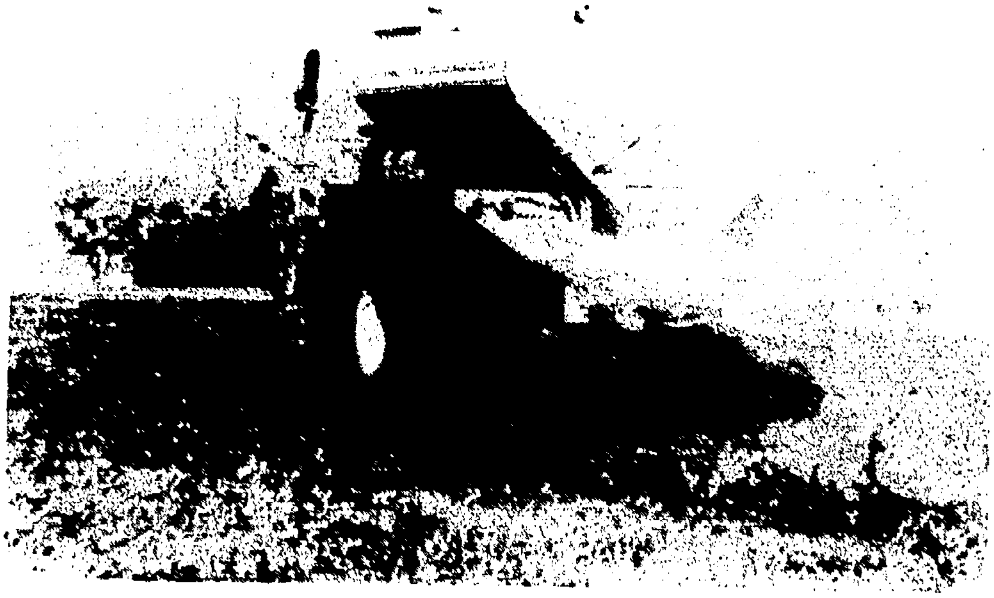


FIG. 92. This type of spreader is used to apply anhydrous ammonia to the soil before plowing.

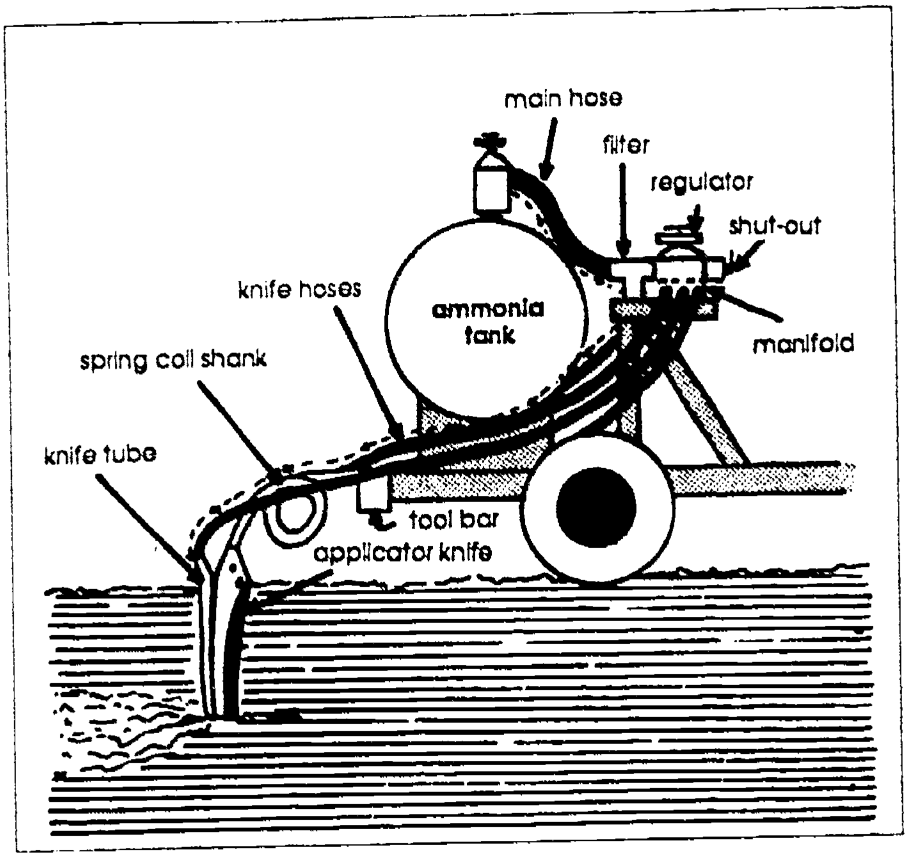


FIG. 93. Anhydrous ammonia is knifed into the soil at a depth of six inches to prevent the gas from escaping into the atmosphere. *(Courtesy Oklahoma Extension Service)*

applied below the soil surface so it does not escape into the atmosphere. As shown in Figure 94, soil conditions and application methods must be exact to get the most benefits from the ammonia.

Use the following guidelines when applying anhydrous ammonia:

1. Apply anhydrous ammonia at a depth of six inches under ideal soil conditions. The ammonia will spread about four inches in the soil and then change to ammonium in a short time.

2. Apply anhydrous ammonia in the recommended amounts. If more ammonia is applied than can be held by the soil, some gas will escape into the atmosphere.

3. Do not apply anhydrous ammonia at a depth of four inches or less. The gas may be too close to the soil surface and escape into the atmosphere.

4. Do not apply anhydrous ammonia to soil that is too wet. The knife opening may not close and gas will escape into the atmosphere. Also, wet soil prevents the gas from spreading into the surrounding soil.

5. Do not apply anhydrous ammonia to soil that is too dry. The gas may spread too far and escape into the atmosphere.

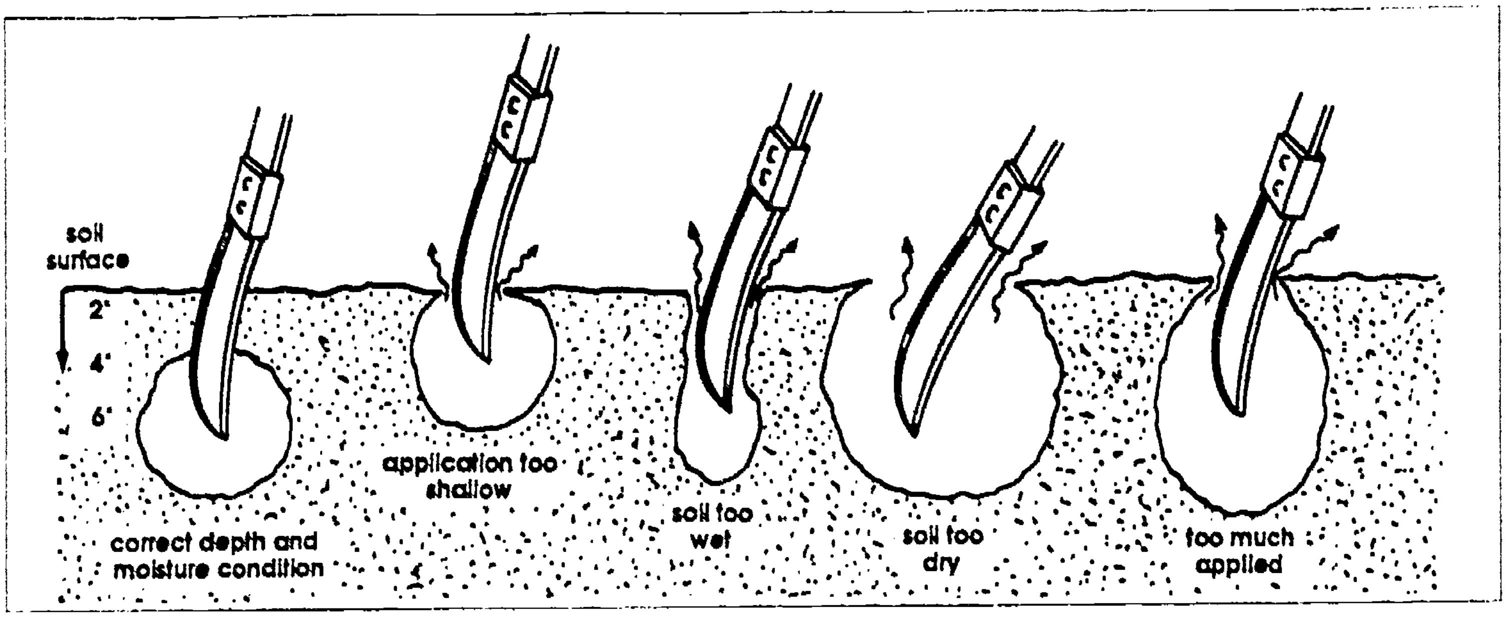


FIG. 94. Anhydrous ammonia gas may escape into the atmosphere if application conditions are not suitable. Soil moisture and application amount and depth all contribute to nitrogen loss.

Cost Comparisons of Fertilizer Materials

Corn producers sometimes pay too much for fertilizer materials. Often this happens because they do not calculate the cost per pound of plant nutrient. When fertilizer shortages and price increases occur, it is important that you understand how to figure the value of different types of fertilizer.

When comparing fertilizer prices, the most important pieces of information on a fertilizer label or delivery ticket are the **net weight** and the **guaranteed analysis.** Use cost per pound of *plant nutrient* rather than the cost per pound of *fertilizer material.* With fertilizers, one pound of a nutrient listed on the label is equal to one pound of the same nutrient listed on the label of another material. This is the case whether the material is in dry or liquid form.

COMPARING FERTILIZER COSTS

Due to transportation costs and shortages of labor and raw materials, fertilizer prices change considerably over short periods of time. For this reason, use current local costs when calculating fertilizer costs. The costs used in the following examples are used only to illustrate this procedure.

Calculating Nutrient Costs of Straight Fertilizers

As stated previously, **straight fertilizers** contain only one nutrient. For example, urea containing 45 percent nitrogen, concentrated superphosphate containing 46 percent P_2O_5, and muriate of potash containing 60 percent K_2O are straight fertilizers.

To calculate the cost of a pound of nutrient in a straight material, use the following formula:

$$\frac{\textbf{Price per ton}}{\textbf{\% of nutrient x 2,000} \text{ (pounds per ton)}} = \textbf{Cost per pound of nutrient}$$

If urea containing 45 percent nitrogen sells for \$240.00 a ton, the cost per pound of nutrient is calculated as follows:

$$\frac{\$240.00}{0.45 \times 2{,}000} = \frac{\$240.00}{900} = \$0.267 \text{ per pound}$$

The same procedure is used for calculating the costs of using phosphorus pentoxide and potassium oxide – nutrient sources of phosphate and potash, respectively. For example, concentrated superphosphate containing 46 percent phosphorus pentoxide (P_2O_5) costs \$140.00 per ton. The cost calculations follow:

$$\frac{\$140.00}{0.46 \times 2{,}000} = \frac{\$140.00}{920} = \$0.152 \text{ per pound}$$

Likewise, the same procedure is used for calculating the cost of using muriate of potash containing 60 percent potassium oxide (K_2O) and costing \$90.00 a ton.

$$\frac{\$90.00}{0.60 \times 2{,}000} = \frac{\$90.00}{1{,}200} = \$0.075 \text{ per pound}$$

Comparing Costs of Mixed Fertilizers with Similar Ratios

Mixed fertilizers with similar ratios contain the same ratios of nitrogen (N), phosphorus pentoxide (P_2O_5), and potassium oxide (K_2O). Examples of these are 6-24-24 and 5-20-20. Their ratios are exactly the same – 1:4:4. The 6-24-24 fertilizer contains 54 percent nutrients (6 + 24 + 24) and costs \$172.00 per ton. The 5-20-20 fertilizer contains 45 percent nutrients (5 + 20 + 20) and costs \$144.00 per ton.

To calculate the cost per pound of material and nutrient in mixed fertilizers with similar ratios, use the following formulas:

$$\frac{\text{Cost per ton}}{2{,}000 \text{ (pounds per ton)}} = \text{Cost per pound of material}$$

$$\frac{\text{Cost per pound of material}}{\text{\% of nutrients}} = \text{Cost per pound of nutrient}$$

For example, calculate the cost per pound of nutrient for 6-24-24.

STEP 1

$$\frac{\$172.00}{2,000} = \$0.086 \text{ cost per pound of material}$$

STEP 2

$$\frac{0.086}{0.54} = \$0.159 \text{ per pound of nutrient}$$

Now calculate the cost per pound of nutrient for 5-20-20.

STEP 1

$$\frac{\$144.00}{2,000} = \$0.072 \text{ per pound of material}$$

$$\frac{0.072}{0.45} = \$0.16 \text{ per pound of nutrient}$$

The 6-24-24 fertilizer supplies nutrients at $0.001 per pound less than the 5-20-20 fertilizer.

Calculating Liquid Fertilizer Costs

Liquid fertilizers are sold as straight fertilizers. They contain only one nutrient, such as nitrogen. Usually liquid fertilizers are sold by the ton and cost comparisons can be made with dry fertilizers. Following is an example of such a cost comparison:

> A liquid fertilizer containing 28 percent nitrogen sells for $152.00 per ton. A dry fertilizer – urea containing 45 percent nitrogen – is selling for $240.00 per ton. Using the formula presented in **Calculating Nutrient Costs in Straight Fertilizers**, the cost per pound of nutrient for each fertilizer can be calculated.

1. Liquid fertilizer – 28 percent nitrogen

$$\frac{\$152.00}{0.28 \times 2,000} = \frac{\$152.00}{560} = \$0.271 \text{ per pound of nitrogen}$$

2. Dry fertilizer (urea) – 45 percent nitrogen

$$\frac{\$240.00}{0.45 \times 2,000} = \frac{\$240.000}{900} = \$0.2667 \text{ per pound of nitrogen}$$

As the calculations on page 125 show, the liquid and dry fertilizer costs are almost the same; however, the dry fertilizer has a slight advantage in cost per pound of nitrogen. If the nutrient costs of liquid and dry fertilizers are almost equal, consider the cost of delivery and application before choosing your fertilizer.

Liquid Fertilizers Sold by the Gallon

A few liquid fertilizer distributors sell their products by the gallon. Unless the crop producer can relate analysis, weight, and price, he or she is at a disadvantage when making cost comparisons.

To compare the costs of liquid fertilizers sold by the gallon with costs of other fertilizers, the weight per gallon of the liquid must be known. Usually, liquid fertilizers weigh 10, 11, or 12 pounds per gallon. Therefore, in the following example we will use a weight of 11 pounds per gallon for liquid fertilizer and the plant nutrient costs calculated on page 123: N - \$0.267 per pound, P_2O_5 - \$0.152 per pound, and K_2O - \$0.075 per pound. Using this information, calculate the cost per gallon of a 10-20-10 liquid fertilizer.

0.10 (10%) x 11 (pounds/gallon) x \$0.0267 = \$0.29
0.20 (20 %) x 11 (pounds/gallon) x \$0.152 = \$0.33
0.10 (10%) x 11 (pounds/gallon) x \$0.075 = \$0.08
\$0.70
per gallon

Next, calculate the number of gallons per ton of this liquid fertilizer.

$$\frac{2{,}000 \text{ pounds/ton}}{11 \text{ pounds/gallon}} = 182 \text{ gallons/ton}$$

Now we can calculate the cost of nutrients per ton.

182 x \$0.70 (cost/gallon) = \$127.40 (actual cost of nutrients per ton)

A liquid fertilizer (such as 10-20-20) usually costs \$3.00 to \$5.00 per gallon. Thus, at \$3.00 per gallon, the selling price of the liquid would be calculated as follows:

182 (gallons/ton) x \$3.00 (cost/gallon) = \$546.00 cost/ton

Obviously, a dry bulk fertilizer selling for \$152.00 per ton is at least three times more economical than this liquid fertilizer selling for \$3.00 per gallon.

Note: Statements regarding the effectiveness of liquid fertilizer are not always true. For example, some people claim that it takes only a few gallons of liquid fertilizer to produce high-yield crops. A common recommendation is five gallons per acre of 10-20-10. Note this would cost \$15.00 per acre and supply only 5.5 pounds of nitrogen, 11 pounds of P_2O_5 and 5.5 pounds of K_2O per acre! A liquid fertilizer costing this much and supplying these small amounts of nutrients would not be economical for a crop producer.

Summary

Use the following methods to compare the costs of using different fertilizer materials:

1. Compare costs of two or more materials supplying the same nutrient (e.g., nitrogen carriers, urea, and ammonium nitrate).
2. Compare costs of mixed fertilizers having identical ratios (e.g., 5-20-20 and 6-24-24).
3. Compare costs of different fertilizer forms (e.g., liquid, dry, or gas) supplying a single nutrient *or* of mixed materials having identical ratios.

Practical Application

The following student exercises will help you use cost comparisons to select fertilizer materials. Check the box after completing each item.

1. Compare costs of fertilizer materials containing one nutrient (straight fertilizers).

   Resources
   - Pencil and notebook
   - Current local costs of straight fertilizer materials
   - References giving cost calculation procedures and suggested straight fertilizer application times and methods.
   - Calculator (optional)

   Procedure

   ☐ List each straight fertilizer material with the nutrient percentage in elemental form. (Use conversion procedures to change P_2O_5 and K_2O to elemental P and K, respectively.)

   ☐ List the cost per pound of each nutrient.

   ☐ List the delivery and application costs.

   ☐ Record information on the form on page 128.

Practical Application (continued)

Costs of Using Straight Fertilizer Materials

Name of Material or Analysis	Form (Liquid, Dry or Gas)	Percentage of Nutrient	Delivery and Application Costs per Cwt. or Ton	Cost/Pound of Nutrient	Cost/Cwt. or Ton of Nutrient

2. Compare costs of fertilizer materials containing more than one nutrient and with identical ratios.

Resources

- Current local costs of mixed fertilizers
- References giving calculation procedures for comparing costs of mixed fertilizers with identical ratios
- Pencil and notebook
- Calculator (optional)

Procedure

☐ Select mixed fertilizer grades with identical ratios.

☐ List the cost of each material.

☐ If purchased in bulk, list the delivery and application costs.

☐ Record information on the form on page 129.

Costs of Using Similar-ratio Fertilizers Containing More Than One Nutrient

Grade of Material	Form (Liquid or Dry)	Percentage of Each Nutrient	Delivery and Application Costs per Cwt. or Ton	Cost/Cwt. or Ton of Material

KEY TERMS

■ The following is a list of important terms found in this chapter. Can you define them?

analysis
broadcasting
bulk
carrier material
dry fertilizer
fertilizer ratio
filler
free ammonia
gaseous fertilizer
grade
guaranteed analysis
liquid fertilizer
mixed fertilizer
net weight
nonpressurized solution
oxide
pelleted
pressurized solution
single analysis fertilizer
solid fertilizer
straight fertilizer

Chapter 6

Fertilizer Application

Introduction

Crop producers apply commercial fertilizers to supply crops with necessary nutrients in the correct amounts and at the proper times during the growing season. The fertilizer application method depends on several factors and varies from farm to farm, and even from field to field.

Chapter 5 discussed selecting commercial fertilizers according to grade, ratio, form, and cost. After selecting your fertilizers, you must also select the application methods.

OBJECTIVES

After studying this unit, you should be able to do the following:

- Determine whether to use immediate buildup (one application) or gradual buildup (several applications) of commercial fertilizers to correct soil deficiencies of phosphorus and potassium.
- Select the time of year to apply bulk applications of commercial fertilizers based on the type of fertilizer and the crop to be grown.
- Select a commercial fertilizer application method based on fertilizer amount, form, grade, ratio, and the crop to be grown.

SCIENCE CONCEPTS

This chapter covers the following science concepts:

- Phosphorus and potassium concentrations accumulate in the soil; nitrogen concentrations do not.
- Phosphate applications proportionately raise the level of phosphorus available to plants.
- The amount of potassium available for plant growth depends on the soil's cation exchange capacity.
- Fertilizer placement affects a nutrient's availability to plants.

Nitrogen Fertilizer Application

Since nitrogen is retained in the soil in only small amounts from year to year, annual nitrogen applications are usually necessary. The amount of nitrogen to apply is determined by the previous crop grown and the crop to be grown. For example, if soybeans are grown in a field one year, and the following crop is also soybeans, additional nitrogen may not be needed. However, if the next crop is corn instead of soybeans, 160 pounds of nitrogen per acre may be needed to produce 130 bushels per acre. The Cooperative Extension Service and state soil testing laboratories can provide crop producers with fertilization recommendations.

Although recommendations provide a basis for selecting nitrogen fertilizers, also consider the following items prior to application:

1. Kind of fertilizer to apply
2. Time of application
3. Method of application
4. Amount of nutrients supplied by animal manure

In many crop-growing situations, large amounts of nitrogen fertilizer are required (see Table 31). Obviously, supplying the required amount of nitrogen may mean selecting more than one kind of nitrogen fertilizer. It may also mean fertilizing more than once and using more than one application method.

The information presented in this chapter and chapters 4 and 5 will help you make accurate fertilizer application decisions.

TABLE 31. Examples of nitrogen recommended for corn and grain sorghum

	YIELD GOALS			
	Corn (bushels/acre)	**80**	**120**	**160**
	Grain Sorghum (cwt./acre)	**50**	**75**	**100**
Previous Crop		**Annual Application Pounds N/A**		
Forage Legumes		20	60	100
Grass crop		20	65	150
Soybeans		20	85	170
Continuous corn and other crops		40	115	200

Soil Buildup and Maintenance of Phosphorus and Potassium

Unlike nitrogen, phosphorus and potassium can be stored in the soil in large amounts. (If necessary, review the sections in Chapter 4 concerning phosphorus and potassium.) Soil tests are used to determine if phosphorus and potassium are present in levels sufficient to produce high crop yields. If insufficient levels of phosphorus and potassium are present, there are two application methods that provide adequate amounts of these nutrients. Either of the following methods is satisfactory if the recommended amounts are applied:

1. Immediate soil buildup
2. Gradual soil buildup

IMMEDIATE BUILDUP

Immediate, quick, or **annual buildup** all mean applying enough fertilizer in one year to raise the soil nutrient content to adequate levels. Advantages of the immediate buildup method follow:

1. *Lower purchasing costs* – Bulk purchasing of large amounts of fertilizer can cost less than purchasing several small amounts.
2. *Lower application costs* – The one or two required yearly fertilizer applications cost less than several applications.

GRADUAL BUILDUP

Gradual buildup of fertilizer brings the soil nutrient content of phosphorus and potassium to a sufficient level over a longer time period – usually five or more years. A crop producer using this method has the advantage of extending the fertilizer costs over several years.

SOIL PHOSPHORUS BUILDUP

As discussed in Chapter 3, crop response to available phosphorus varies depending on the crop. Therefore, the following available phosphorus levels are needed:

1. Corn and soybeans require 30 pounds per acre of available phosphorus in the soil for maximum yields.
2. Wheat, oats, and forage legumes require 60 pounds per acre of available phosphorus in the soil for maximum yields.

If a soil test report shows the available soil phosphorus is below the required amount for the crop to the grown, phosphorus fertilizer must be applied. About 100 pounds of phosphate (P_2O_5) are needed to raise the level of available phosphorus 10 pounds per acre. Therefore, if the soil test shows the available phosphorus is 10, then 200 pounds of phosphate are needed to raise the phosphorus level to 30 pounds of available phosphorus per acre for corn and soybean production. However, if wheat, oats, or forage legumes are to be grown and the soil test report shows the available phosphorus is 10, then 500 pounds of phosphate are needed to provide 60 pounds per acre of available phosphorus in the soil. Table 32 gives the approximate amounts of phosphorus fertilizer needed to raise a soil test result to a level sufficient to grow different crops.

Consider the following when planning phosphorus fertilizer applications:

1. Phosphorus fertilizer is most available to crops when the soil pH is 6.5.
2. Phosphorus fertilizer is lost from the soil through erosion.
3. The amount of phosphorus fertilizer needed in one year is determined by the crop grown and whether an immediate or gradual plan of soil buildup will be used.

TABLE 32. Approximate amounts of phosphate (P_2O_5) needed to raise the soil test result to a sufficient level*

Soil Test Value (Pounds/Acre)	Corn and Soybeans (Pounds P_2O_5 per Acre)	Wheat - Oats - Forage Legumes (Pounds P_2O_5 per Acre)
5	250	550
15	150	450
25	50	350
30	0	300

*Source: *Ohio Agronomy Guide*

SOIL POTASSIUM BUILDUP

The amount of potassium required for optimum plant growth depends upon the soil's ability to hold the nutrient in an available form. Unlike phosphorus, *potassium can leach from the soil.* The desired soil potassium level (exchangeable) is determined by the soil's cation exchange capacity. Therefore, the higher the cation exchange capacity, the more potassium (as exchangeable K) the soil will hold.

As discussed in Chapter 3, the equation to determine the amount of K a soil will hold is **220 + (5 x the cation exchange capacity of a soil)**. Table 33 gives the amount of exchangeable K that can be held by soils with different cation exchange capacities.

It takes 100 pounds of potash (K_2O) to raise the potassium (K) soil test level 50 pounds per acre. Thus, if the soil test report shows 190 pounds of exchangeable potassium (K), it will take 120 pounds of potash (K_2O) to raise the soil test level to 250 pounds per acre of exchangeable potassium (K).

Cooperative Extension Service publications, such as the *Ohio Agronomy Guide*, provide information about the amounts of potassium required for various field crops at different yields and soil cation exchange capacities. Table 34 on page 136 provides this information for corn.

When planning potassium fertilizer applications, consider the following:

1. Large, one-time potassium fertilizer applications can put the magnesium-potassium ratio out of balance. (Refer to Chapter 3.)
2. The amount of potassium buildup in the soil is determined by the soil's cation exchange capacity.
3. If more potassium fertilizer is applied than the soil can hold, potassium leaches from the soil and is lost for crop use.
4. The amount of potassium to apply is also determined by the crop to be grown and the buildup plan (immediate or gradual).

TABLE 33. The amount of exchangeable K held by soils with different cation exchange capacities

Cation Exchange Capacity of Soil	Calculation	Amount of K the Soil Will Hold (pounds/acre)
5	220 + (5 x 5) =	245
10	220 + (5 x 10) =	270
15	220 + (5 x 15) =	295
20	220 + (5 x 20) =	320
25	220 + (5 x 25) =	345
30	220 + (5 x 30) =	370

TABLE 34. Examples of potassium recommendations for corn (pounds K_2O per acre)

Soil Test Value	YIELD GOALS (bushels/acre)								
	C.E.C.*			C.E.C.*			C.E.C.*		
Pounds K/A	10	20	30	10	20	30	10	20	30
	Annual Recommendation**								
50	110	130	150	120	140	160	130	150	170
150	70	90	110	80	100	120	90	110	130
250	30	50	70	40	60	80	50	70	90
350	20	20	30	30	30	40	45	45	50
450	20	20	20	20	20	30	20	35	45
550	20	20	20	20	20	20	20	20	20
	Buildup Recommendation***								
50	440	540	640	440	540	640	440	540	640
150	240	340	440	240	340	440	240	340	440
250	40	140	240	40	140	240	50	140	240
350 and above - same as annual recommendation									

* Cation exchange capacity

** 40 pounds K in row is minimum recommendation on dark clay soils.

*** First-year buildup recommendation supplies sufficient nutrient for crop. Second- and third-year recommendations are based on recalculated soil test values.

Commercial Fertilizer Application Methods

More than one commercial fertilizer application method may be required to deliver the kinds and amounts of fertilizers needed to produce the highest crop yields. Several application methods are available, for example:

1. Broadcasting
2. Soil injection
3. Row placement
4. Top-dressing
5. Side-dressing
6. Foliar spraying

BROADCASTING

The **broadcast** method is generally used when large amounts of fertilizer are to be applied at one time. This is also called **bulk application.** Broadcast applications are made by spreading either liquid or dry materials over the entire surface of the area being fertilized. This is typically accomplished by using low pressure spray rigs for liquid fertilizers, and air or fan spreaders for dry materials. (Both of these application methods are shown in Chapter 5, Figures 88, 89, 90, and 91.)

Nutrients supplied by broadcasting include nitrogen, phosphorus, and potassium. Nitrogen is usually broadcast to supply the large amounts required for high corn yields. Phosphorus and potassium fertilizers are broadcast to supply the large amounts required for their immediate buildup in the soil.

Most broadcast applications are followed by plowing or other procedures to work the fertilizer into the soil. This is important for some forms of fertilizer because they can be lost before being used by the crop. (Refer to Chapter 5 - **Fertilizer Selection.**)

SOIL INJECTION

Two forms of nitrogen fertilizer are commonly applied by **soil injection:**

1. Anhydrous ammonia
2. Nitrogen liquid solution under pressure

Descriptions of these nitrogen fertilizer forms and their application methods are provided in Chapter 5 - **Fertilizer Selection.**

ROW PLACEMENT

Many mixed fertilizers are applied at planting time to guarantee the crop a good start. Therefore, fertilizer applied at this time is called **starter fertilizer.**

Often, starter fertilizers are placed in or near each seed row during the planting process. This practice is called **row placement.** Its value depends on several factors including the following:

1. Crop to be grown
2. Location of the fertilizer in relation to the seed
3. Amount and grade of fertilizer used

Row Placement for Different Crops

Crops in the grass family (e.g, corn, wheat, and oats) have difficulty taking up phosphorus during their early growth. Consequently, row placement fertilizers are important to get these crops off to a good start. Other crops using row placement are soybeans and meadow crops (e.g., seeded alfalfa).

The method of row placement varies depending on the crop growth.

Fertilizer Location in Relation to the Seed

Fertilizer placed in the rows is usually applied in small bands. Depending on the plant growth stage, the fertilizer occupies between 1/100 and 1/1,000 of the total root volume. Obviously, such a small volume of fertilizer must be placed where it provides the most benefits for the roots. Since roots do not grow toward fertilizer, fertilizer is placed where the roots will contact it.

A corn plant's **primary root** grows almost straight down. Just a few days after primary root growth begins, a series of *secondary* roots appear along the primary root. These roots grow outward and downward. Since nutrient uptake occurs primarily in the **secondary roots**, place the fertilizer down and to the side of the seed instead of below it (see Figure 95). This method, called **side banding**, places the fertilizer in the path of the secondary roots. For example, in corn and soybean seedings, place the fertilizer about two inches to the side and two inches below the level of the seed. In a legume seeding, place the fertilizer in a band about one to two inches below the seed (see Figure 96).

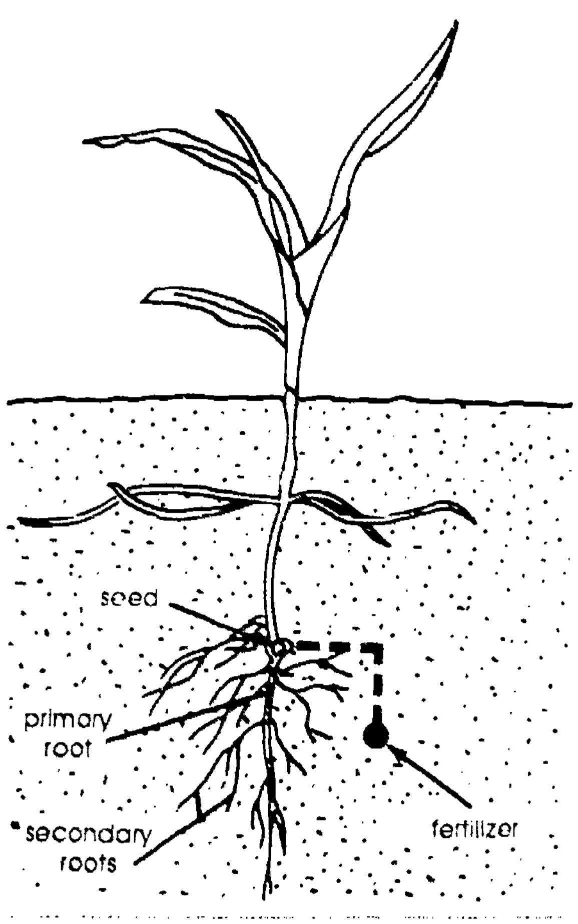
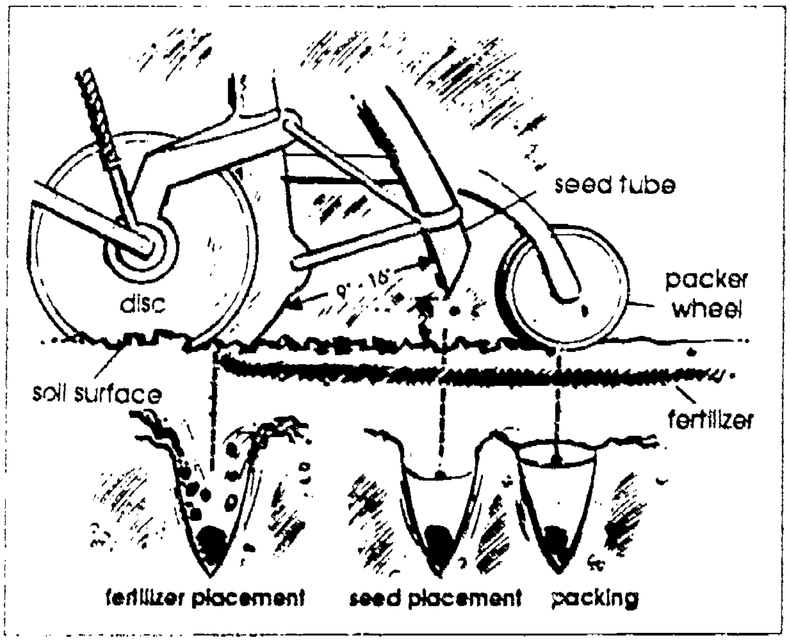


FIG. 95. Side banding places fertilizer in the path of the secondary roots.

FIG. 96. In legume seeding, the fertilizer is placed about one to two inches below the seed.



Since most nitrogen and potassium sources in commercial fertilizers are salts, do not place fertilizer too close to seeds or seedlings (see Figure 97). These salts absorb soil moisture and dry out seeds or seedlings. This causes poor germination or seedling death. Also, when the fertilizer is placed in this position, the secondary roots cannot intercept it.

The crop to be grown and the amount and grade of fertilizer used determine the fertilizer placement in relation to the seed. Following are guidelines for fertilizer placement:

1. *To avoid corn seedling injury:* If row placement is two inches to the side and two inches below the seed, limit a nitrogen and potassium combination to 100 pounds per acre.
2. *To avoid soybean seedling injury:* If row placement is two inches to the side and two inches below the seed, limit a nitrogen and potassium combination to 70 pounds per acre.

TOP-DRESSING

As the term suggests, **top-dressing** is applying fertilizer to the field surface where a crop is growing. Although top-dressing is used mainly to fertilize meadows and pastures, it is also used on winter annual crops such as wheat. The same methods used to broadcast fertilizers prior to planting are used to apply top-dress fertilizer. Top-dress fertilizer is seldom, if ever, plowed under or worked into the soil.

The effectiveness of top-dressing depends on soil conditions and the crop being grown. For example, fertilizers applied on frozen ground can be washed away if a heavy rain occurs before the ground thaws.

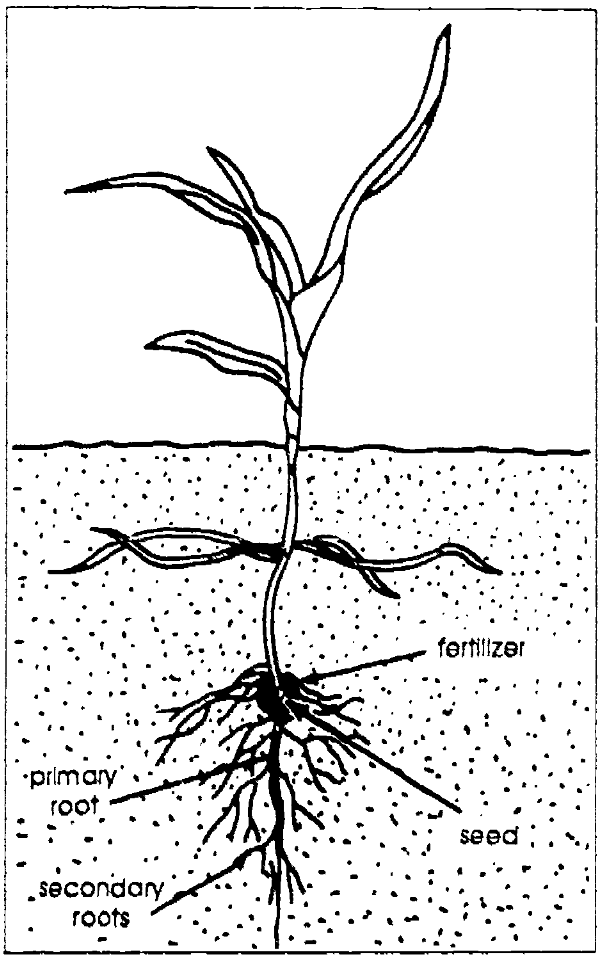


FIG. 97. Incorrect fertilizer placement. The fertilizer is too close to the seed. Salts may draw moisture away from the germinating seed. Also, the secondary roots cannot intercept the fertilizer when it is placed in this position.

SIDE-DRESSING

Side-dressing is the application of additional fertilizer to the sides of the rows after the crop has emerged. It usually supplies nitrogen and is used mainly on corn crops when the plants are six to twelve inches tall. Most side-dressing places the nitrogen fertilizer in bands between corn rows. Depending on the nitrogen source, fertilizer is inserted in the soil to a depth of three to six inches. **Caution:** Deep side-dressing too close to the corn plants can damage the roots and reduce yields.

Some crop producers choose side-dressing rather than broadcasting and plowing under because they can apply nitrogen according to the plant population. For example, if the plant population is low, the amount of extra nutrients can be reduced.

FOLIAR SPRAYING

Foliar spraying is the application of nutrients in solution form to crop plant leaves. This fertilizer application method has limited use because it usually requires special equipment such as a helicopter, airplane, or hi-boy. The major limitations of this method are

1. High application costs
2. The amounts of nitrogen, phosphorus, and potassium absorbed through the leaves' stomata are too small to meet plant needs.

For these reasons, foliar spraying is used mainly to apply micronutrients, such as zinc or manganese. However, this is done only when a micronutrient deficiency is observed in the growing plants. Otherwise, the micronutrient is included in the row placement fertilizer. The Cooperative Extension Service can provide details regarding micronutrient application.

Selecting Fertilizer Application Methods

As previously stated, the method of applying commercial fertilizer depends on several factors. Consider the following when selecting an application method:

1. *Amount of fertilizer to be applied*
    - In row placement, the amount of nitrogen and potassium fertilizer salts (total for both) that can be safely applied must be calculated.
    - Large amounts of a fertilizer may require more than one application method.
2. *Fertilizer form selected* – Losses can occur by improper application of some fertilizer forms.
3. *Crop to be grown* – Different crops respond differently to the amount of fertilizer applied and the application method.

Practical Application

The following exercise should help you select suitable commercial fertilizer application methods. When making your selections, refer to the information presented in Chapters 4 and 5 concerning nutrient sources and fertilizer selection.

Resources

- Pencil and notebook
- *Ohio Agronomy Guide* or similar reference containing fertility information (Contact Cooperative Extension Service)
- Soil test results from a field(s)
- Practical application information from Chapters 4 and 5 of this manual

Procedure

☐ Reproduce the following form in your notebook. Complete a separate form for each field having a soil test report.

Crop to be grown ____________________ Yield goal ______________

Previous crop ____________________ Tons of manure applied ____________

For each ton of properly handled manure with bedding, allow 5 pounds of N, 2 pounds of P, and 5 pounds of K.

	AMOUNT IN POUNDS		
	Nitrogen (N)	**Phosphate (P_2O_5)**	**Potash (K_2O)**
Total amount needed (soil test report)			
Supplying the needed nutrients from manure (optional) - amount of each nutrient			
Row placement: Ratio ___ ___ ___ Grade ___ ___ ___ Total pounds per acre ____________ Amount of each nutrient supplied ________ ____________________			
Supplying remaining needs by broadcasting, soil injection, side-dressing, or top-dressing ____________________			
Form of material ____________ % nutients ____________ Application method(s) ____________ ____________________ Application time(s) ____________ ____________________ Amount of each nutrient supplied ____________________			
Total amount supplied by manure, row placement, other methods (Should equal or nearly equal amount needed.)			

KEY TERMS

■ Following is a list of important terms found in this chapter. Can you define them?

- annual buildup
- broadcasting
- bulk application
- foliar spraying
- gradual buildup
- immediate buildup
- primary roots
- quick buildup
- row placement
- salts
- secondary roots
- side banding
- side-dressing
- soil injection
- starter fertilizer

Chapter 7

Lime Selection and Application

Introduction

Previous chapters discussed the importance of proper fertilizer selection and application. However, before these fertilizers are applied, a **liming program** must be in operation. Liming corrects **soil acidity** – a serious crop production limitation. If the soil is too acid, the crop cannot efficiently use the applied fertilizer. Therefore, the proper use of both lime and fertilizer is necessary for high crop yields.

OBJECTIVES

After studying this unit, you should be able to do the following:

- Describe the importance of an adequate liming program for crop production.
- Describe how lime is lost from the soil.
- Select liming material based upon fineness, calcium-magnesium content, and comparative costs of materials.
- Select liming material application methods and times.

SCIENCE CONCEPTS

The following science concepts are covered in this chapter:

- Soil acidity is determined by the number of hydrogen and aluminum ions occupying sites on the clay and organic matter particles.
- Calcium and magnesium ions provided by liming materials can displace hydrogen and aluminum ions in the soil and raise soil pH.

- The amount of bacteria present in soil is influenced by soil pH.
- Cations provided by liming materials can reduce toxic concentrations of elements such as iron, aluminum, or manganese.
- Lime alters the availability of plant nutrients.
- The rate at which liming materials react with the soil is proportional to the amount of surface area exposed on the liming material.
- Different liming materials have different degrees of acid-neutralizing capability.
- The relative values of acid-neutralizing compounds can be determined mathematically.

Importance of Correcting Soil Acidity

Interpreting Soil Test Reports in Chapter 3 discussed the importance of correcting soil acidity. The discussion is continued in this chapter because correcting soil acidity is an essential practice for obtaining maximum crop yields.

LIMING NEUTRALIZES ACID SOILS

Lime contains calcium and magnesium. If present in the soil in adequate amounts, these two nutrients occupy most of the exchange sites of the soil's clay and organic matter particles (see Chapter 2). In an acid soil, these exchange sites are occupied by hydrogen (H^+) and aluminum (Al^+) ions. These ions combine with other ions in the soil to form acid compounds. Thus, when lime is applied, the ions of calcium (Ca^{++}) and magnesium (Mg^{++}) replace the acid-causing ions.

LIMING SUPPLIES CALCIUM AND MAGNESIUM

Calcium and magnesium are classified as **secondary plant nutrients**. In other words, most crops use more of the **primary nutrients** (nitrogen, phosphorus, and potassium) than they use of calcium and magnesium. However, if calcium and magnesium are not supplied in adequate amounts, crop growth can be seriously affected. (Review Chapter 1 for information regarding crop plant calcium and magnesium requirements.) Table 35 provides the amounts of calcium and magnesium used by various field crops.

TABLE 35. Approximate amounts of calcium and magnesium in harvested portions of various field crops

Crop	Yield	Calcium (Pounds/Acre)	Magnesium (Pounds/Acre)
Corn (grain)	150 bushels	12	10
Soybeans (grain)	50 bushels	9	9
Wheat (grain)	60 bushels	2	8
Oats (grain)	100 bushels	3	6
Alfalfa	6 tons	168	32
Timothy	2.5 tons	10	5
Bluegrass	2 tons	18	6
Sugar beets	30 tons	66	48

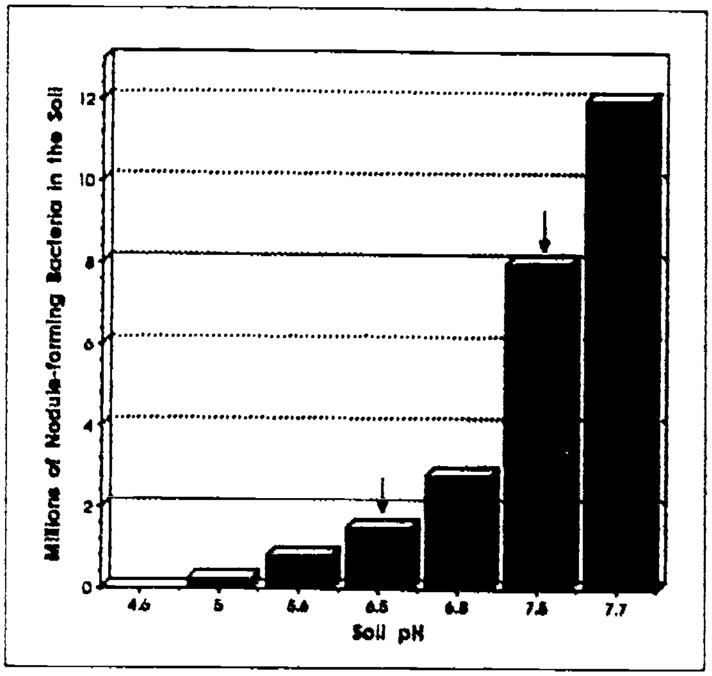


FIG. 98. The soil pH affects the number of nitrogen-fixing bacteria in the soil. For example, a soil with a pH of 7.5 has approximately six times the nitrogen-fixing bacteria of a soil with a pH of 6.5.

LIMING INCREASES SOIL BACTERIAL ACTIVITY

Liming acid soils also helps bacteria to grow and increase in number. One important soil bacteria species is the nodule-forming bacteria (*rhizobia*) of legume plants. Soil bacteria decompose organic matter which, in turn, releases nutrients such as nitrogen and phosphorus (review Chapter 4). As Figure 98 shows, the number of these bacteria present in the soil more than triples when the soil pH is increased from 5.6 to 7.0. Soil tests show that liming some acid soils can increase the amount of available nitrogen and phosphorus.

LIMING INCREASES SOIL TILTH

Limed soil grows crops superior to those grown in an acid soil. When these superior crops are plowed under and mixed with the soil, they are decomposed by soil bacteria. This decomposition improves the soil structure and results in improved soil tilth. In turn, improved soil tilth produces an increase in soil aeration (exchange of oxygen for carbon dioxide in the soil atmosphere). Proper soil aeration allows plant roots to absorb plant nutrients (e.g., potassium) at rates producing maximum crop yields.

LIMING REDUCES TOXIC SUBSTANCES

Elements such as iron, manganese, and aluminum can be harmful to plants if present in high concentrations. Liming helps to reduce the amounts of these toxic (poisonous) substances in the soil. For example, suppose a test shows that a soil with a pH of 5.4 has 50 to 60 pounds of soluble aluminum per acre. Liming the soil to raise this pH to 6 would reduce the amount of soluble aluminum to 1 to 2 pounds per acre.

LIMING INCREASES PLANT NUTRIENT AVAILABILITY

Liming acid soils increases the availability of many plant nutrients (e.g., nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, and molybdenum). This improved soil condition increases crop yields. In turn, greater crop yields usually produce greater profits. On the other hand, liming to raise the pH to above 7.0 can decrease the availability of some micronutrients and phosphorus. For example, phosphorus has maximum availability between 6.5 and 7.0 pH.

How Lime Is Lost from the Soil

After an acid soil is limed to a desirable pH range of 6.5 to 7.0, periodic reliming is necessary because lime can be lost from soil through the following (see Figure 99):

1. Leaching
2. Soil erosion
3. Crop removal
4. Application of acid-forming fertilizers

The amount of lime lost from a soil varies depending on soil conditions, kind of fertilizer applied, and the amount of rainfall. For example, in a study conducted in Ohio the crop rotation was corn, wheat, and red clover. These crops were grown on a soil with 4 percent slope. The rainfall was average. Under these conditions the loss of agricultural ground limestone per acre per year was 651 pounds. These losses were due to the following:

1. Crop removal - 91 pounds
2. Erosion - 280 pounds
3. Leaching - 280 pounds

LEACHING

Leaching results when water drains through the soil. This water moves the nutrients away from the plant root zone (see Figure 99). Water moving through a silt loam soil can leach up to 90 pounds of calcium and 20 pounds of magnesium per acre per year. Generally, a silt loam soil needs about 270 pounds of agricultural ground limestone per acre each year to replace the lime lost to leaching.

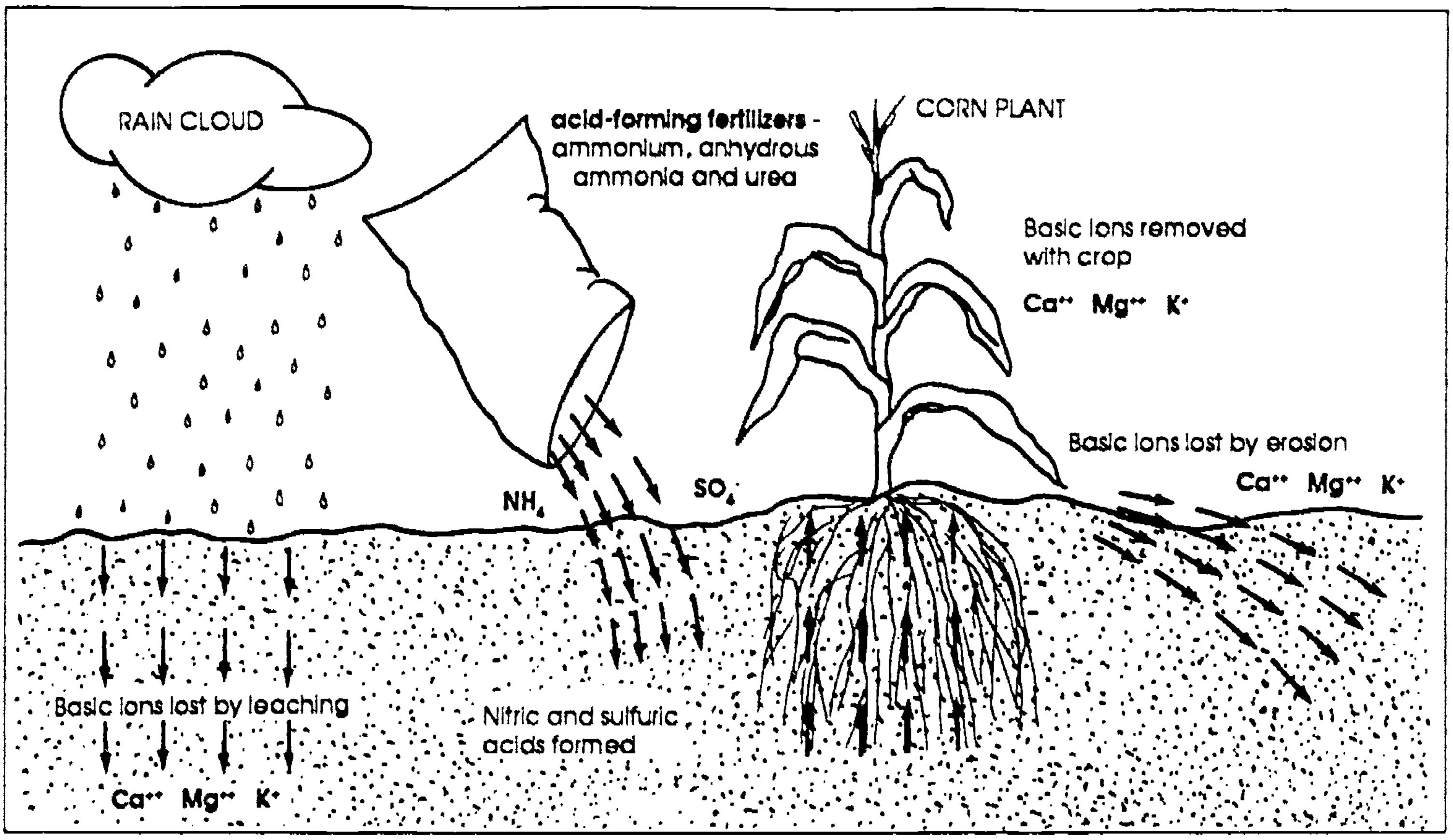


FIG. 99. Soils become acid when the basic elements, such as calcium, magnesium, and potassium are removed from the soil. For example, large amounts of rain cause the hydrogen in the rain water to replace the basic ions in the soil particles. These basic ions then leach out of the soil. Hydrogen ions are also formed when acid-forming nitrogen fertilizers react with the soil. These hydrogen ions replace the basic ions on the soil particles. If nitrates leach out of the soil, so do the basic ions Finally, basic ions can also be removed by crops and soil erosion.

SOIL EROSION

Soil erosion is soil loss sometimes caused by water movement on the soil's surface (see Figure 100). Erosion also causes nutrient loss. Soils with a 4 percent slope can lose up to 80 pounds of calcium and 30 pounds of magnesium per acre per year. Generally, soils subject to erosion require 275 pounds of agricultural ground limestone per acre to replace lime lost through erosion.

FIG. 100. Water movement on the soil's surface can remove large amounts of fertile soil.

CROP REMOVAL

As stated earlier, crops remove considerable amounts of calcium and magnesium from the soil. The amount of agricultural ground limestone required to replace these losses varies. It is estimated that producing a one-ton alfalfa crop requires 500 to 700 pounds of agricultural ground limestone per acre per year to replace the amounts of nutrients used by that crop.

ACID-FORMING FERTILIZERS

Most nitrogen fertilizers increase soil acidity. These fertilizers are ammonium sulfate, ammonium nitrate, urea, anhydrous ammonia, nitrogen solutions (liquids), and ammonium phosphate. Nitrate fertilizers combined with sodium (sodium nitrate), potassium (potassium nitrate) and calcium (calcium nitrate) do not increase acidity. In fact, these fertilizers decrease acidity.

Phosphorus and potassium fertilizers, such as superphosphate and muriate of potash, have little effect on soil acidity.

How Nitrogen Fertilizers Cause Soil Acidity

Nitrogen fertilizer causes soil acidity in a number of ways. For example, ammonium nitrogen fertilizer is oxidized by soil bacteria and forms nitric acid. These bacteria also oxidize urea to form ammonium carbonate. In turn, ammonium carbonate oxidizes and forms nitric acid. Nitric acid is also produced by ammonium sulfate. In addition, the sulfate compound in ammonium sulfate forms sulfuric acid (see Figure 99).

Lime Is Required to Neutralize Acidity

Lime is required to neutralize the acid formed by nitrogen fertilizers. For example, ammonium nitrogen fertilizer sources (except ammonium sulfate) require about 2.5 pounds of agricultural ground limestone to neutralize the acid formed from 1 pound of fertilizer. Ammonium sulfate requires about 7 pounds of agricultural ground limestone to neutralize the acid it forms from 1 pound of fertilizer.

Amount of Lime to Apply

Soil testing laboratories typically provide recommendations for the amount of lime to apply. These recommendations are determined by the following:

1. Soil's lime index
2. Plowing depth
3. Lime applications during the last two years
4. Crops to be grown
5. Soil type
6. Use of agricultural ground limestone with a total neutralizing power (TNP) of 90 or more

For example, consider a field with the following characteristics:

1. Soil test index of 67
2. Planned plowing depth of 7 inches
3. No lime applications during the last two years
4. Next crop to be grown is alfalfa

Using this information, the soil testing laboratory determines that two tons of agricultural ground limestone should be applied per acre. If any changes are made in crop production plans, adjustments in the application amount must also be made.

LIME TEST INDEX

The **lime test index** is a two-digit number calculated by the soil testing laboratory. Although this number is used primarily by the laboratory, a crop producer can also use it to determine the lime required to obtain different pH levels. The lime test index was discussed in detail in Chapter 3 (see Table 11 on page 55).

PLOWING DEPTH

As shown in Table 36, the plowing depth helps to determine the amount of lime to apply. Eight inches is the **base** or recommended plowing depth for incorporating lime. So, if you plan a shallower or deeper plowing depth, adjust the lime application as recommended in this table.

A deep plowing depth involves more soil than a shallow plowing depth. Consequently, more lime is required for deep plowing than for shallow plowing (see Figure 101 on page 150). For example, if three tons of lime are needed for an eight-inch plowing depth, less than three tons are needed for a six-inch plowing depth. As shown in Table 36, the amount of lime required for a six-inch plowing depth is calculated by multiplying 0.75 by 3 tons; this equals 2.25 tons. Likewise, if the plowing depth is 10 inches, multiply 1.25 by 3 tons. These calculations show that 3.75 tons of lime are needed for a 10-inch plowing depth.

TABLE 36. Adjustments in the amount of lime to apply for a specific plowing depth

Plowing Depth (inches)	Multiplying Factor
3	0.38
6	0.75
7	0.88
8	**BASE** 1.00
9	1.13
10	1.25
11	1.38
12	1.50

FIG. 101. The plowing depth determines how much lime to apply. Deep plowing requires more lime than shallow plowing.

PREVIOUS LIME APPLICATIONS

Since most liming materials do not react immediately in the soil, allowance is made for lime applied in the previous two years. This allowance is known as **lime credit**. Lime credit assumes that 50 percent of the lime applied in the last two years is still active. If coarse material is used, less lime is available at one time; but it continues to react in the soil for a longer time period.

CROPS TO BE GROWN

Figure 53 in Chapter 3 (page 54) shows the tolerance of various crops to soil acidity. For example, if alfalfa is the crop to be grown, a pH of 7 is needed. However, for grain crops such as corn, a pH as low as 5.5 may be satisfactory.

SOIL TYPE

The soil's lime requirement is affected by several conditions, such as soil texture, clay type, pH level, organic matter percentage, and aluminum content.

As Table 37 shows, the lime requirement increases as the soil's particle fineness increases. This is due to the soil's cation exchange capacity. For example, clay has a

TABLE 37. The amount of agricultural ground limestone required to raise the pH on various Ohio soils

Soil Type (Soil Name and Texture)	Region in Ohio	TONS OF LIME REQUIRED From pH 4.5 to 5	From pH 5 to 6	From pH 6 to 7	From pH 4.5 to 7
Plainfield sand	Northwest	—	0.80	1.00	1.80
Canfield silt loam	Central	—	1.30	2.15	3.45
Clermont silt loam	Southwest	0.80	1.10	1.75	3.65
Crosly silt loam	West central	1.00	1.85	4.40	7.25
Miami silt loam	Southwest	—	1.35	2.65	4.00
Muskingum silt loam	East	1.20	1.40	2.15	4.75
Plainfield loamy sand	North central	0.60	1.50	2.35	4.45
Mahoning silty clay loam	Northeast	1.20	2.95	—	4.15
Trumbull silty clay loam	Northeast	1.00	2.00	4.15	7.15
Vincent silty clay loam	Southeast	1.75	1.75	2.00	5.50
Upshur clay	Southeast	—	1.70	2.55	4.25
Mahoning silty clay loam	Northeast	—	6.00	—	—

higher cation exchange capacity than silt; therefore, clay requires more liming material to neutralize acid. Likewise, silt has a higher cation exchange capacity than sand; so silt requires more lime to neutralize acid. Therefore, if three different soils have the same pH level, the one with the highest cation exchange capacity has more total acidity to neutralize and requires more liming material. The figures in Table 37 show that Plainfield sand requires much less liming material to reach a pH of 7 than Vincent silty clay loam requires to reach the same pH.

Liming Material Selection

As noted earlier, the soil test report from the Research-Extension Analytical Laboratory recommended the use of agricultural ground limestone with a 90+ total neutralizing power. In general, this is the best material for many crop growing situations. However, if several liming materials are available, it is important to know the characteristics of these different materials. When selecting liming materials, remember they are applied to correct soil acidity over a short time period and to supply the correct proportions of calcium and magnesium. Consider the following items when selecting your liming material:

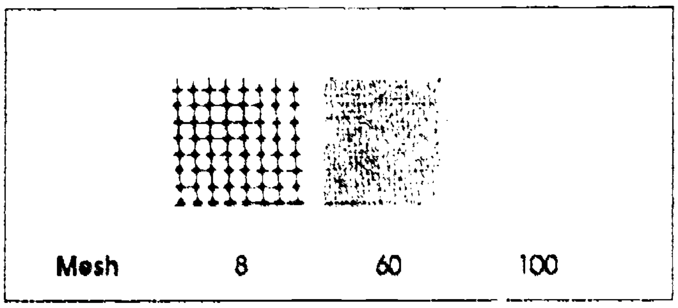
1. Material fineness
2. Total neutralizing power
3. Material grade
4. Moisture content
5. Material cost

FINENESS

The Ohio Lime Law specifies that **liming material fineness** must be stated on the material's delivery invoice. Liming material fineness is determined by the amount of material that can pass through screens of different sizes. Screen sizes are determined by the number of openings per linear inch of mesh in the screen. For example, an eight-mesh screen has eight openings per inch; a 100-mesh screen has one hundred openings per inch (see Figure 102). Therefore, the more material that can pass through a screen, the finer the material. Common screen sizes are 8, 20, 60 and 100 mesh.

A material is given a **fineness efficiency rating** determined by that material's ability to pass through a particular screen size. Table 38 provides examples of fineness efficiency ratings. Efficiency ratings are assigned because finer lime provides more limestone surface area in the soil. Figure 103 illustrates this concept. For example, a one-inch cube has 6 square inches of surface area. If this one-inch cube is divided into quarter-inch cubes, the total surface area is now 96 square inches or 16 times that of the one-inch cube. The more surface area exposed, the faster a chemical reaction takes place. Therefore, fine liming materials work faster in the soil than coarse materials (see Figure 104).

FIG. 102. Eight-, sixty-, and one hundred-mesh screens.



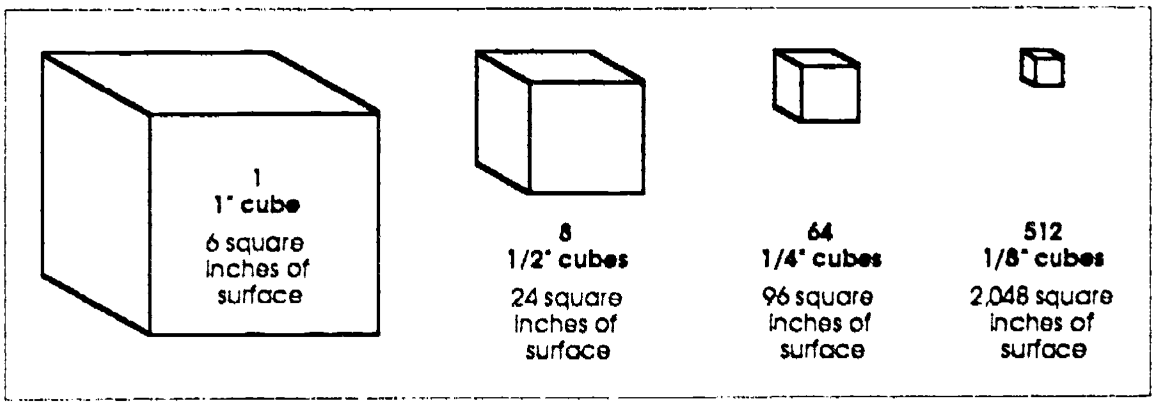


FIG. 103. When a one-inch cube is divided into half-inch cubes, the surface area is increased four times. Consequently, when the half-inch cubes are divided into quarter-inch cubes, the surface area is increased 16 times over that of the one-inch cube. In other words, the smaller the cubes, the more surface area exposed in the same volume of material.

TABLE 38. Fineness efficiency ratings for liming materials passing through various screen sizes

Fineness	Rating
Material passing a 60-mesh screen	100
Material passing a 20-mesh, but not a 60-mesh screen	60
Material passing an 8-mesh, but not a 20-mesh screen	20

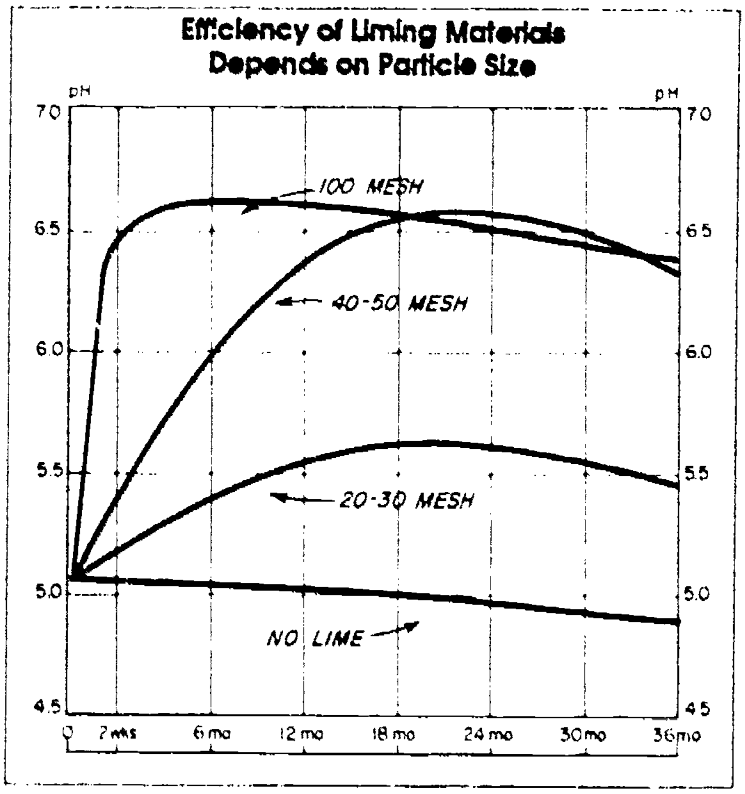


FIG. 104. Efficiency of liming materials varies with particle size or fineness. The finer the material, the faster it reacts in the soil. Reaction time also varies with type of soil and liming material.
(Courtesy Plant Food Review)

TOTAL NEUTRALIZING POWER (TNP)

Total neutralizing power indicates a liming material's capacity to neutralize soil acids. It gives a liming material's strength based on **calcium carbonate content**. Pure calcium carbonate has a total neutralizing power of 100. Therefore, when comparing liming materials, assume a material's neutralizing power number is equivalent to its calcium carbonate content.

A given weight of magnesium carbonate corrects 1.2 times as much soil acidity as the same weight of calcium carbonate because these materials have different molecular weights. **Dolomitic limestones** contain magnesium; therefore, they have a higher neutralizing power than **calcitic limestones** which contain calcium.

Hydrated limes also have a high neutralizing power (130 to 160) because the calcium or magnesium source is calcium oxide or magnesium oxide, respectively. By weight, these oxides contain more calcium or magnesium than carbonates.

When the total neutralizing power of a liming material is less than 90, make adjustments in the amount of material applied to offset its lower neutralizing power (see Table 39 on page 154).

LIMING MATERIAL GRADES

The Ohio Lime Law specifies that the **liming material grade** must be shown on the material's invoice. A wide variation in liming material fineness is permitted within each market grade (see Table 39).

TABLE 39. Equivalent amounts of liming materials (based on TNP and fineness)

		Fineness % Passing Mesh size				Pounds to Equal One Ton of Agricultural Ground Limestone – 90+ TNP	% of Agricultural Ground Limestone to Apply
Grade	**TNP**	**100**	**60**	**20**	**8**		
AGRICULTURAL LIMESTONES AND/OR SLAG (air cooled)							
Hydrated	160+	90	95	98	100	1,000	50
Hydrated	130 - 140	90	95	98	100	1,200	60
Ag-superfine	90+	80	95	100	100	1,600	80
	80 - 89	80	95	100	100	1,800	90
Ag-pulverized	90+	60	70	95	100	1,700	85
	80 - 89	60	70	95	100	1,900	95
Ag-ground (base)	90+	40	50	70	95	2,000	100
	80 - 89	40	50	70	95	2,300	115
Ag-fine meal	90+	30	40	60	85	2,500	125
	80 - 89	30	40	60	85	2,800	140
Ag-coarse meal	90+	20	30	50	80	2,900	145
	80 to 89	20	30	50	80	3,200	160
Ag-fine screenings	90+	10	20	45	80	3,400	170
	80 - 89	10	20	45	80	3,800	190
Ag-coarse screenings	90+	5	15	40	80	4,000	190
	80 - 89	5	15	40	80	4,300	215
AGRICULTURAL GRANULATED SLAG (water cooled)							
Ag-granulated slag	90+	10	15	60	95	2,000	100
	80 - 89	10	15	60	95	2,300	115

(*Courtesy* Ohio Agronomy Guide)

Liming material grades are commonly classified according to the chemical forms of the calcium and magnesium they contain – that is, whether they are **oxides, hydroxides, or carbonates.**

Oxide of Lime

Oxide of lime is commonly known as **burned lime or quicklime.** This material is finely ground and usually marketed in bags. Although oxide of lime has a high neutralizing power, it is more caustic than limestone and disagreeable to handle.

Hydroxide of Lime

Hydroxide of lime, commonly known as **hydrated lime,** has a high neutralizing power. This material – finely ground and sold in bags – is produced by adding water to burned lime. This process is called **skaking** and accounts for the term **skaked lime,** which is also used to refer to hydrated lime.

Carbonate of Lime

The remainder of the materials listed in the following section contain calcium or magnesium in the **carbonate** form. Pulverized or ground limestone is the most common material. Ground limestone grades are determined by material fineness, not by total neutralizing power (see Table 39).

CALCITE AND DOLOMITE LIMESTONE

As stated earlier in this chapter, limestone carries two important elements: calcium and magnesium. If a limestone carries mainly calcium, it is **calcite** and consists mostly of calcium carbonate. However, if the limestone carries both calcium and magnesium, it is **dolomite** and consists mostly of calcium magnesium carbonate. The soil's calcium-magnesium ratio determines whether a calcitic or dolomitic limestone must be applied. (See Chapter 3 for ratio determination methods.) Actually, calcitic and dolomitic limestones are not true limestone grades, but it is important to know the sources of these elements when correcting some acid soil conditions.

Limestone grades, according to the Ohio Lime Law, are primarily classified according to material fineness. The limestone grades appearing in Table 39 are listed in order of material fineness (beginning with the finest). Table 39 also shows that a difference in neutralizing power may be found within the same grade. Following are some common limestone grades and their descriptions:

1. *Agricultural superfine* - This superfine grade is used when a rapid change in pH is desired and cost is not a critical factor. Generally, the high cost of agricultural superfine is prohibitive, even though it requires 20 percent less than the less expensive agricultural ground limestone to produce the same results.
2. *Agricultural pulverized* - This material, although similar to agricultural superfine, is less fine and usually less expensive. However, it is more expensive than agricultural ground.
3. *Agricultural ground* - This grade accounts for a large percentage of purchased liming materials. The prices of other liming materials are based on the price of agricultural ground.
4. *Agricultural meal* - This material is coarser than agricultural ground. Consequently, more meal must be applied to produce the same results in the same time period as agricultural ground. Although more agricultural meal is required to do the job, a cost comparison may show it is equal to the cost of using agricultural ground limestone. Agricultural meal is available in two grades determined according to material fineness: *fine* and *coarse*.
5. *Agricultural screening* - To produce the same results, twice as much agricultural screening is needed as agricultural ground limestone. This can result in higher delivery and application costs. To be competitive, the cost of agricultural screening should be no more than half the cost of agricultural ground limestone. As with agricultural meal, two grades are available: *fine* and *coarse*.

6. ***Agricultural granulated slag*** - This material is a byproduct of the steel industry. There are two forms of slag: *air cooled* and *water cooled*. Table 39 gives the properties of water-cooled slag. Most slags vary in water content. The water content depends on the time elapsed since the slags were water cooled and the amount of recent rainfall on slag stockpiles. Slags are applied in the same amounts as agricultural ground limestone.
7. ***Marl*** - This material contains shell fragments and calcium carbonate precipitated in ponds. Due to its high water content, it is sold by the cubic yard rather than by the ton.
8. ***Gypsum*** - This material does not correct soil acidity. However, since its chemical form is calcium sulfate, it does add calcium and sulfur to the soil.

MOISTURE CONTENT

The Ohio Lime Law does not require that liming material invoices state the material's **moisture content**. Nor is there any provision for checking the material's moisture content. However, if a liming material contains more than 5 percent moisture, make an adjustment in the application amount (see Table 40).

Slag can be spread at a higher moisture content than limestone. Usually, limestone must contain less than 8 percent moisture in order to promote uniform spreading of the material. However, some samples of granulated slag containing 40 percent moisture are just as spreadable as limestone.

COMPARING MATERIAL COSTS

Use the following procedure to compare costs of two different limestone grades (e.g., agricultural ground and agriculture meal):

1. First, use the information presented in Table 39 to determine their equivalent weights. For example, determine the pounds of agricultural meal required to equal 2,000 pounds of agricultural ground if their total neutralizing powers are the same. The answer appears in column seven: 2,500 pounds agricultural meal equal 2,000 pounds of agricultural ground.

TABLE 40. Moisture correction table for liming materials

Moisture Content (%)	Increase Material Weight by This Percent	Moisture Rating
0 to 5	no correction	100
5 to 10	5.3	95
10 to 15	11.1	90
15 to 20	17.7	85
20 to 25	25.0	80
25 to 30	33.2	75
30 to 35	42.7	70
35 to 40	53.7	65
40 to 45	62.7	60
45 to 50	81.0	55

2. Next, consider the delivery and application cost per ton for the two materials. For example:
    - The delivery and application cost for agricultural ground is $12.00 per ton.
    - The delivery and application cost of agricultural meal is $10.00 per ton.
3. Now use the following formula to calculate the *competitive* costs of agricultural meal and agricultural ground:

$$\frac{\textbf{Agricultural ground as the base is 2,000 pounds} \quad \times \quad \textbf{Cost per ton of agricultural ground}}{\textbf{Equivalent amount of agricultural meal to equal 2,000 pounds of agricultural ground}}$$

$$\frac{2{,}000 \times \$12.00}{2{,}500} = \$9.60$$

Therefore, to be competitive with agricultural ground at $12.00 per ton, agricultural meal must cost $9.60 per ton rather than $10.00.

Liming Material Application

When applying liming materials, consider the following factors:

1. Application time
2. Application method

Since most crop producers buy their liming materials from a supplier, the application methods are often determined by the equipment the supplier has. These suppliers are usually equipped to spread the liming material on the producer's fields. Therefore, many times the crop producer chooses only the application time.

APPLICATION TIME

Liming materials can be applied at any time of year and at any point in the cropping sequence. However, consider the following when determining a liming material application time:

1. It is preferable to apply liming materials before growing the crop with the highest pH requirement. This is usually a legume crop, such as alfalfa.
2. Liming materials are usually applied at the time of year most suitable to the crop producer and the supplier. Usually this is in late summer or autumn when the soil is dry and firm and able to support heavy spreading equipment.

3. If crop producers wait until spring to apply liming materials, they run the risk of encountering wet, soft soil. These soil conditions result in mired spreading equipment and soil compaction. Sometimes these conditions completely prevent liming material application.

4. If liming materials are applied in summer or fall, the lime is able to dissolve and react with the soil during the winter. When the following growing season arrives, the soil is ready for the crops.

5. If five or more tons of lime are needed per acre, make two applications: half before plowing and half before soil finishing. This procedure promotes thorough mixing of the lime and soil. For best results, apply liming material at least six months before a legume seeding.

6. Established hay or pasture fields can be limed anytime during the year if soil conditions are suitable. During the growing season, it is preferable to apply the liming material after harvesting the hay crop, and when pasture plants are short from grazing or clipping.

APPLICATION METHOD

Apply liming material evenly: uneven coverage or distribution results in uneven crop growth. Following is a list of some typical liming material application equipment:

1. ***Twin fan spreader*** - As the name implies, two fans spread the liming material: one fan runs clockwise and the other runs counterclockwise (see Figure 105). A fan spreader provides adequate material distribution; however, if it is windy, some material may blow away.

2. ***Hood spreader*** - This spreader places the material close to the soil surface (see Figure 106). During windy conditions, a hood spreader allows less material drift than a fan spreader.

3. ***Tube spreader*** - This spreader delivers an even amount of lime to tubes positioned on the spreader (see Figure 107). These tubes then place the liming material close to the soil in an action similar to that of an auger.

In conclusion, remember that an adequate liming program is the foundation of good crop production. If you cannot afford to buy all the liming and fertilizing materials recommended by soil tests, *buy the liming materials first.* Liming material application corrects the soil pH and makes nutrients more available to plants. This creates a better environment for plant roots and produces high crop yields.

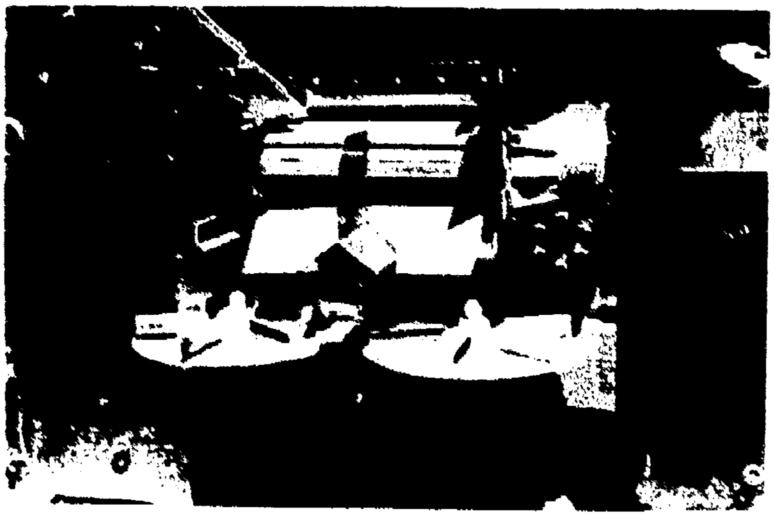


FIG. 105. The fans on this twin-fan spreader run in different directions: one clockwise and the other counterclockwise.

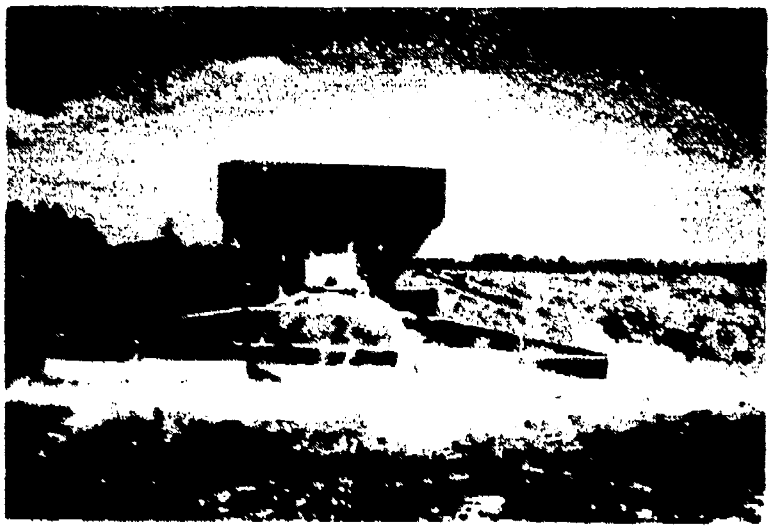


FIG. 106. This hood spreader places liming material close to the soil's surface.

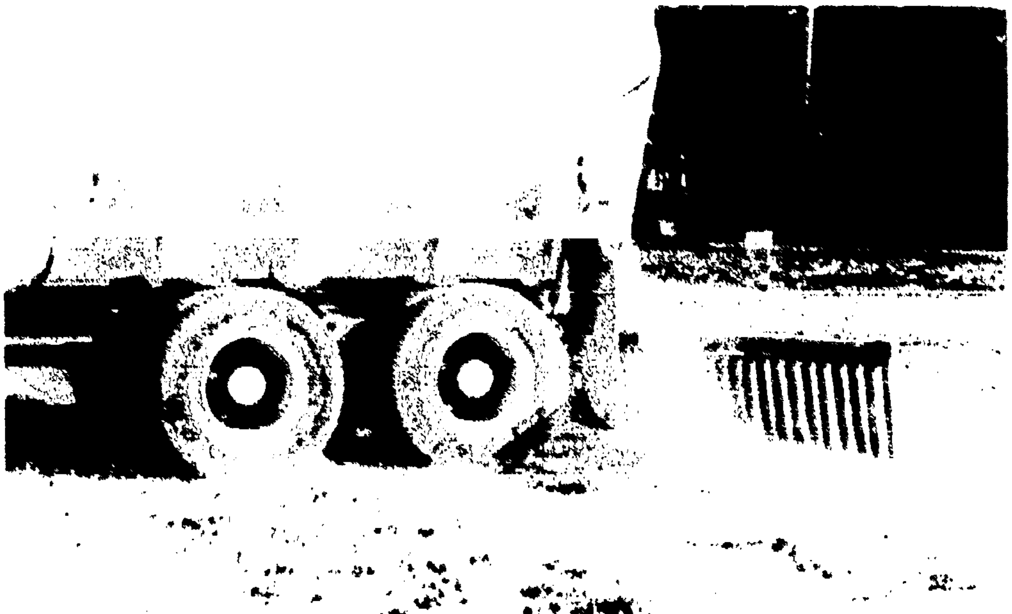


FIG. 107. This tube spreader evenly places the liming material close to the soil's surface. *(Courtesy Ebberts Field Seeds, Inc., Covington, Ohio)*

Practical Application

The following exercises or activities will help you select and apply the most suitable liming material for field crop production. Check the box as each item is completed.

1. Take a class field trip to a local lime supplier.

   - ☐ Obtain samples of each liming material.
   - ☐ Determine the cost per ton of each liming material.
   - ☐ Obtain information from supplier regarding magnesium and calcium content.
   - ☐ If possible, ask supplier to demonstrate spreading equipment.

2. Determine the fineness efficiency rating of liming materials.

   Resources
   - One or two lime grade samples
   - Screens (8-, 20-, and 60-mesh)
   - Pencil and notebook
   - Scales
   - Several paper bags or similar containers
   - Calculator (optional)

   Procedure
   - ☐ Weigh a one- or two-pound sample of each lime grade.
   - ☐ Screen each material (grade) through each of the three screens (8-, 20-, and 60-mesh).
   - ☐ Weigh each material passing through screens.
   - ☐ Record each weight in following chart.
   - ☐ Calculate the fineness efficiency rating.
   - ☐ Record the information on the following form.

Name or Grade of Liming Material	Cost/ Ton	Weight of Sample	Material through 60-mesh	Material through 20-mesh	Material through 8-mesh	Fineness Efficiency Rating
			(weight %)	(weight %)	(weight %)	

Practical Application (continued)

3. Compare cost of two or more liming materials using agricultural ground limestone as the base.

Resources

- Pencil and notebook
- Cost per ton of each liming material
- Calculator (optional)

Procedure

- ☐ Multiply the cost per ton of agricultural ground limestone by 2,000 (pounds per ton)
- ☐ Divide by the equivalent weight of another liming material found in Table 39 on page 154.
- ☐ Compare answer with material cost.
- ☐ Record information on the following form.

Liming Material	**Fineness Efficiency Rating**	**Pounds to Equal One Pound Agricultural Ground**	**TNP**	**Cost of Material**	**Cost/Ton to Equal Cost of Agricultural Ground**
Agricultural Ground Limestone					
Material #1					
Material #2					
Material #3					

KEY TERMS

■ Following is a list of important terms found in this chapter. Can you define them?

agricultural granulated slag
agricultural ground
agricultural meal
agricultural pulverized
agricultural screening
agricultural superfine
base plowing depth
burned lime
calcite
calcitic limestone
calcium carbonate content
carbonate
carbonate of lime
dolomite
dolomitic limestone
fineness efficiency rating
gypsum
hood spreader
hydrated lime (hydroxide of lime)
hydroxide
leaching
lime credit
lime test index
liming material fineness
liming material grade
liming program
marl
moisture content
Ohio Lime Law
oxide
oxide of lime
primary nutrients
quicklime
secondary plant nutrients
soil acidity
skaked lime
skaking
soil erosion
soil tilth
total neutralizing power (TNP)
toxic
tube spreader
twin fan spreader

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Suggested Readings

Agronomy Guide. Columbus, OH: Ohio Cooperative Extension Service, The Ohio State University (current issue).

Aldrich, S. R., et.al. *Modern Corn Production,* 3rd edition. Champaign, IL: A & L Publications, 1986.

Berger, K. C. *Be Your Own Corn Doctor.* Washington, DC: The Fertilizer Institute. (This pamphlet has color prints of nutrient deficiency symptoms or hunger signs of corn leaves and developed ears.).

Brady, Nyle C. *The Nature and Property of Soils.* New York, NY: MacMillan Publishing Company, Inc., 1974.

The Effects of Soils and Fertilizers on Human and Animal Nutrition. Bulletin 378. Washington, DC: Agricultural Research and Soil Conservation Service, USDA and Cornell University, 1975.

The Fertilizer Handbook. Washington, DC: The Fertilizer Institute, 1972.

Fertilizer Management for Today's Tillage Systems. Atlanta, GA: Potash and Phosphate Institute, 1988.

How to Take a Good Soil Sample. Leaflet 168. Columbus, OH: Ohio Cooperative Extension Service, The Ohio State University.

Moving Toward MEY Corn. Atlanta, GA: Potash and Phosphate Institute, 1988.

Our Land and Its Care. Washington, DC: The Fertilizer Institute.

Soil Fertility Manual. Atlanta, GA: Potash and Phosphate Institute, 1987.

Soils Handbook. Lexington, KY: Cooperative Extension Service, University of Kentucky, 1970.

Audiovisuals

Alfalfa - a Cash Crop. Potash Institute of North America, 1649 Tullie Circle, NE, Atlanta, GA 30329. (This slide set is available on a ten-day loan basis.)

Corn - Grow Top Profits. Potash Institute of North America, 1649 Tullie Circle, NE, Atlanta, GA 30329. (This slide set is available on a ten-day loan basis.)

How to Take a Soil Sample. (10 slides) The Fertilizer Institute, 1015 18th Street, NW, Washington, DC 20036.

Audiovisuals *(continued)*

Liming Ohio Soils. (73 slides) Columbus, OH: Ohio Agricultural Education Curriculum Materials Service, The Ohio State University, 1984.

Nutrient Deficiency Symptoms on Plants. (slide set) The Fertilizer Institute, 1015 18th Street, NW, Washington, DC. 20036. (A catalog describing the nutrient deficiencies shown in each slide can be obtained from this address.)

Soybeans - Fertilize Them. Potash Institute of North America. 1649 Tullie Circle, NE, Atlanta, GA 30329. (This slide set is available on a ten-day loan basis.)