OKLAHOMA
SOIL FERTILITY
HANDBOOK

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FOREWORD

The first edition of the Oklahoma Soil Fertility Handbook was published in 1977. Many of the basic concepts and information regarding general soil fertility remain unchanged, or only slightly changed over time. The second edition was published in 1993, the fourth edition in 1997, and the fifth edition in 2000. We are grateful to Drs. Gordon Johnson, Billy B. Tucker, Robert L. Westerman, James H. Stiegler, Lawrence G. Morrill, Raymond C. Ward, Earl Allen, Jeff Hattey, and Shannon Taylor for their insight, contributions, and editing that made these previous editions successful.

Since the first edition, we have greatly benefited from evolution of computer technology and its impact on our ability to manage and transfer information. Examples of this change are showcased in Chapter 6, which describes two computer programs developed at OSU, to aid in determining profitability of fertilizer use, and keeping records of soil tests and fertilizer use. Management of huge research databases, that would otherwise be impossible to objectively examine and statistically evaluate, is now quickly processed for interpretation and extension to the public (Chapter 10). The new concept of “Precision Agriculture” would not be possible to research without intensive use of computer technology (Chapter 11). This new concept of electronically sensing nutrient deficiencies and simultaneously correcting them with a variable-rate fertilizer applicator represents the nutrient management tools for the 21st century.

An additional change since the first edition in 1977 is society’s concern for the impact of fertilizer use and nutrient management on the environment, especially as it pertains to animal waste management and water quality. In this regard, Chapter 7 presents important guidelines for managing this resource for maximum food production and minimum environmental impact. We are grateful to Jerry Baker with the State Department of Agriculture for updating Chapter 9 on laws and regulations.

H. Zhang and B. Raun
January 2006

Chapter 1 Soil and Soil Productivity

Soil is perhaps the most important natural resource in Oklahoma. It is important to all, for without soil there would be no life on Earth. Our food and much of our clothing and shelter come from the soil. Soil supports the gigantic agricultural system which is the major contributor to the state's development and continued prosperity.

Oklahoma has a land area of over 44 million acres, part of which is covered by water. The majority, some 41 million acres, is used for production of food and fiber. This land has an average value of over $400 per acre or a total value in excess of $16.4 billion, an asset well worth protecting.

Many different kinds of soil occupy this land area. Some soils are extremely productive while others are not so productive. Each soil has a set of unique characteristics which distinguishes it from other soils. These characteristics determine the potential productivity of the soil.

Soil productivity is a result of how well the soil is able to receive and store moisture and nutrients as well as providing a desirable environment for all plant root functions.

WHAT IS SOIL?

Soil is the unconsolidated mineral and organic material on the immediate surface of the Earth which provides nutrients, moisture, and anchorage for land plants.

The principal components of soil are mineral material, organic matter, water and air. These are combined in widely varying amounts in different soils. In a typical loam soil, solid material and pore space are equally divided on a volume basis, with the pore space containing nearly equal amounts of water and air. The approximate proportions are illustrated in Figure 1.1.

HOW SOILS ARE FORMED

The development of soils from parent rock is a long term process involving physical and chemical weathering along with biological activity. The wide variety of soils and their properties are a function of the soil forming factors including parent material, climate, living organisms, topography and time.

The initial action on the parent rock is largely mechanical-cracking and chipping due to temperature changes. As the rock is broken, the total surface area exposed to the atmosphere increases. Chemical action of water, oxygen, carbon dioxide and various acids further reduce the size of rock fragments and change the chemical composition of many resulting particles. Finally, the microorganism activity and higher plant and animal life contribute organic matter to the weathered rock material, and a true soil begins to form.

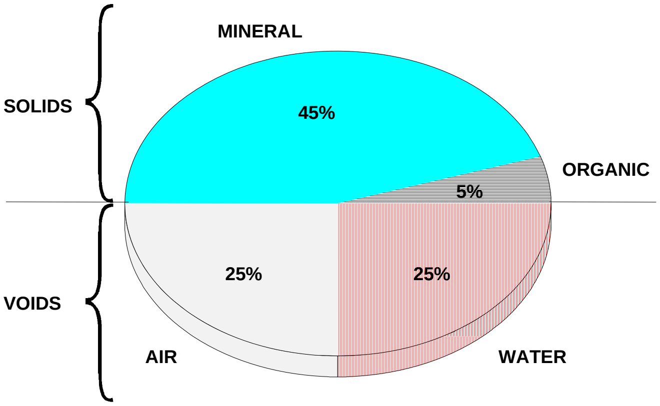


Figure 1.1. Volume composition of a desirable surface soil.

Since all of these soil-forming agents are in operation constantly, the process of soil formation is continual. Evidence indicates that the soils we depend on today to produce our crops required hundreds and even thousands of years to develop. In this regard, we might consider soil as a nonrenewable resource measured in terms of man's life span. Thus, it is very important that we protect our soils from destructive erosive forces and nutrient depletion which can rapidly destroy the product of hundreds of years of nature's work, as well as greatly reduce soil productivity.

SOIL PROFILE

A vertical cross-section through a soil typically represents a layered pattern. This section is called a "profile" and the individual layers are called "horizons". A typical soil profile is illustrated in Figure 1.2.

The uppermost layer includes the "surface soil" or "topsoil" and is designated the A horizon. This is the layer which is most subject to climatic and biological influence. It is usually the layer of maximum organic accumulation, has a darker color, and has less clay than subsoil. The majority of plant roots and most of the soil's fertility are contained in this horizon.

The next successive horizon is called the "subsoil" or B horizon. It is a layer which commonly accumulates materials that have migrated downward from the surface. Much of the deposition is clay particles, iron and aluminum oxides, calcium carbonate, calcium sulfate and possibly other salts. The accumulation of these materials creates a layer which is normally more compact and has more clay than the surface. This often leads to restricted movement of moisture and reduced crop yields.

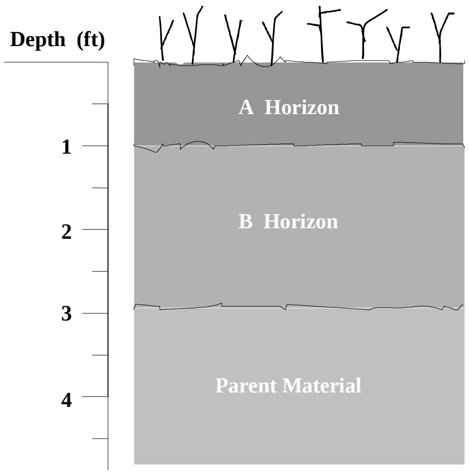


Figure 1.2. A typical soil profile.

The parent material (C horizon) is the least affected by physical, chemical and biological weathering agents. It is very similar in chemical composition to the original material from which the A and B horizons were formed. Parent material which has formed in its original position by weathering of bedrock is termed "residual", or called "transported" if it has been moved to a new location by natural forces. This latter type is further characterized on the basis of the kind of natural force responsible for its transportation and deposition. When water is the transporting agent, the parent materials are referred to as "alluvial" (stream deposited). This type is especially important in Oklahoma. These are often the most productive soils for agricultural crops. Wind-deposited materials are called "aeolian".

Climate has a strong influence on soil profile development. Certain characteristics of soils formed in areas of different climates can be described. For example, soils in western Oklahoma are drier and tend to be coarser textured, less well developed and contain more calcium, phosphorus, potassium and other nutrients than do soils in the humid eastern part of the state.

The soil profile is an important consideration in terms of plant growth. The depth of the soil, its texture and structure, its chemical nature as well as the soil position on the landscape and slope of the land largely determine crop production potential. The potential productivity is vitally important in determining the level of fertilization.

SOIL TEXTURE

Soils are composed of particles with an infinite variety of sizes. The individual particles are divided by size into the categories of sand, silt and clay. Soil texture refers to the relative proportion of sand, silt and clay in the soil. Textural class is the name given to soil based on the relative amounts of sand, silt, and clay present, as indicated by the textural triangle shown in Figure 1.3. Such divisions are very meaningful in terms of relative plant growth. Many of the important chemical and physical reactions are associated with the surface of the particles, and hence are more active in fine than coarse texture soils.

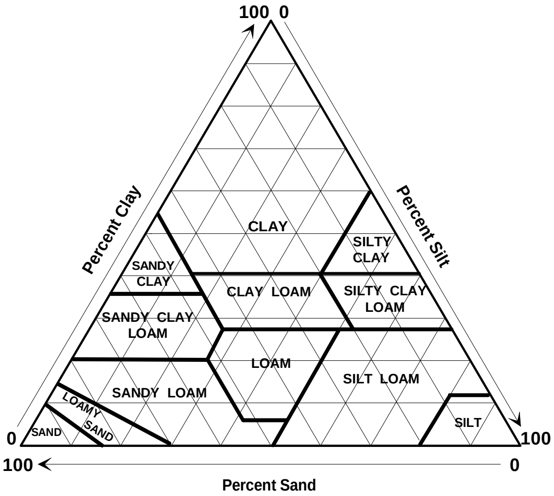


Figure 1.3. Triangle for determining soil textural classes.

A textural class description of soils can tell a lot about soil-plant interactions, since the physical and chemical properties of soils are determined largely by texture. In mineral soils, exchange capacity (ability to hold plant nutrient elements) is related closely to the amount and kind of clay in soils. Texture is a major determining factor for water holding capacity. Fine-textured soils (high percentage of silt and clay) hold more water than coarse-textured soils (sandy). Water and air movement through the finer textured soils is reduced and they can be more difficult to work.

From the standpoint of plant growth, medium-textured soils, such as loams, sandy loams and silt loams, are probably the most ideal. Nevertheless, the relationships between soil textural class and soil productivity cannot be generally applied to all soils, since texture is one of the many factors that influence crop production.

Check the texture of the surface and subsoil. Normally, the surface includes the top foot of soil, but it may be shallower or deeper in certain situations. Soil below the tillage zone is called "subsoil". It is also necessary to consider the subsoil texture when determining productivity potentials.

SOIL STRUCTURE

Soil structure refers to the presence of aggregates of soil particles that have been bound together to form distinct shapes. Sometimes the binding or cementing is only weak, however the aggregates are much larger than individual soil particles. Soil organic matter contributes significantly as a cementing agent. Air and water movement and root penetration in the soil is related to the soil structure. The better the structure, the higher the productivity of the soil is.

Size and shape of the structure units is important. When height of the structure unit is approximately equal to its width (blocky structure) we expect good air and water movement. Structure units that have greater height than width (prismatic structure) are often associated with subsoils that swell when wet and shrink when dry, resulting in poor air and water movement. When particles have greater width than height (platy structure) water and air movement and root development in the soil is restricted, compared to a soil with desirable structure.

Granular structure particularly in fine-textured soils is ideal for water penetration and air movement. Water and air move more freely through subsoils that have blocky structure than those with platy structure. Good air and water movement is conducive to plant root development. Types of soil structure are illustrated in Figure 1.4.

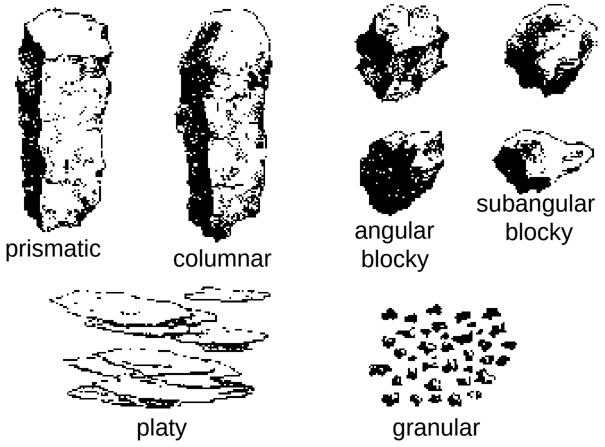


Figure 1.4. Types of soil structure.

The productivity of the soil is influenced by both surface and subsoil texture and structure. An approximate rating for soils considering texture and structure is shown in Table 1.1.

Table 1.1. Soil productivity rating as affected by texture*

Subsoil Texture	Surface Soil Texture: Sand	Sandy Loam	Loam	Clay Loam	Clay; Silty Clay
	-------- Percent of Maximum Productivity --------				
Sandy	50	55	65	60	55
Sandy Loam	60	70	80	75	65
Loam	70	80	95	90	75
Clay Loam	70	80	90	90	75
Clay; Silty Clay	65	70	80	80	70

*Numbers represent average soil conditions.

Raise or lower the rating 10 to 20 percent, according to whether the soil structure is more, or less, favorable than the average. If gravel occurs in the soil, lower the rating according to its effect on the productive capacity.

SOIL DEPTH

Soil depth is generally used to describe how deep roots can favorably penetrate. Soils that are deep, well drained, and have desirable texture and structure are suitable for production of most crops. For satisfactory production, most plants require considerable soil depth for root development from which to secure nutrients and water. Plants growing on shallow soils have little soil volume from which to secure water and nutrients. Depth of soil, and its capacity to hold nutrients and water, frequently determines crop yield, particularly for summer crops.

Roots of most crops will extend three feet or more into favorable soil. Soils should be at least six feet deep to give maximum production. Look for materials or conditions that limit soil depth, such as hardpans, shale, coarse gravelly layers and tight impervious layers. These are almost impossible to change. On the other hand, a high water table may limit root growth, but it can usually be corrected by drainage. Soil productivity estimates on the basis of soil depth can be made using Table 1.2.

Table 1.2. Soil productivity rating as affected by depth

Soil Depth Usable by Crop Roots	Relative Productivity
(Feet)	(Percent)
1	35
2	60
3	75
4	85
5	95
6	100

SOIL SLOPE

Topography of the land largely determines potential for runoff and erosion, method of irrigation, and management practices needed to conserve soil and water. Higher sloping land requires more management, labor and equipment expenditures.

Table 1.3 can be used to rate land productivity based on slope. If slope varies, use steeper slopes for the rating.

Table 1.3. Soil productivity ratings as affected by slope.

	Relative Productivity	
Slope	Stable Soil	Unstable, Easily Eroded soil
%		
0-1	100	95
1-3	90	75
3-5	80	50
5-8	60	30
8-12	40	10

EROSION

Principal reasons for soil erosion in Oklahoma are: (1) insufficient vegetative cover, which is usually a result of inadequate fertility to support a good plant cover, (2) growing cultivated crops on soils not suited to cultivation, and (3) improper tillage of the soil. Soil erosion can be held to a minimum by (1) using the soil to produce crops for which it is suitable, (2) using adequate fertilizer and lime to promote vigorous plant growth, and (3) using proven soil preparation and tillage methods.

Soils that have lost part or all their surfaces are usually harder to till and have lower productivity than non-eroded soils. To compensate for surface soil loss, more fertilization, liming and other management practices should be used.

SOIL AND AVAILABLE WATER

Plants are totally dependent upon water for growth and production. Even with well fertilized soils, limited water can greatly reduce yields. Rainfall is not always dependable in Oklahoma, and therefore, crops are dependent upon the moisture stored in the soil profile for growth and production.

Soils differ in their ability to supply water to plants. Limited root zones caused by shallow soils, high water table or claypans, or extremely porous subsoils cause drought stress in plants faster than more desirable soils. Table 1.4 illustrates the differences in available water in selected soil profiles. Soils with silt loam or fine sandy loam surface textures have high available water holding capacities. Differences in available water holding capacity between the soils caused by widely varying textures of the subsoil and soil depth point out the need for knowing what is below the surface. (This kind of information is available in county soil survey manuals). During a drought, differences of two inches of available water can keep plants growing for an extra ten days during peak plant use and could be the difference between success and crop failure.

Table 1.4. Effect of depth and texture on available water for crop use

Soil Name	Texture	Depth	Available Water
		---------- inches	----------
Dennis	silt loam	0-11	1.98
	silty clay loam	11-23	2.52
	clay	23-60	5.55
	TOTAL	60	10.05
Sallisaw	silt loam	0-10	1.80
	silt loam	10-20	1.80
	gravelly clay loam	20-40	2.80
	very gravelly clay loam	40-60	1.60
	TOTAL	60	8.00
Shellabarger	fine sandy loam	0-16	1.92
	sandy clay loam	16-52	5.86
	fine sandy loam	52-60	0.88
	TOTAL	60	8.66
Stephenville	fine sandy loam	0-14	1.82
	sandy clay loam	14-38	3.84
	sandstone	38+	-----
	TOTAL	38+	5.66

SOIL FERTILITY

Soil fertility is the soil's ability to provide essential plant nutrients in adequate amounts and proper proportions to sustain plant growth. These nutrients and their functions are covered in details in the next chapter. Soil fertility is a component of soil productivity that is quite variable and strongly influenced by management. Other components of soil productivity, especially soil slope and soil depth, will be the same year after year. Together with climate, these components set the soil productivity limits, above which yields cannot be obtained even with ideal use of fertilizer. It is important to realize this and understand that added fertilizer cannot compensate for a soil that is unproductive because it is excessively stony or has a subsoil layer that restricts normal root growth and development. This point is illustrated in Fig. 1.5.

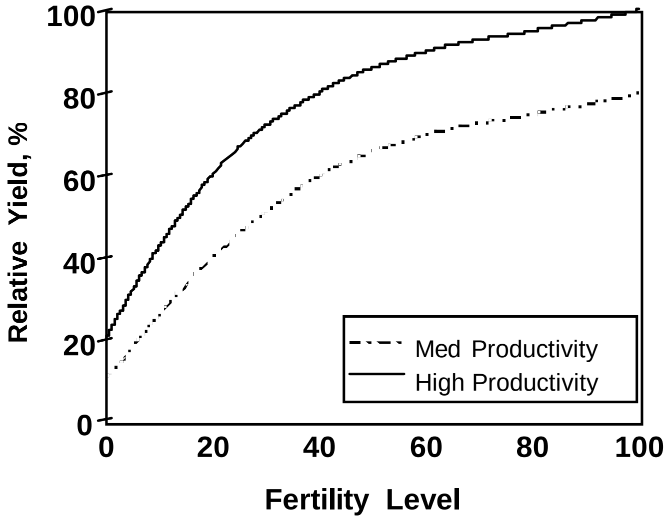


Figure 1.5. Influence of soil productivity on yield response to fertility.

SOIL MANAGEMENT

There are numerous other soil characteristics that can be important to soil productivity in specific areas. These include: soil drainage, soli salinity, presence of stone and/or rocks, and organic matter content. They are not major limiting factors over wide areas, and therefore, will not be discussed here.

One additional factor on which soil productivity is highly dependent is soil management. This implies using the best available knowledge, techniques, materials, and equipment in crop production. The use of minimum tillage is an important management practice used to reduce the potential damage to soil structure from overworking, and for economic and fuel conservation purposes as well as to allow farming of more acres per unit of labor.

Soil conservation is a concept integrating important management practices which deserves close attention. It is estimated that annually in the U.S. four billion tons of sediment are lost from the land in runoff waters, and with it much of the natural and applied fertility. That is equivalent to the total loss of topsoil (six inches deep) from four million acres. Wind erosion is also a problem in certain areas. Management practices such as contouring, strip planting, covercropping, reduced tillage, terracing and crop residue management help to eliminate or minimize the loss of soil from water and wind erosion.

Proper utilization of crop residues can be a key management practice. Crop residues returned to the soil improve soil productivity through the addition of organic matter and plant nutrients. The organic matter also contributes to an improved physical condition of the soil, which increases water infiltration and storage and aids aeration. This is vital to crop growth.

SUMMARY

Limitations of soil, water, or climate reduce the soil's ability to produce. These limitations increase the need for better management practices. Poor management, or the presence of weeds, compact soils, soil erosion, etc., will result in low yields even on the most productive soils. On the other hand, good management on moderately productive soils can give high yields. Hopefully, by considering the factors discussed in this chapter, one can make a better determination of the soil's overall crop productivity and in turn make better decisions about nutrient management including use of fertilizers.

Chapter 2 Essential Plant Nutrients, Functions, Soil Reactions, and Availability

More than 100 chemical elements are known to man today. However, only 16 have proven to be essential for plant growth.

In order for a nutrient to be classified as essential, certain rigid criteria must be met. The criteria of essentiality are as follows:

1. The element is essential if a deficiency prevents the plant from completing its vegetative or reproductive cycle.
2. The element is essential if the deficiency in question can be prevented or corrected only by supplying the element.
3. The element is essential if it is directly involved in the nutrition of the plant and is not a result of correcting some microbiological or chemical condition in the soil or culture media.

The essential elements and their chemical symbols are listed in Table 2.1. Three of the 16 essential elements - carbon, hydrogen and oxygen - are supplied mostly by air and water. These elements are used in relatively large amounts by plants and are considered to be non-mineral since they are supplied to plants by carbon dioxide and water. The non-mineral elements are not considered fertilizer elements. The other 13 essential elements are mineral elements and must be supplied by the soil and/or fertilizers.

Table 2.1. Essential plant nutrients, chemical symbols and sources

Mostly from air and water ----(non-mineral)----		From soil and/or fertilizers --------------------(mineral)--------------------			
Element	Symbol	Element	Symbol	Element	Symbol
Carbon	C	Nitrogen	N	Iron	Fe
Hydrogen	H	Phosphorus	P	Manganese	Mn
Oxygen	O	Potassium	K	Zinc	Zn
		Calcium	Ca	Copper	Cu
		Magnesium	Mg	Boron	B
		Sulfur	S	Molybdenum	Mo
				Chlorine	Cl

The essential plant nutrients may be grouped into three categories. They are as follows:

1. Primary nutrients - nitrogen, phosphorus and potassium
2. Secondary nutrients - calcium, magnesium and sulfur
3. Micronutrients - iron, manganese, zinc, copper, boron, molybdenum, and chlorine

This grouping separates the elements based on relative amounts required for plant growth, and is not meant to imply any element is more essential than another.

PRIMARY NON-MINERAL NUTRIENTS

Carbon, Hydrogen, and Oxygen

Carbon is the backbone of all organic molecules in the plant and is the basic building block for growth. After absorption of carbon dioxide (CO_2) by the leaves of the plant, carbon is transformed into carbohydrates by combining with carbon, hydrogen, and oxygen through the process of photosynthesis.

Metabolic processes within the plant transform carbohydrates into amino acids and proteins and other essential components.

PRIMARY MINERAL NUTRIENTS

Nitrogen

Nitrogen (N) is an integral component of amino acids, which are the building blocks for proteins. Proteins in turn are present in the plant as enzymes that are responsible for metabolic reactions in the plant. Because N is so important, plants often respond dramatically to available N.

Soil N Reactions and Availability. Most of the N in Oklahoma soils is present as organic nitrogen in the soil organic matter. There are about 1,000 lb/acre of N in this form for every 1% organic matter in the soil. However, since the soil organic matter is resistant to further decay, most of this Nn is unavailable during any given growing season. Normally each year about 2% of the nitrogen from soil organic matter will be released to mineral forms when soils are cultivated. This 20 to 40 lb/acre of mineral N is typical of the small amount present in unfertilized soils after cultivation and seed bed preparation.

NITROGEN MINERALIZATION AND IMMOBILIZATION

Because N release from organic matter is dependent upon decay by microorganisms, which themselves require mineral N, the amount of mineral N available for a crop is in constant flux. Unlike crops, which get their carbon as carbon dioxide from the air, many microorganisms get their carbon by decaying organic matter. Nitrogen availability depends upon the relative amount of carbon and N in the organic matter, its resistance to decay, and environmental conditions to support microbial activity. Figure 2.1 illustrates how nitrogen becomes more concentrated as soil organic matter decays.

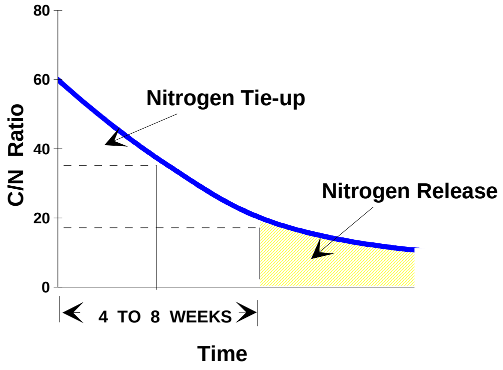


Figure 2.1. Narrowing of carbon to nitrogen ratio as residue is decayed until mineral nitrogen finally becomes available.

Note that nitrogen is not released during the first stages of decay. This is because N that is released is immediately consumed by active microorganisms. With time, remaining organic material becomes more resistant to decay, microorganisms die off, and there is more mineral N present than can be consumed by the few active microorganisms. This results in a final release of measurable mineral N in the form of ammonia (NH_3). The ammonia readily reacts with soil moisture to form ammonium (NH_4^+). These two reactions can be stated simply as

$$\text{organic N} \rightarrow NH_3\ \text{(gas)} \quad [1]$$

$$\underset{\text{ammonia + water}}{NH_3 + H_2O} \rightarrow \underset{\text{ammonium + hydroxide}}{NH_4^+ + OH^-} \quad [2]$$

The process of converting or transforming N from organic compounds to inorganic compounds is called *mineralization*. This results in increasing N available for crops. When the reverse happens and available mineral N is absorbed by crops or microorganisms the process is called *immobilization* and results in a decrease in the amount of N immediately available for crops. These processes and their interacting nature with soil N for a typical field situation are illustrated in Figure 2.2.

Approximately 98% of the soil nitrogen is unavailable for plant uptake. This large reservoir of organic N provides an important buffer against rapid changes in available N and plant stress. The small reservoir of mineral N can often be slowly replenished by mineralization (Fig. 2.2) when crops need additional N.

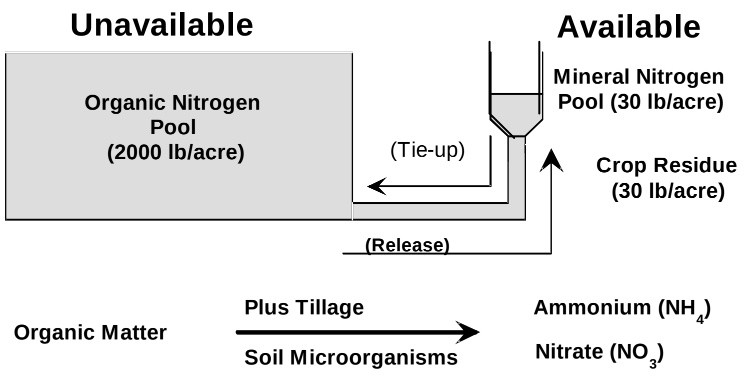


Figure 2.2. Interacting pools of soil nitrogen.

Usually supplemental N as fertilizer must be added to support high, economic production levels. Immediately following fertilization with 120 lb N, the system may be illustrated by Figure 2.3a. Addition of fertilizer N will stimulate microorganism activity resulting in consumption of mineral N and breakdown of some crop residues (immobilization) as illustrated in (b). The immobilized N will be present as microbial tissue and other new material in the organic pool. As indicated by the two arrows pointing in opposite pathways, mineralization and immobilization are both taking place simultaneously. Immobilized fertilizer N will again become available in a few weeks if conditions favor crop uptake.

NITRIFICATION

Other reactions, in addition to the general mineralization and immobilization reactions, are responsible for N changes (transformations) in the soil. Nitrification is one of the first reactions to occur after organic N has been converted to ammonium-N. This change is also a result of aerobic microorganism activity as depicted in the following reaction.

$$\underset{\text{ammonium}}{2NH_4^+} + \underset{\text{oxygen}}{3O_2} \rightarrow \underset{\text{nitrite}}{2NO_2^-} + \underset{\text{water}}{2H_2O} + \underset{\text{hydrogen ion}}{4H^+} \qquad [3]$$

This reaction produces nitrite-N and hydrogen ions. Since hydrogen ions are generated, it is easy to see this step will at least temporarily contribute to soil acidity. However, this production of acidity is partially compensated for by the hydroxide (OH^-) produced from reaction [2]. The hydrogen and hydroxide will combine to form water, so the net effect on acidity when organic nitrogen is mineralized will be one pound of hydrogen produced for every 14 pounds of nitrogen mineralized. The same reactions and acidity will occur when fertilizer nitrogen is added in the ammonia form (anhydrous ammonia or urea). Ammonium sulfate will be twice as acidifying because equation [2] will be avoided by adding the ammonium (NH_4^+) form of nitrogen.

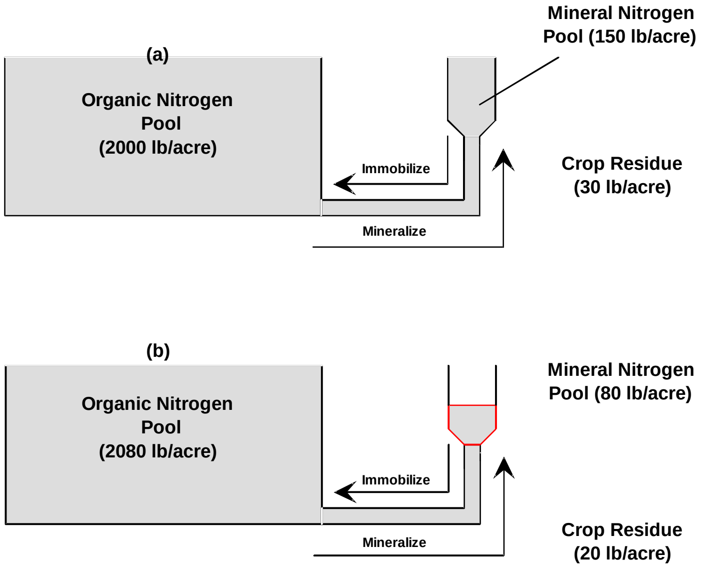


Figure 2.3. Relative amounts of organic and mineral nitrogen in soil immediately after fertilizing (a) and several days after active immobilization (b).

Almost immediately after nitrite (NO_2^-) nitrogen is produced (reaction [3]), a companion reaction occurs that is also carried out by soil microorganisms resulting in nitrate-N (NO_3-N) being produced from nitrite.

$$2NO_2^- + O_2 \rightarrow 2NO_3^- \qquad [4]$$

Because this change is quite rapid compared to the change from ammonium to nitrite [3] there is seldom any nitrite (NO_2^-) present in soils. Ammonium and nitrate are common and will increase or decrease depending on microbial activity that will both generate and consume ammonium and nitrate. This cyclic interaction of N transformations is shown in Figure 2.4.

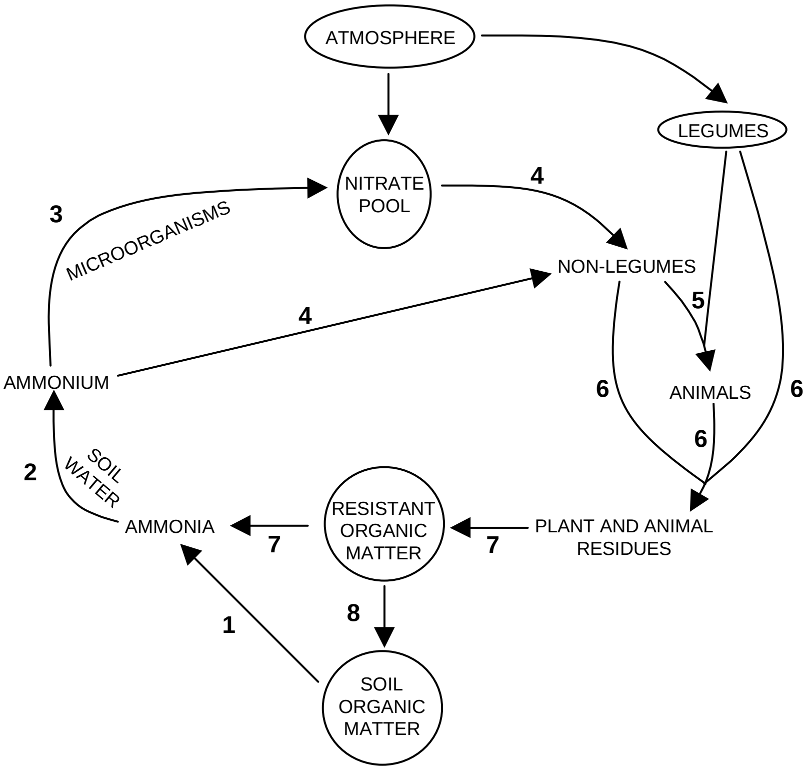


Figure 2.4. Primary forms of nitrogen in soils and the transformations among them. (1) Decay of soil organic matter releasing ammonia; (2) reaction of ammonia with water to form ammonium; (3) transformation of ammonium to nitrate by microorganisms; (4) uptake of ammonium and/or nitrate by plants and microorganisms; (5) plants eaten by animals; (6) animal manures, nitrogen fixation and plant residue returned to soil; (7) residues decayed to resistant organic matter, ammonia produced from nitrogen rich materials; (8) soil organic matter produced as decay continues.

Whenever nitrate and/or ammonium nitrogen are measured in the soil, these measurements provide a view of two components of the N cycle at a single point in time. If the measurement is made when the system is likely to be in balance, or equilibrium, such as when wheatland soils are tested for nitrate in July or August, then the value can be a useful guide for determining N fertilizer needs. Figure 2.5 illustrates the changes that took place for ammonium and nitrate nitrogen in soil during wheat production under different rates of fertilizer use. Because ammonium and nitrate nitrogen are the two forms of nitrogen that higher plants utilize, these two forms have received the greatest attention.

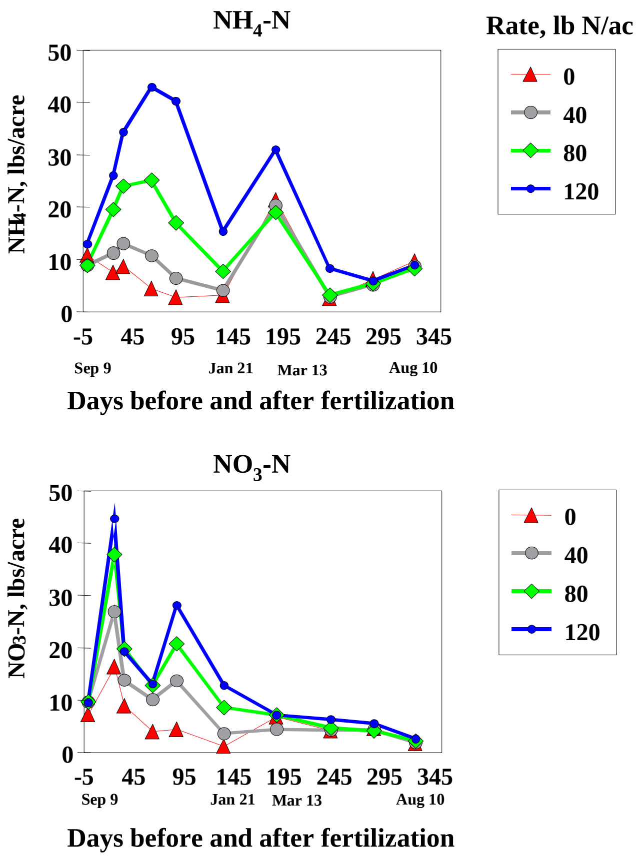


Figure 2.5. Surface soil (0-6") ammonium and nitrate nitrogen following fertilization at different rates from OSU Soil Fertility Research.

OSU soil fertility research has documented the change of ammonium and nitrate nitrogen following fertilization (Fig. 2.5). Only about 60% of the fertilizer N could be accounted for at the first sampling after fertilization. This was mostly present as nitrate although the fertilizer (ammonium nitrate) was an equal mixture of the two nitrogen forms measured. Apparently in the short period after application, some transformations had taken place. These continued, resulting in a gradual increase in ammonium nitrogen (probably from some mineralization) and a rapid decline in nitrate, likely from immobilization caused by microbial activity and uptake by the wheat crop.

When crop production is added to the cycle in Figure 2.4, it becomes obvious that the cycle is not self sustaining. Harvesting removes significant amounts of nitrogen each year and eventually the system becomes depleted in organic matter and available N to support normal crop yields. A common response to this result is to begin adding nitrogen back by using legumes and commercial fertilizers. When additions are balanced with removals, soil organic matter and productivity can potentially be sustained. However, excessive tillage, residue removal (straw and chaff in wheat production) and residue burning often result in continued soil organic matter decline. This loss in soil organic matter also contributes to "hard" ground and soil that easily crusts after drying.

NITROGEN FIXATION

Additions to soil N are made as a result of either atmospheric, biological, or industrial fixation of atmospheric nitrogen (N_2). These processes are responsible for transforming N from the atmosphere to either ammonium or nitrate nitrogen that can be used by plants. The atmosphere contains an inexhaustible amount (78%) of nitrogen. Approximately 35,000 tons of N are present in the atmosphere above every acre of the earth’s surface.

Atmospheric nitrogen fixation occurs when there is electrical discharge or lightning during thunderstorms. This causes elemental nitrogen (N_2) to combine with elemental oxygen (O_2) to form nitrate (NO_3^-). The nitrate is added to the soil with rainwater and accounts for about 3 to 5 pounds of N per acre per year.

Biological N fixation can be either symbiotic or non-symbiotic. Symbiotic N fixation occurs within legumes. Bacteria (*rhizobium sp*.) infect the root of the legume and cause a nodule to form. The rhizobium obtain their energy from the legume and convert free N to ammonia (NH_3), which the host plant utilizes to make amino acids and proteins. Legumes may fix as much as 500 pounds of nitrogen per acre per year (alfalfa) by this process. However, only a small fraction of the N fixed by legumes will be available for subsequent crops unless the legume is "plowed down" when a significant amount of top growth is present. Normally, most of the fixed N is removed in the harvest. Typical amounts of N added from legumes are shown in Table 2.2.

Biological N fixation is an extremely important source of adding nitrogen to soils when fertilizer nitrogen is unavailable. In Oklahoma the addition of nitrogen to soils as a result of growing legumes is significant, and should always be accounted for when determining N needs for non-legume crops in the subsequent season. However, the cost of establishing and growing legumes for this purpose alone, precludes their use as a sole substitute for nitrogen fertilizers.

Table 2.2. Average nitrogen remaining (N-credit) in the soil after legume crops.

Legume	N-credit (lb N/acre)	Legume	N-credit (lb N/acre)
Alfalfa	80	Cowpeas	30
Ladino clover	60	Lespedeza (annual)	20
Sweet clover	60	Vetch	40
Red clover	40	Peas	40
Kudzu	40	Winter peas	40
White clover	20	Peanuts	20
Soybeans	20	Beans	20

Non-symbiotic nitrogen fixation is accomplished by certain "free-living" microorganisms (cyanobacteria or blue-green algae), which live independently of other living tissue. The total contribution of nitrogen from these microorganisms is usually insignificant.

Industrial fixation of nitrogen involves reacting atmospheric nitrogen (N_2) with hydrogen (H), usually in the form of natural gas, under high temperature and pressure to form ammonia (NH_3). The ammonia may be used directly as anhydrous ammonia gas or converted to other nitrogen fertilizers such as urea, ammonium nitrate, urea-ammonium nitrate solution, ammonium sulfate or ammonium phosphates. Industrial fixation in Oklahoma is responsible for additions of about 300,000 tons of N per year. This amount of N is roughly equal to N removed in harvested crops.

Nitrogen fixation results in addition of nitrogen to the soil through utilization by plants and their residues subsequently added back to the soil (Figure 2.6). In order for soil organic matter to be maintained it is necessary for these additions to be at least equal to the amount of nitrogen removed from the field by harvest. Figure 2.6 illustrates how nitrogen fixation interacts with other forms of nitrogen and their transformations.

NITROGEN LOSSES

The major nitrogen loss from soils is the removal of nitrogen by harvest of non-legume crops. Other significant nitrogen losses include:

1. Volatilization of ammonia.
2. Volatilization of nitrous oxide (N_2O) and nitric oxide (NO) from nitrate in poorly aerated soils (denitrification).
3. Leaching of nitrate out of the root zone in permeable soils receiving heavy rainfall or irrigation.
4. Volatilization of nitrogen (presumably as ammonia) from plants containing nitrogen in excess of what the plant can use in seed production, just after flowering.

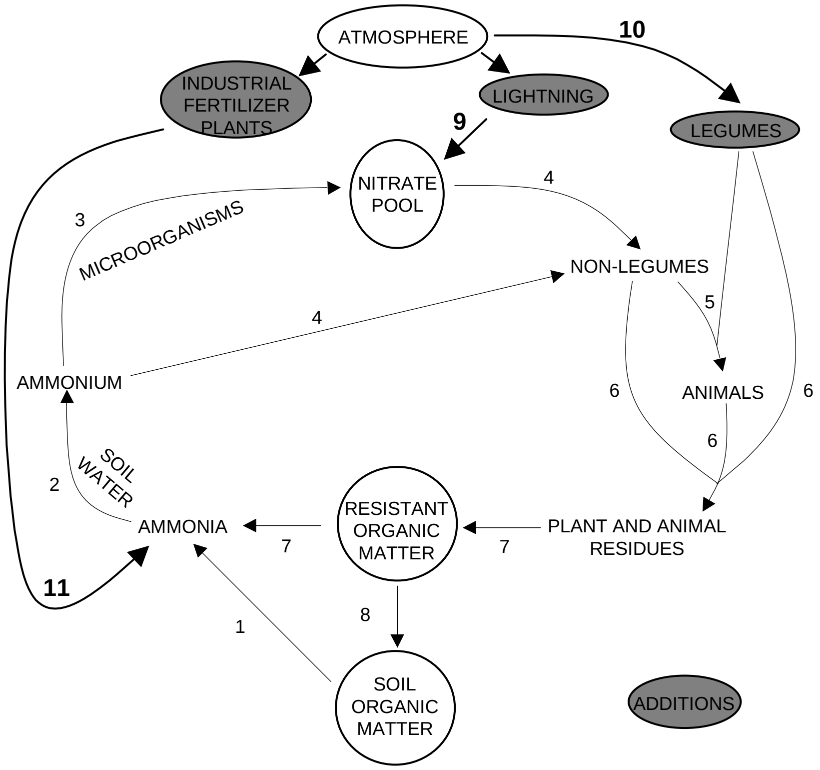


Figure 2.6. Addition of nitrogen to the nitrogen cycle from fixation of atmospheric nitrogen by: (9) lightning; (10) symbiosis with legumes; (11) industrial fertilizer plants.

Each of these processes is only responsible for very small amounts of nitrogen loss over the course of a crop growing season. However, when considered over a generation of farming, or even just a few years, the amount of nitrogen lost can be significant. Nitrogen losses by these processes are at least partially responsible for the fact that only 50 to 70% of the fertilizer nitrogen applied is actually found in the crop. Research at OSU and other institutions continues to examine practices that will improve fertilizer nitrogen use efficiency. Figure 2.7 illustrates the interaction of these nitrogen losses with other forms of nitrogen and their transformations.

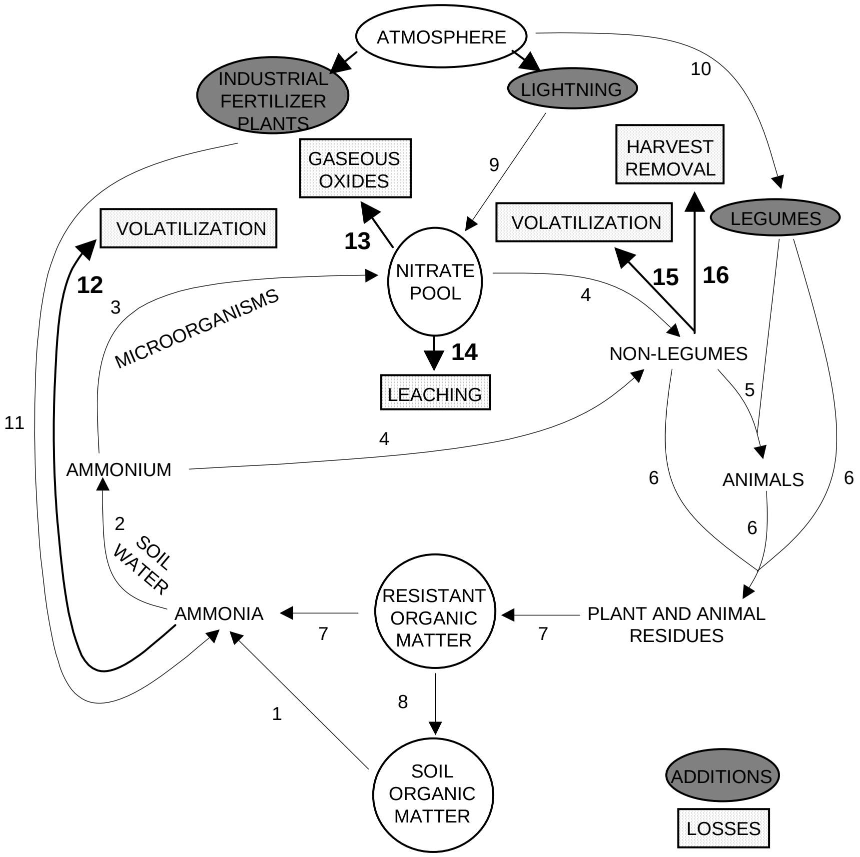


Figure 2.7. Losses of nitrogen from the nitrogen cycle as a result of: (12) ammonia volatilization; (13) transformation of nitrate to gaseous oxides (denitrification); (14) leaching below the root zone; (15) volatilization from crops; and (16) harvest removal.

Phosphorus

Most of the total phosphorus in soils is tied up chemically in compounds with low solubility. In neutral to alkaline pH soils, calcium phosphates are formed, while in acid soils, iron and aluminum phosphates are produced.

Soil Phosphorus Reactions and Availability. Available soil phosphorus, or that fraction which the plant can use, makes up about one percent or less of the total phosphorus in soils. The availability of inorganic phosphorus in soils is related to solubilities of the compounds present. Solubilities are controlled by a number of factors.

The amount of precipitated phosphorus is one factor. The greater the total amount presents in soil, the greater the chance to have more phosphorus in solution. Another important factor is the extent of contact between precipitated phosphorus forms and the soil solution. Greater exposure of phosphate to soil solution and plant roots increases its ability to maintain replacement supplies. During periods of rapid growth, phosphorus in the soil solution may be replaced 10 times or more per day from the precipitated or solid phase. The rate of dissolution and diffusion of soluble P determines soil phosphate availability. As phosphate ions (mainly $H_2PO_4^-$ and HPO_4^{2-}) are taken up by the plant, more must come from the solid phase.

Soil pH can be a controlling factor that determines phosphorus solubility. Maximum phosphorus availability occurs in a pH range of 5.5 to 7.2. At soil pH levels below 5.5, iron (Fe), aluminum (Al) and manganese (Mn) react with phosphorus to form insoluble compounds. When soil pH exceeds 7.2, phosphorus will complex with calcium (Ca) to form plant unavailable P forms. However, it should be noted that the solubility of calcium phosphates is much greater than aluminum and iron phosphates.

The proportion of total soil phosphorus that is relatively available is dependent upon time of reaction, type of clay present in the soil, organic matter content and temperature. The solubility of phosphate compounds formed from added phosphorus due to time of reaction can be broken down in three major groups (Figure 2.8). Fertilizer phosphates are generally in the readily available phosphate group but are quickly converted to slowly available forms. These can be utilized by plants at first, but upon aging are rendered less available and are then classified as being very slowly available. At any one time, 80 to 90 percent of the soil phosphorus is in very slowly available forms. Most of the remainder is in the slowly available form since less than 1 percent would be expected to be readily available.

The formation of insoluble phosphorus containing compounds in soils that renders phosphorus unavailable for plant use is called phosphorus fixation. Each soil has an inherent fixation capacity that must be satisfied in order to build available phosphorus levels. In Oklahoma, a large portion of the clays have a lower fixation capacity than the highly weathered soils found in high rainfall areas. It is important to understand that the actual amount of P in the soil and the amount available to crops will not necessarily be reflected in a soil test. These soil tests simply provide an index of sufficiency and not an index of build-up or accumulation. Because different soils will have differing fixation capacities, the importance of annual soil testing becomes clear since this practice is the only method we have to estimate future crop fertilizer needs. In addition, these tests should reflect past management (farmers applying more than enough or not enough on an annual basis) and thus compensate accordingly.

Very slowly available phosphates
Apatites, aged Fe, Mn and Al phosphates,
stable organic phosphates

↓↑

Slowly available phosphates
$Ca_3(PO_4)_2$, freshly formed Fe, Al, Mn phosphates
(small crystals), and mineralized organic phosphates

↓↑

Readily available phosphates
Water-soluble
ammonium phosphates
$NH_4H_2PO_4$ (MAP 11-52-0)
$(NH_4)_2HPO_4$ (DAP 18-46-0)
monocalcium phosphate
$Ca(H_2PO_4)_2$ (0-46-0)
Water-insoluble
dicalcium phosphate
$CaHPO_4$

Figure 2.8. Relative availability of different phosphate forms and their transformations.

Organic matter and microbial activity affect available soil phosphorus levels. As was the case with nitrogen, the rapid decomposition of organic matter and consequent high microbial population results in temporary tying up of inorganic phosphorus (immobilization) in microbial tissue, which is later rendered available through release (mineralization) processes. This is one of the reasons why broadcasting P in zero/minimum tillage systems can be beneficial, especially where soil P fixation capacities are high.

Less than 30% of the phosphorus fertilizers applied is actually recovered in the plants. Therefore, due to fixation reactions, more P must be added than is actually removed by crops. Legumes, in general, require much larger amounts of P than many of the common grain crops grown in Oklahoma.

Because phosphorus is immobile in the soil, roots must come in direct contact with this element before the plant can take it up. However, phosphorus is mobile within the plant and if deficient, lower leaves will generally demonstrate outer edge leaf margins that are purple in color.

Over a wide range of soils and cropping conditions, phosphorus has proven to be one of the more deficient elements in Oklahoma production agriculture. Soil testing on an annual basis should assist in determining crop needs.

Potassium

Plants take up potassium as the potassium ion (K^+). Potassium within plants is not synthesized into compounds and tends to remain in ionic form in cells and plant tissue. Potassium is essential for photosynthesis, starch formation and translocation of sugars within plants. It is necessary for the development of chlorophyll, although it is not part of its molecular structure.

The main functions of potassium in plants are in the translocation of sugars and its involvement in photosynthesis.

Soil Potassium Reactions and Availability. In most soils (except those that are extremely sandy in high rainfall regions), total potassium contents are high. Similar to nitrogen and phosphorus, not all of the total potassium is available for plant growth. The relationship of unavailable, slowly available and readily available forms of potassium is illustrated in Figure 2.9. Only 1 to 2 percent of the total potassium in soils is readily available. Of this, approximately 90 percent is exchangeable or attached to the outside edge of clays and the remaining 10 percent is in the soil solution. Equilibrium exists between the nonexchangeable, exchangeable and water soluble forms. When the plant removes potassium from the water soluble form, the concentration is readjusted by the exchangeable and nonexchangeable forms. In the case of added potassium, some of the available forms will move toward nonexchangeable forms. The nonexchangeable form may also be referred to as fixed. Certain 2:1 type clay minerals have pore space large enough for the potassium ions (K^+) to become trapped, rendering the ions unavailable for immediate plant use. Potassium is positively charged and clays are negatively charged and this makes the potassium ion relatively immobile in the soil. Except in extremely sandy soils, leaching losses under normal Oklahoma conditions are minimal. The largest loss comes from crop removal, particularly where hay crops are produced. Most of western Oklahoma soils have adequate plant available potassium, however, this can best be determined for individual fields by soil testing.

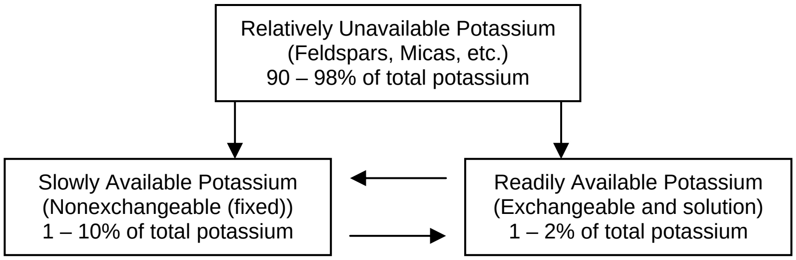


Figure 2.9. Relative amounts of soil potassium present in different levels of availability to plants.

SECONDARY MINERAL ELEMENTS

Nutrients that are used in relatively moderate amounts by most plants have been categorized as secondary nutrients. These nutrients are calcium (Ca), magnesium (Mg), and sulfur (S).

Calcium

Calcium is taken up by plants as the cation, Ca^{2+}. Calcium functions in the plant in cell wall development and formation. Calcium is not translocated in plants and consequently, the deficiency of calcium will be observed first in the new, developing plant tissue. Calcium deficient tissue fails to develop normal morphological features and will appear to be an undifferentiated gelatinous mass in the region of new leaf development.

The calcium ion is referred to as a basic ion because the element reacts with water to form the strong base calcium hydroxide, $Ca(OH)_2$. Calcium is held tightly on the negatively charged clay and organic particles in soils and is abundant in soils that have developed in arid and semi-arid climates. Because of this, it is primarily responsible for maintaining these soils at or near a neutral pH. In addition to unweathered primary and secondary minerals, soils often contain calcium in the form of impure lime (calcium carbonate, $CaCO_3$) and gypsum (calcium sulfate, $CaSO_4$). Except in the production of peanuts on sandy, acid soils, calcium deficiency in Oklahoma crops has not been substantiated by research. However, because calcium absorption by the developing peanut pod is not very effective from soils with a marginal supply of calcium, peanut producers often apply gypsum over the pegging zone just before the plant begins to peg to assure the crop will be adequately supplied with calcium. For most soils, before the available calcium level reaches a critically low point, the soil pH will become so low that soil acidity will be a major limitation to crop production. Since the common correction of acid soils is to add lime in amounts of tons per acre, this practice will incidentally maintain a high level of available calcium for crops.

Magnesium

Magnesium is absorbed as the divalent cation, Mg^{2+}, and functions in many enzymatic reactions as a co-factor or in a co-enzyme. The most noteworthy function of magnesium in plants is as the central cation in the chlorophyll molecule. Without magnesium, plants cannot produce adequate chlorophyll and will lose their green color and ability to carry out photosynthesis, the process responsible for capturing energy from sunlight and converting it into chemical energy within the plant. Magnesium deficiency will result in yellow, stunted plants.

Magnesium reactions in soils are similar to calcium in many respects. Magnesium, like calcium is a basic ion that is generally abundant in arid and semi-arid soils that are near neutral in pH. Deficiencies most often occur in deep sandy soils with a history of high forage production (8 to 10 tons per acre annually), where forage has been removed as hay. In Oklahoma, deficiencies have occasionally been noted under these conditions in the eastern half of the state. Like calcium, deficiencies are likely to occur on acid soils, and since most lime will contain a small amount (2 to 5%) of magnesium carbonate, liming acid soils on a regular basis usually will assure an abundant supply of plant available magnesium. If magnesium deficiency is a reoccurring problem, dolomitic lime (primarily magnesium carbonate) should be sought as a liming source.

Sulfur

Sulfur is absorbed by plants as the sulfate anion, SO_4^{2-}. Sulfur is a component of three of the 21 essential amino acids and thus, is critical to the formation and function of proteins. Sulfur deficiency causes plants to become light green and stunted. Most crops require about 1/20 the amount of sulfur that they do of nitrogen. Bumper yields of most crops can be supported by 5 to 15 lb/acre of sulfur.

Sulfur is found in soil in the form of soil organic matter (like nitrogen), dissolved in the soil solution as the sulfate ion, and as a part of the solid mineral matter of soils. Sulfur compounds, like gypsum for example, are slightly soluble in water. Like nitrate nitrogen, the negatively charged sulfate ion is not readily adsorbed to clay and humus particles and may be leached into the subsoil with a porous surface soil layer. Sulfur deficiencies most often occur in deep sandy soils, low in organic matter, with a history of high crop production and removal. Soils that have a well developed B horizon seldom will be deficient in sulfur because sulfur will not leach out of the root zone and the accumulated sulfur in the subsoil will adequately satisfy crop needs. This is one of the reasons why early S deficiencies often disappear at late stages of growth, at which time roots have penetrated subsoil horizons rich in sulfur. Soils that contain normal amounts of organic matter will release sulfur by mineralization, much like nitrogen, and this will contribute significantly to meeting crop needs. Sulfur deficiencies in Oklahoma are very rare because on the average there is about 6 lb/acre of sulfur added to soils annually in the form of rainfall. Sulfur is still added incidentally as a component of phosphate fertilizers and other agricultural chemicals which contribute significantly to the requirement of crops. Also, Oklahoma irrigation waters are usually high in sulfate, and add significant amounts each year (for every ppm of sulfate-S, 2.7 lb/acre of S is added for each acre-foot of irrigation).

MICRONUTRIENTS

The micronutrients are grouped together because they are all required by plants in very small amounts. Some, like molybdenum (Mo), are required in such small amounts that deficiencies can be corrected by applying the element at only a fraction of a pound per acre. Similarly, chlorine is needed in such small quantities that when researchers at the University of California were attempting to document its essentiality, they found that touching plant leaves with their fingers transferred enough chlorine from the perspiration on their skin to meet the plant's requirements. These elements do not function in plants as a component of structural tissues like primary and secondary nutrients. Instead, micronutrients are mainly involved in metabolic reactions as a part of enzymes where they are used over and over without being consumed. Nevertheless, their functions are very specific and cannot be substituted for by some other element. Deficiencies of any of the elements can be corrected by foliar application of solutions containing the element.

Manganese, Chlorine, Copper, and Molybdenum

Deficiencies of these nutrients have yet to be documented in Oklahoma, except for chlorine in wheat on a deep sandy soil near Perkins. Each of the elements is adsorbed by plants in the ionic form, manganese and copper as the divalent cations Mn^{2+} and Cu^{2+}, molybdenum as the oxyanion MoO_4^{2-}, and chlorine as the simple Cl^- anion. Of these four nutrients, molybdenum and chlorine are probably the most likely to receive attention. Molybdenum functions in plants in the enzyme nitrate reductase, which is very important in nitrogen metabolism in legumes. Availability is reduced in acid soils and often if molybdenum availability is marginal it can be increased to adequate levels by simply liming the soil. Where large seeded legumes are grown, like soybeans or peanuts, obtaining seed that was grown with a good supply of Mo will avoid the deficiency because normal levels of Mo in the seed will be enough to meet the plant needs.

Soil fertility research in the Great Plains has occasionally shown small grain response to fertilizers containing chlorine. Often the response has been the result of disease suppression rather than correction of an actual nutrient deficiency in the plant, and usually it has been in areas that do not commonly apply potassium fertilizers containing chloride (such as muriate of potash or potassium chloride, 0-0-62).

Boron

Boron (B) is absorbed by plants as uncharged boric acid, $B(OH)_3$, the chemical form also present in soil solution. Boron is believed to function in plants in the translocation of sugars. Because B is uncharged in soil solution and it forms slightly soluble compounds, it is also relatively mobile in soils and can be leached out of the surface soil. This is sometimes critical in peanut production because of the very sandy, porous soils peanuts are produced in. As a result, B deficiency has been reported in peanuts. The deficiency manifests itself as a condition known as "hollow heart" whereby the center of the nut is not completely filled and an inferior crop is harvested. Although alfalfa has an annual requirement twice that of peanuts, the deficiency of B has never been documented in alfalfa. The reason for this is likely because alfalfa is usually grown in deep, medium textured soils and because alfalfa has an extensive root system even at lower depths in the soil profile. Whenever B deficiencies are suspected, and if B fertilizer is applied, care should be exercised as toxicities can be created by simply doubling the recommended rate.

Iron and Zinc

Iron and zinc deficiencies both occur in Oklahoma and are associated with unique soil and crop situations. Zinc is absorbed as the divalent cation Zn^{2+}, while iron is absorbed as a "plant provided" chelated Fe^{3+} complex by grass type plants and as the "plant-reduced" divalent cation Fe^{2+} by broad-leaved plants.

Corn is sensitive to moderately low soil zinc levels and deficiencies may occur at DTPA soil test values below 0.8 ppm. Winter wheat, on the other hand, has been grown in research experiments near Woodward, Oklahoma where the soil test zinc value was less than 0.15 ppm without showing any deficiency or responding to zinc fertilizer. Zinc deficiency has yet to be found in winter wheat in Oklahoma. Obviously winter wheat is very effective in utilizing small amounts of soil zinc. Zinc deficiencies in corn are most common where fields have been leveled or for some other reason the topsoil has been removed and the surface soil has very little organic matter. Deficiencies are easily corrected by broadcast application of about 4 to 6 lb/acre of zinc preplant. An application of this rate should remove the deficiency for 3 to 4 years. The most sensitive plant to zinc deficiency in Oklahoma is pecans. Deficiencies may occur whenever DTPA soil test values are less than 2.0 ppm. Foliar sprays are very effective in preventing and/or correcting the deficiency, a single application usually lasting the entire growing season.

Iron deficiency is most common in sorghum and sorghum-sudan crops in Oklahoma. The occurrence is limited to the western half of the state in soils that are slightly alkaline (pH above 7.5). All soils in Oklahoma contain large amounts of iron, usually in excess of 50,000 lb/acre. However, almost all of this iron is in a form (like rust) that is not available to crops. Iron availability is increased greatly in acid soils, consequently the deficiency is seldom observed in any crops in eastern and central Oklahoma, where soil pH is usually less than 7.0. Iron deficiency cannot be corrected by soil application of iron containing fertilizers because the iron from the fertilizer is quickly converted to unavailable iron just like that already present in the soil. The exception to this general rule is the use of chelated iron. However, these fertilizer materials are cost prohibitive for field scale use. Foliar application of iron sulfate solutions is effective for supplying iron to deficient plants. Unfortunately, iron is not translocated in the plant and subsequent new leaves will again exhibit the interveinal chlorosis (yellow between the veins) so characteristic of iron deficiency. Repeated spraying will provide iron for normal growth but will often be cost prohibitive. The most effective long-term corrective measure for dealing with iron chlorosis is to increase soil organic matter since iron deficiency is usually limited to small areas of a field. Organic matter can be effectively increased by annual additions of animal manure or rotted hay. This results in additional chelating of iron and also has a tendency to acidify the soil. Broadleaf plants have what is called an "adaptive response mechanism" that allows them to make iron more available if they experience iron stress. The strength of this mechanism is a genetic trait and some varieties, such as ‘Forest’ soybeans, do not possess this ability and will often become chlorotic if grown in neutral or alkaline soils.

THE MOBILITY CONCEPT

The nutrient mobility concept as it relates to soil fertility was first proposed in 1954 by Roger H. Bray at the University of Illinois. Much research since then has supported his mobility concept and it is now considered basic to the understanding of soil fertility. Bray simplified all the soil chemistry surrounding the essential nutrients to the fact that some are quite mobile in soils and others are relatively immobile.

Mobile Nutrients

Plants are able to extract mobile nutrients from a large volume of soil, even soil beyond the furthest extension of their roots because as the plants extract water from around their roots, water from further away moves toward the root and carries the mobile nutrient with it. Figure 2.10 illustrates this point. Plants obtain mobile nutrients from a "root system sorption zone" and are capable of using nearly all of the mobile nutrient (or mobile form of the nutrient) if the supply is limited. According to Bray, the mobile nutrients are: **Nitrogen, Sulfur, Boron,** and **Chlorine**.

In a field situation, where there is more than one plant, root system sorption zones overlap if plants are close enough together as illustrated in Figure 2.11. As a result there is a volume of soil between plants where the nutrient is in demand by both plants. As plants are placed closer and closer together (e.g. increasing plant population to increase potential yield) the competition for nutrients increases. Unless the competition among plants in a field for a mobile nutrient is satisfied by supplying more of the nutrient, the growth and yield of plants will be restricted. From this simple illustration we learn that the supply of mobile nutrients like nitrogen must be provided in direct proportion to the number of plants, or potential yield of the crop. This "supply" can be easily determined by calculating the amount of nutrient that will be taken up by the crop. In order to do this we only need to know the average concentration of the nutrient in the crop and what the crop yield will be. Average nutrient concentrations are commonly known, however yields vary from field to field and year to year. For this reason it is critical to have in mind a "yield goal" or expected yield in order to determine fertilizer needs for mobile nutrients like nitrogen. For example, in Oklahoma the rule "2 lb nitrogen per acre for every bushel of wheat" is commonly used to estimate the nitrogen requirements of winter wheat. This rule takes into account that soil test and fertilizer nitrogen will only be about 70% utilized by the plant. Because mobile nutrients are almost completely extracted from the root system zone, soil test values like nitrate nitrogen will change drastically from one year to the next in relation to how much nitrogen was available and the crop yield.

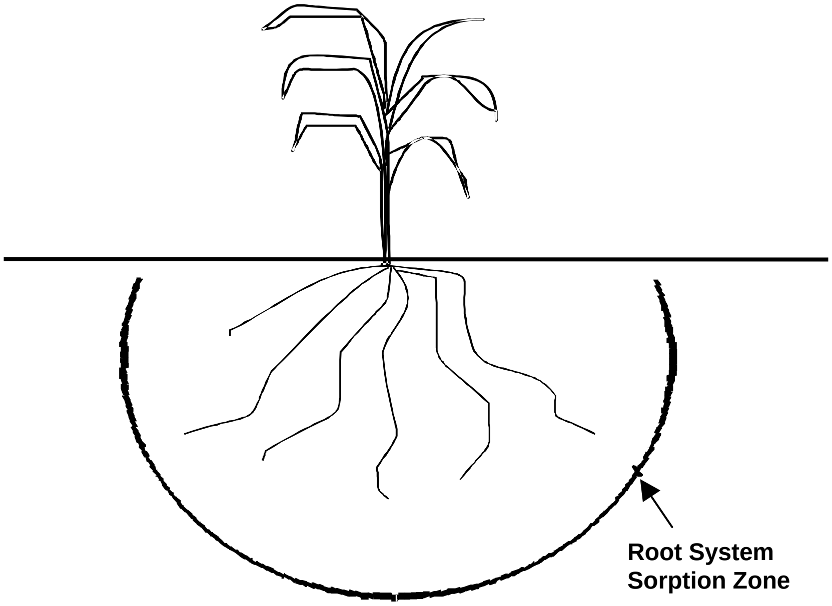


Figure 2.10. The large volume of soil from which plants extract mobile nutrients (root system sorption zone).

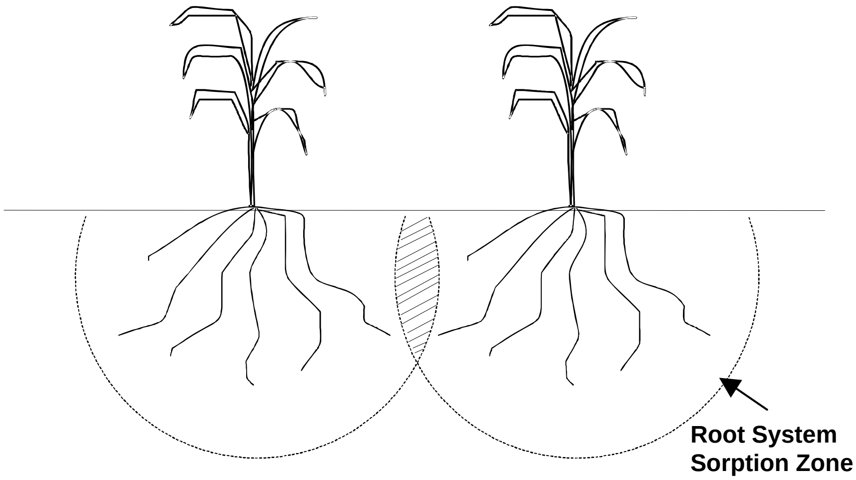


Figure 2.11. Competition among plants brought about by increasing yield goal.

Immobile Nutrients

Nutrients that are immobile in the soil are: **Phosphorus, Potassium, Calcium, Magnesium, Iron, Zinc, Manganese, Copper and Molybdenum.** These nutrients are not transported to plant roots as soil water moves to and is absorbed by the root. These nutrients are absorbed from the soil and soil water that is right next to the root surface. Because of this there is only a small volume of soil next to the root surface that is involved in supplying immobile nutrients to plants. Figure 2.12 identifies this soil volume as the "root surface sorption zone". This figure illustrates that only a small fraction of the soil in the total rooting zone is actually involved in supplying immobile nutrients. The total amount of immobile nutrient in the whole soil volume is not as important as the concentration right next to the root surface. Because only the thin layer of soil surrounding the roots is involved in supplying immobile nutrients, when more plants are considered as in Figure 2.13, there is still little or no competition among the plants for immobile nutrients. Competition would only occur at points where roots from adjacent plants actually came in contact with one another. This illustration indicates that the supply of immobile nutrients like phosphorus does not have to be adjusted (increased) in relation to an increase in yield goal or yield potential. If soil availability is adequate for a 25 bushel wheat yield, then in the event that conditions are favorable (better moisture supply) for 50+ bushel yield, the more extensive root system that develops for the higher yield will explore new soil and extract the required phosphorus.

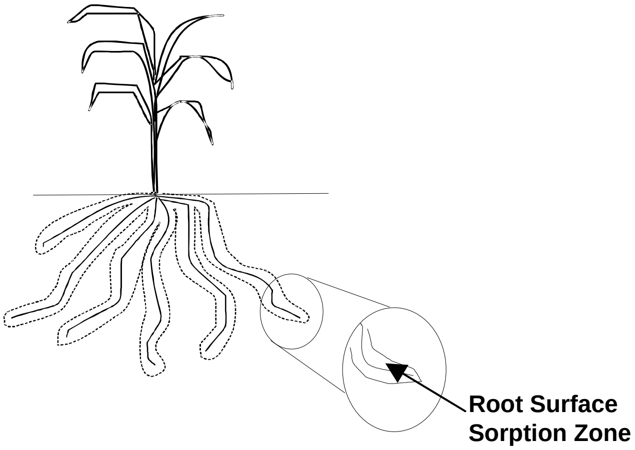


Figure 2.12. Small volume of soil from which plants extract immobile nutrients (root surface sorption zone).

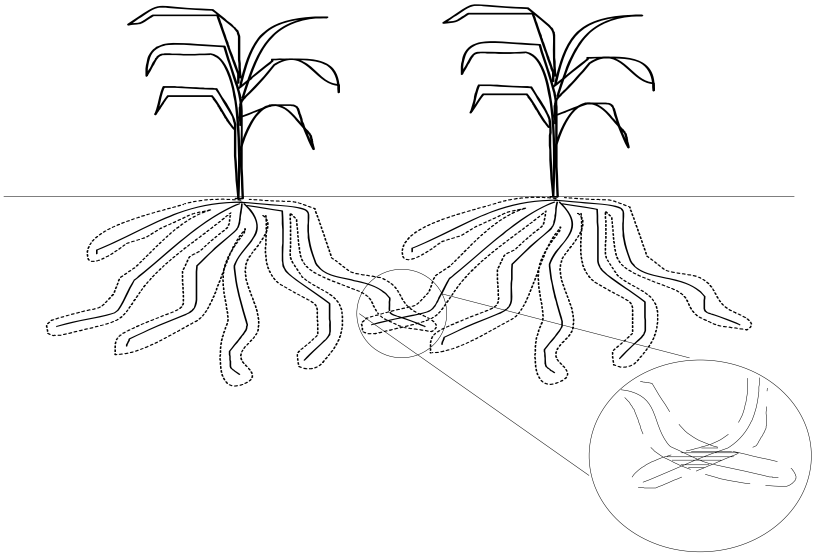


Figure 2.13. Limited competition among plants for immobile nutrients.

The mobility concept and these simple illustrations can help one understand the basis for some common practices and observations. For example, immobile nutrient fertilizers are usually more effective if they can be incorporated, but especially should be placed where roots have a high probability of coming in contact with the fertilizer. This is why band applying phosphate fertilizers is generally more effective than the same rate broadcast and incorporated. Mobile nutrients like nitrogen can be broadcast during the growing season (topdressing wheat) because they are easily moved to the roots with rain or irrigation. The phosphorus soil test does not change much from year to year regardless of the previous year’s yield or fertilizer rate because much of the soil was not in contact with the roots or fertilizer and its available phosphorus status was therefore unchanged. Continued broadcast application of high rates of phosphorus will cause a build up and an increase in the soil test phosphorus because only a fraction (15 to 20%) of the fertilizer comes in contact with the roots (fertilizes the crop) and the rest reacts only with the soil (fertilizes the soil).

It is sometimes useful to compare mobile and immobile nutrients and their management to fuel and oil for a tractor or pickup. Fuel is required in relation to the amount of work expected from the tractor in much the same way nitrogen is required in relation to the amount of yield expected from the crop. Oil is required more in relation to the level in the crankcase identified by the dipstick than by what or how much work is expected from the tractor (oil burners excepted!). Similarly, phosphorus and potassium requirements are determined from the soil test and the amount of fertilizer recommended does not depend on the yield goal. Like the dipstick that is calibrated with a mark showing "full" and "1-quart" low, the soil test for phosphorus (and any immobile nutrient) must be calibrated by field research. Just as the dipstick is uniquely calibrated for each kind of tractor, soil test calibrations vary slightly for different crops and soils and may be somewhat unique for states and regions.

ADVANCED CONSIDERATIONS

The students and faculty at Oklahoma State University developed a nitrogen cycle (Figure 2.14) that includes various components which are interlinked with what has been presented here. In addition, this cycle includes the relationships of temperature, pH, and oxygen with N dynamics in plant-soil systems. As you will note, this cycle is more complex than that illustrated in Figures 2.4, 2.6, or 2.7.

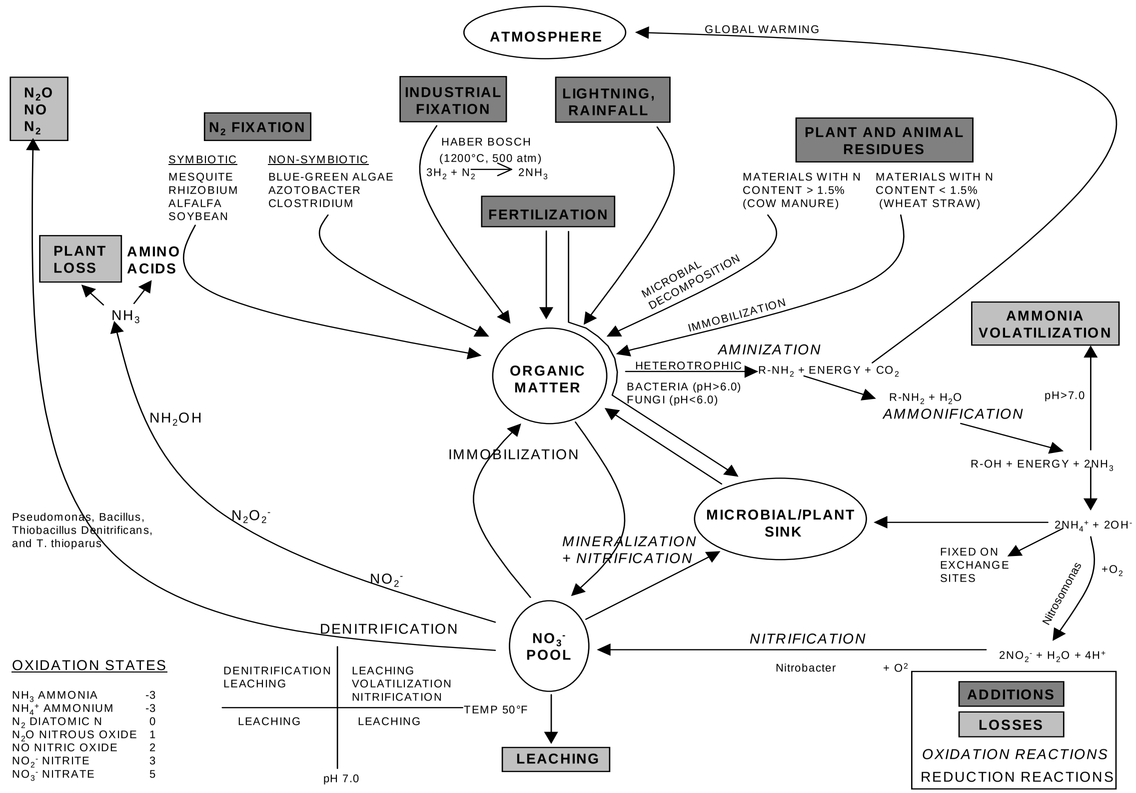


Figure 2.14. Nitrogen cycle.

Chapter 3 Problem Soils

Most soils in Oklahoma have developed under conditions that have resulted in them being naturally productive. Because of how they have been managed for agricultural production and otherwise changed by man's activities, some of these soils are now less productive. Two of the most common causes of productivity loss are the development of acid and saline (including saline-alkali and alkali) conditions. These soils develop under different conditions and their treatment and management is also different. They are often recognized as problem soils because they do not respond to normal management.

ACID SOILS

Soil acidity is a crop production problem of increasing concern in central and western Oklahoma. Although acid soil conditions are more widespread in eastern Oklahoma, their more natural occurrence has resulted in farm operators being better able to manage soil acidity in that part of the state. However, in central and western Oklahoma this problem is increasing with time.

The median soil pH of all agricultural samples tested by the Soil, Water and Forage Analytical Laboratory from 2000 to 2003 was 5.9. It means 50% of the sample had a pH less than 5.9 and 50% higher than 5.9 statewide. Some counties had more than 35% of fields with pH lower than 5.5, which is critically low for most field crops. The median soil pH for all counties is shown in Figure 3.1. More acidic soils are frequently found in the central part of the state due probably to intensive crop production.

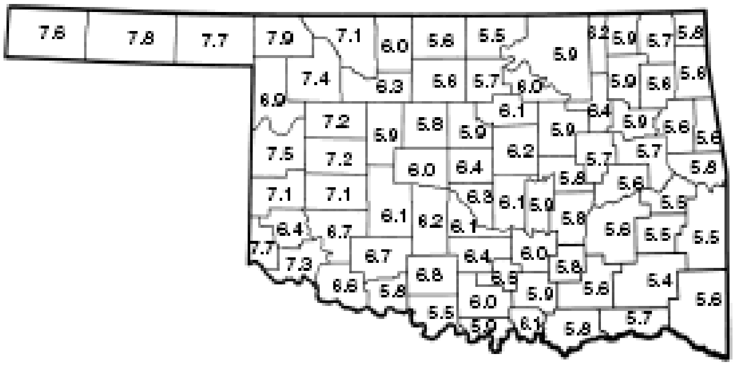


Figure 3.1. Median soil pH for all Oklahoma counties tested between 2000 and 2003.

Why Soils are Acid

The four major causes for soils to become acid are listed below:

1. Rainfall and leaching
2. Acidic parent material
3. Organic matter decay
4. Harvest of high yielding crops

The above causes of soil acidity are most easily understood when we consider that a soil is acid when there is an abundance of acidic cations (pronounced cat-eye-on), like hydrogen (H^+) and aluminum (Al^{3+}) present compared to the alkaline cations like calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and sodium (Na^+).

Rainfall and Leaching. Excessive rainfall is an effective agent for removing basic cations. In Oklahoma, for example, we can generally conclude that soils are naturally acidic if the rainfall is above about 30 inches per year. Therefore, soils east of I-35 tend to be acidic and those west of I-35, alkaline. There are many exceptions to this rule though, mostly as a result of item 4, intensive crop production. Rainfall is most effective in causing soils to become acidic if a lot of water moves through the soil rapidly. Sandy soils are often the first to become acidic because water percolates rapidly, and sandy soils contain only a small reservoir (buffer capacity) of bases due to low clay and organic matter contents. Since the effect of rainfall on acid soil development is very slow, it may take hundreds of years for new parent material to become acidic even under high rainfall.

Parent Material. Due to differences in chemical composition of parent materials, soils will become acidic after different lengths of time. Thus, soils that developed from granite material are likely to be more acidic than soils developed from calcareous shale or limestone.

Organic Matter Decay. Decaying organic matter produces H^+ which is responsible for acidity. The carbon dioxide (CO_2) produced by decaying organic matter reacts with water in the soil to form the weak acid called carbonic acid. This is the same acid that develops when CO_2 in the atmosphere reacts with rain to form acid rain. Several organic acids are also produced by decaying organic matter, but they are also weak acids. Like rainfall, the contribution to acid soil development by decaying organic matter is generally very small, and it would only be the accumulated effects of many years that might ever be measured in a field.

Crop Production. Harvesting of crops has its effect on soil acidity development because crops absorb lime-like elements, as cations, for their nutrition. When these crops are harvested and the yield is removed from the field, some of the basic material responsible for counteracting the acidity developed by other processes is lost, and the net effect is increased soil acidity. Increasing crop yields will cause greater amounts of basic material to be removed. Grain contains less basic materials than leaves or stems. For this reason, soil acidity will develop faster under continuous wheat pasture than when only grain is harvested. High yielding forages, such as bermudagrass or alfalfa, can cause soil acidity to develop faster than with other crops.

Table 3.1 identifies the approximate amount of lime-like elements removed from the soil by a 30 bushel wheat crop. Note that there is almost four times as much lime material removed in the forage as the grain. This explains why wheat pasture that is grazed will become acidic much faster than when grain alone is produced. Using 50 percent ECCE lime, it would take about one ton every 10 years to maintain soil pH when straw (or forage) and grain are harvested annually at the 30 bushel per acre level.

The use of fertilizers, especially those supplying nitrogen, has often been blamed as a cause of soil acidity. Although acidity is produced when ammonium containing materials are transformed to nitrate in the soil, this is countered by other reactions and the final crop removal of nitrogen in a form similar to that in the fertilizer. The effect of nitrogen fertilizers has been to increase yields and thus increase the removal of bases as shown in Table 3.1.

Table 3.1. Bases removed by a 30-bushel wheat crop.

	Calcium	Potassium	Magnesium	Sodium	Total
	------------- CALCIUM CARBONATE EQUIVALENTS ----------				
Grain	2	10	10	2	24
Straw*	11	45	14	9	79
Total	13	55	24	11	103**

*Straw/forage

**One ton of alfalfa will remove slightly more than this amount.

What Happens in Acid Soils

Knowing the soil pH helps identify the kinds of chemical reactions that are likely to be taking place in soils. Generally the most important reactions, from the standpoint of crop production, are those dealing with solubilities of compounds or materials in soils. In this regard, we are most concerned with the effects of pH on the availability of toxic elements and nutrient elements.

Toxic elements like aluminum (Al) and manganese (Mn) are the major causes for crop failure in acid soils. These elements are a problem in acid soils because they are more soluble (available for plant uptake) at low pH. In other words, more of the solid form of these elements will dissolve in water when the pH is very low. There is always a lot of solid Al present in soils because it is a part of most clay particles.

Element Toxicities. When soil pH is above about 5.5, Al in soils remains in a solid combination with other elements and is not harmful to plants. As pH drops below 5.5, Al containing materials begin to dissolve. Because of its nature as a trivalent cation (Al^{3+}), the amount of dissolved

Al is 1000 times greater at pH 4.5 than at 5.5, and 1000 times greater at 3.5 than at 4.5. For this reason, some crops may seem to do very well, but then fail completely with just a small change in soil pH. Wheat, for example, may do well even at pH 5.0, but usually will fail completely at a pH of 4.0.

The relationship between pH and dissolved Mn in the soil is similar to that described for Al, except that manganese (Mn^{2+}) only increases 100 fold when the pH drops from 5.0 to 4.0.

Toxic levels of aluminum harm the crop by "root pruning". That is, a small amount of Al in the soil solution in excess of what is normal causes the roots of most plants to either deteriorate or stop growing. As a result, the plants are unable to normally absorb water and nutrients, appear stunted and exhibit nutrient deficiency symptoms, especially those for phosphorus. The final effect is either complete crop failure or significant yield loss. Often times the field will appear to be under greater stress from pests, such as weeds, because of the poor crop conditions.

Toxic levels of Mn interfere with normal growth processes in above ground plant parts. This usually results in stunted, discolored growth and poor yields.

Desirable pH

The adverse effect of these toxic elements is most easily (and economically) eliminated by liming the soil. Liming raises soil pH and causes Al and Mn to go from the soil solution back into solid (non-toxic) chemical forms. For grasses, raising soil pH to 5.5 will generally restore normal yields. Legumes, on the other hand, do best in a calcium rich environment and often need a soil pH between 6.5 and 7.0 for maximum yields.

Soil pH in the range of 6.0 to 7.0 is also desirable from the stand point of optimum nutrient availability. However, the most common nutrient deficiencies in Oklahoma are for N, P and K, and availability of these elements will not be greatly changed by liming. Nutrients most affected by soil pH are iron and molybdenum. Iron deficiency is more likely to occur in non-acid (high pH) soils. Molybdenum deficiency is not common in Oklahoma, but would be most apt to occur in acid soils and could be corrected by liming.

Soil Buffer Capacity and Buffer Index. Although crops remove large quantities of lime-like materials that are harvested each year, the soil pH usually does not change noticeably from one season to the next. Because soil pH does not change quickly, it is said to be buffered. *Buffer* means the resistance to change of pH.

There are several reasons why soils have this buffer ability or buffer capacity. For example, in the Oklahoma Panhandle, soils commonly contain free calcium carbonate (lime). The term caliche is used to describe layers of soil material cemented by accumulated calcium carbonate. These accumulations provide a huge reserve of lime that will maintain soil pH in the alkaline range (above pH 7) for generations, perhaps centuries, even under the most productive agricultural systems.

A second contribution to the buffering capacity of soils is the release of basic chemical elements from normal chemical weathering of soil minerals. This is a very slow process that occurs whenever water is added to soil. The effect is influenced by the type of minerals in the soil, the amount and frequency of water addition, and soil temperature.

The most important source of buffer capacity in acid soils (no "free" lime present) is exchangeable cations. These are the lime-like chemical elements (mostly calcium) that are adsorbed on the surface of soil particles. These adsorbed basic materials act like a large reservoir that continually replenishes basic materials in the soil solution when they are removed by a crop or neutralized by acid. Figure 3.2 illustrates this and the relationship between soil pH and buffer capacity.

As crops remove bases from soil water in the reservoir on the right (Fig. 3.2), bases from the large reservoir of soil solids (clay and humus) on the left move to the soil solution and replenish the supply. Because of this relationship and the large reserve of bases from soil solids, the pH does not change much from month to month or even year to year. Also since the large reservoir on the left is shaped like a pyramid, pH can often be changed more easily by liming at pH near 6 than in the very acid pH 4.5 to 5.5 range.

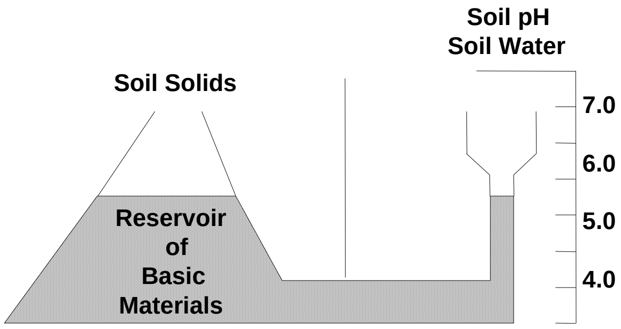


Figure 3.2. The relationship of basic materials in soil solids to pH of the soil solution.

Figure 3.3 shows the influence of soil organic matter and texture on buffer capacity. Both soils have a pH of 4.3, and are too acidic for efficient crop production. In order to provide a more favorable pH, the soils must each be limed. The amount of lime required will depend on the size of the large reservoirs and how base depleted they may be.

From these diagrams it is easy to understand why it takes much more lime to raise the pH of a clay soil with its large reservoir than it does for a sandy soil and its small reservoir. Also, because the reservoir of sandy soil is small, if acidifying conditions are equal, sandy soil will tend to become acid more rapidly and need to be limed more frequently than clayey soil.

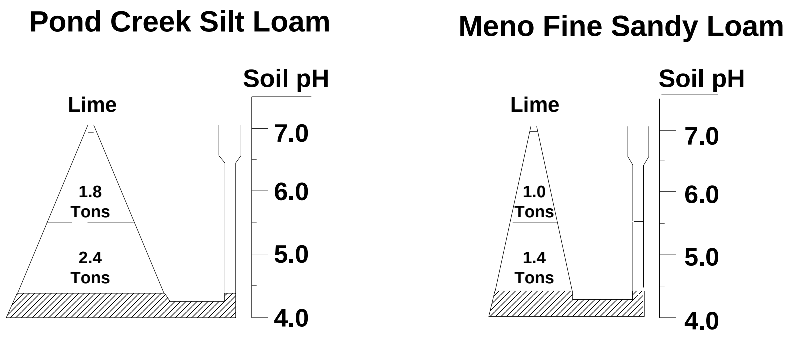


Figure 3.3 Reservoirs of soil solids in clayey vs. sandy soil.

The Soil Test

Buffer Index (BI) measured in the laboratory, as a part of the OSU routine soil test, is an indirect estimate of the soil reservoir size for storing basic material. Because the test involves adding basic (lime-like) material to soils of pH less than 6.3 and then measuring pH again, the BI pH is larger when the reservoir is small. The two soils illustrated in Figure 3.3 need to be limed. The Pond Creek Silt Loam soil would have a BI value of about 6.2. About 4.2 tons of ECCE lime would be required to raise the soil pH to 6.8. The sandy soil, having the same soil pH, would have a BI value of about 6.5 and require only 2.5 tons of ECCE lime to reach the same pH. The field calibration for BI and lime requirement is provided in Table 3.2.

How to Interpret pH and Buffer Index. Considering a soil test result of pH 5.8 and Buffer Index 6.8, where establishment of alfalfa is intended, the following steps are taken to determine the lime requirement.

Table 3.2. Tons of ECCE* lime required to raise soil pH of a 6-7 inch furrow slice to pH 6.8 or 6.4.

	LIME REQUIRED	
Buffer Index	pH 6.8	pH 6.4
over 7.1	none	none
7.1	0.5	none
7.0	0.7	none
6.9	1.0	none
6.8	**1.2**	0.7
6.7	1.4	1.2
6.6	1.9	1.7
6.5	2.5	2.2
6.4	3.1	2.7
6.3	3.7	3.2
6.2	4.2	3.7

*Effective calcium carbonate equivalent guaranteed by lime vendor.

First, the soil test pH of 5.8 is compared to the preferred pH for alfalfa in Table 3.3. Since the soil pH 5.8 is below the lowest pH in the preferred range, lime must be added to raise the pH to the desired level.

The amount of lime required is determined from Table 3.2 by locating the Buffer Index value of 6.8 in the left hand column and matching it to the number directly across from it (**bold**) under the middle column of numbers. In this case, 1.2 tons of ECCE lime would be required.

If the intended crop were wheat instead of alfalfa, no lime would be required this year because Table 3.3 shows that pH 5.8 is satisfactory for wheat production. Since the pH is satisfactory for wheat, the lime requirement would not be reported, even though the Buffer Index was measured. It would be important to regularly test this soil, especially if it were sandy, so lime could be applied before the soil became seriously acid (below pH 5.0) for wheat production.

Remember, the Buffer Index is only used as a guide for how much lime should be added to an acid soil when it is necessary to raise soil pH.

CORRECTING SOIL ACIDITY

Lime Reactions

Soil acidity can only be corrected by neutralizing the acid present, which is done by adding a basic material. While there are many basic materials which can neutralize acids, most are too costly or difficult to manage. The most commonly used material is agricultural limestone (aglime). It is used because it is relatively inexpensive and easy to manage.

Table 3.3. Common pH preference of field crops.

Crops	pH Range
Legumes	
Cowpeas, Crimson Clover, Soybeans, and Vetch	5.5-7.0
Alsike, Red and White, (Ladino) Clovers, and Arrowleaf Clover	6.0-7.0
Alfalfa and Sweet Clover	6.5-7.5
Non-Legumes	
Fescue and Weeping Lovegrass	4.5-7.0
Buckwheat	5.0-6.5
Sorghum, Sudan, and Wheat	5.5-7.0
Bermuda	5.7-7.0
Barley	6.5-7.0

The reason limestone is easy to manage is because it is not very soluble, meaning it does not dissolve easily in water. For this reason, it is not very corrosive to equipment and more importantly, its pH at equilibrium (after it has dissolved as much as it can and there is still some lime left in the water) is only about 8.3. This latter aspect is very important because even if an excessive amount of lime is applied, a harmful effect on crop yields would generally not take place.

The reaction of lime, or calcium carbonate ($CaCO_3$), with an acid soil is illustrated by Figure 3.4.

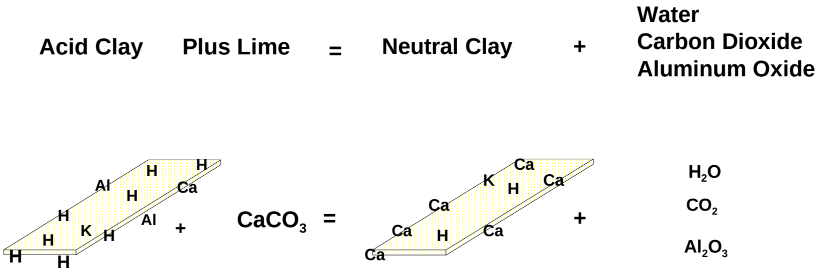


Figure 3.4. Illustration of how aglime neutralizes soil acidity.

This diagram shows that the acidity is on the surface of soil particles. As lime dissolves in the soil, calcium (Ca) from the lime moves to the surface of soil particles and replaces the acidity (H^+ and Al^{3+}). The acidity reacts with carbonate (CO_3) to form carbon dioxide (CO_2) and water (H_2O). The end result is a soil that is less acid.

Lime Research

Several field research experiments have been conducted on wheat over the past 20 years to examine suitable liming materials and application rates. A common feature of all effective commercially available liming materials is that they contain a basic lime-like material such as calcium or magnesium carbonate. Since it is ultimately the material from which other basic materials are derived, aglime is usually the lowest cost per ton of active ingredient (ECCE or Effective Calcium Carbonate Equivalent, finely ground pure $CaCO_3$ is defined to have an ECCE of 100).

A long-term liming study on wheat was conducted during a nine year period on a Pond Creek silt loam soil near Carrier, Oklahoma. Results of the study are illustrated in Figure 3.5. and show that through nine harvests, the yield of wheat was greatly improved by a single application of lime. It is important to note that although 4.8 tons of ECCE lime were recommended from the soil test in order to raise the pH to 6.8, one-fourth that rate (only 1.2 ton ECCE) was sufficient for eight years to restore yields to almost 100 percent of the yield obtained when 4.8 tons ECCE were applied. The 2.4 tons ECCE rate, 1/2 the normally recommended rate, was still effective at the end of the experiment.

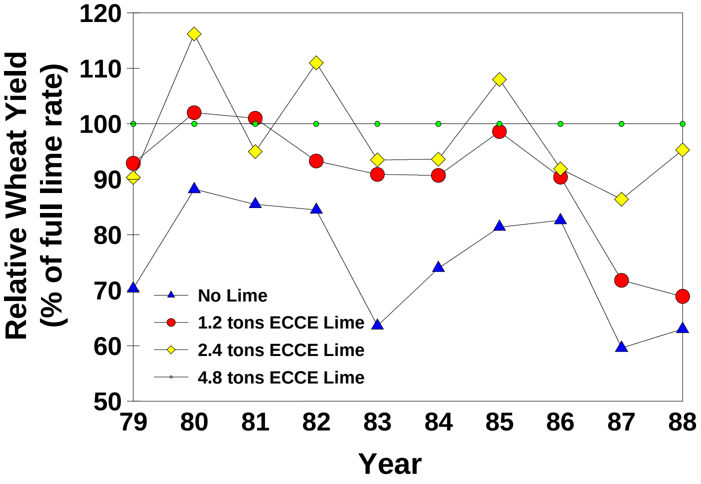


Figure 3.5. Long-term effect of lime on wheat yield.

Using information from recent field studies, such as the Carrier site, a relationship between OSU soil test pH values and expected wheat yield has been developed (Figure 3.6). The yield at a given pH is expressed as relative yield. This term means the expected yield as a percentage of that possible if soil acidity was not a limiting factor. For example, if a 40 bushel yield is expected with no acidity problems then at a soil pH of 5.0 a relative yield of 85%, or 34 bushels (40 x 0.85), would be expected.

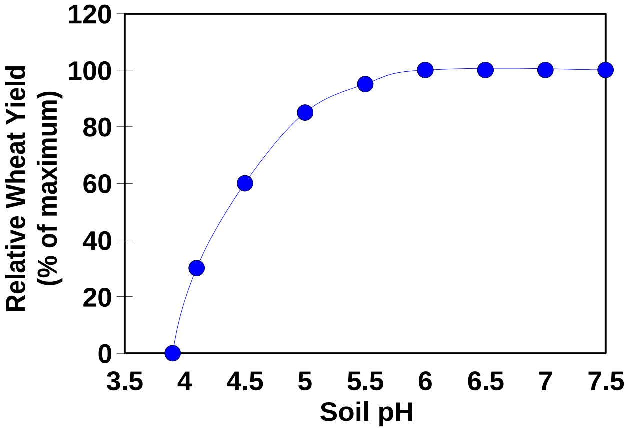


Figure 3.6. The effect of soil pH on wheat yield.

Lime Rates

Minimum Amounts. The amount of lime to apply for wheat production depends on whether or not you are growing continuous wheat or will rotate wheat with a legume. If wheat alone is grown year after year, it is necessary to only apply a rate of lime to raise the pH to above 5.5. If legumes are sometimes grown then soil pH should be raised to 6.5 or above. Thus, for continuous wheat the following recommendation is made:

> The minimum amount of lime to apply is 0.5 ton ECCE lime or 25% of the soil test deficiency amount required to raise the pH to 6.8, whichever is greater. An OSU soil test will identify these lime rates for wheat whenever the soil pH is below 5.5.

Calculating Rates. Lime requirements are expressed in terms of ECCE. The ECCE is provided as a guarantee from lime vendors who are registered to sell aglime in Oklahoma. The guarantee is obtained by an analysis of the lime by the Oklahoma State Department of Agriculture, Food and Forestry. There are two components to the determination by their lab. First, the purity of the lime is determined chemically (purity factor). In this test they analyze for the fraction of $CaCO_3$, or its equivalent, in the lime material. The second measure is a determination of how finely the lime particles are ground (fineness factor). The fineness factor is determined by weighing sieved portions of a lime sample. The factor is then calculated by taking ½ times the fraction (e.g. 0.90) of sample passing an 8 mesh sieve plus ½ times the fraction (e.g. 0.70) of sample passing a 60 mesh sieve. The fineness factor for these example values would be:

$$\tfrac{1}{2} \times 0.90 + \tfrac{1}{2} \times 0.70 = 0.80$$

The purity factor (a fraction) and the fineness factor (a fraction) are multiplied and then times 100 to obtain the ECCE value. If the purity factor was 0.90 (90% pure or equivalent calcium carbonate) then the ECCE would be (0.90 x 0.80) x 100, or 72%. The more $CaCO_3$ in the material and the finer the particle size, the greater the ECCE. Good quality lime will have an ECCE value above 50 percent. Because aglime does not always have an ECCE of 100 percent, the amount required to provide a given amount of 100 percent ECCE must be calculated. The calculations to use are shown below:

$$\frac{\text{ECCE lime required}}{\text{\% ECCE}} \times 100 = \text{aglime required}$$

For example, let us assume that the available aglime was 72% ECCE and the soil test indicated a need for 1.5 tons ECCE to raise the soil pH to the desired level. The calculations would be:

$$\frac{1.5 \times 100}{72} = 2.1 \text{ tons of aglime.}$$

So, 2.1 tons per acre of the 72% ECCE lime would have to be applied in order to get the 1.5 tons of 100 percent ECCE lime required to do the job.

Lime Applications

Because lime does not dissolve easily in water, it must be treated similarly to fertilizers that supply the soil with immobile nutrients like phosphorus. Thus, for lime to be most effective in neutralizing soil acidity it must be thoroughly mixed with the soil. Since neutralization involves a reaction between soil particles and lime particles, the better lime is mixed with the soil, the more efficiently the acidity is neutralized. For this reason, wet materials (like that from water treatment plants) which cannot be thoroughly mixed with the soil are often less effective. Similarly, pelleted lime particles are too large to mix well with small soil particles. Attempts to mix these materials with soil often result in soil acidity being neutralized only near the lime aggregates (or pellets), whereas acidity between aggregates remains unaffected. Once the proper rate has been determined and the lime has been spread to give a uniform application over the field, it is best to incorporate it with a light tillage operation such as disking. Disking can be followed by plowing, but care should be taken not to plow too deeply or the lime will be diluted by subsoil and be less effective. Lime rates are calculated on the basis of neutralizing the top six inches of soil.

Since the lime reaction involves water, the effect of lime will be very slow in dry soil. Even when everything is done correctly and the soil is moist, it often takes a year or more for a measurable change in soil pH to occur. For this reason, liming for wheat production should be done as soon after harvest as possible. However, when the soil pH is extremely low, sufficient change may occur in just a few weeks and make the difference between being able to establish a wheat crop and having a failure.

A similar approach should be used for annual planting of other grasses. When continuous production of perennial grasses is planned, the full rate identified by the soil test buffer index should be applied pre-plant. This practice allows incorporation of the lime to maximize its reaction with soil and will maintain a desirable pH for several years after establishment. Careful monitoring of high producing forage grasses, such as bermudagrasses, by periodic soil testing will identify lime needs early enough to maintain desirable soil pH by unincorporated broadcast application.

Liming Materials

The most common and most effective liming material continues to be ground aglime. It is marketed by the ton, should generally be powdery with only a small percentage of coarse (sand size) particles, and have an ECCE of 50% or greater. Variations and different formulations of ground aglime have been developed and marketed. These materials are often promoted on the basis of being more effective or less expensive. The merits of these products should be considered carefully.

"Liquid Lime" is a formulation of high quality aglime (usually ECCE is above 90%) with water and enough clay to keep the lime in suspension. The amount of water added may range from 35 to 50%. Care should be taken to make sure that the added water is not being charged for, as if it were high quality lime. When 90% ECCE lime is mixed 50% (weight to weight) with water, the resulting product is only 45% ECCE lime (90% x .50 = 45%). The fact that it is suspended in water does not increase its effectiveness. On the contrary, wet lime will not mix as easily with soil and therefore, its neutralizing effectiveness may be less than an equal amount of dry ECCE aglime.

Similarly, "water treatment lime" may not be as effective as an equal rate of aglime. This material is a waste product from water treatment plants. Although it has a high ECCE, it is often wet when applied and a good mixture with soil is difficult to obtain. Too often, large chunks or globs remain mixed with the soil and only the acid soil next to the chunk of lime is neutralized, leaving large areas of soil between chunks that remain acid.

Pelleted lime is finely ground lime that is pressed into pellets. Until the pellets physically break up and the fragments of powder size lime become thoroughly mixed with soil, these too are limited in neutralizing soil acidity. Pellets, liquid lime, and water treatment lime can be spread or applied without dust common to good aglime. Although easily visible, airborn dust associated with aglime application represents only a small fraction of the total applied, and loss from the field should not be significant.

Finally, sometimes coarse "road grade" lime is in abundance and can be purchased at a very low cost. This cheap lime is too coarse to have a reasonable ECCE and will not be sold as aglime. Because of the existing aglime law in Oklahoma, whenever a material is marketed and sold in Oklahoma as aglime it must be accompanied by a guaranteed ECCE. The guaranteed ECCE must be of the formulated product and not its ingredients.

REDUCING METAL TOXICITY

Fertilizer Reactions

Phosphate in the soil has long been known to be less available to crops in some extremely acid soils because it reacts with aluminum and/or manganese, which are more available in acid soils. When phosphate reacts with these metals, the compound formed is a very insoluble solid (such as aluminum phosphate). As a result, not only is the phosphate unavailable, but the aluminum and manganese are also unavailable. For these reasons, when phosphate fertilizers are banded with the seed at planting time, the harmful effects of toxic aluminum and manganese are greatly reduced and near normal yields may be obtained. Figure 3.7 illustrates the benefit of this practice for both grain and forage production.

Phosphate Materials and Rates

Figure 3.7 also shows that a higher rate of phosphate may be needed in order to get maximum benefits for fall forage production. It is especially important to use the higher rate for forage production on soil that has a pH below 4.5. The use of phosphate fertilizer in this way does not change soil pH. Also, within a few months after all the phosphate has been "used up", more aluminum and manganese may become available. While this may not affect the developed crop, it will affect the next crop in the seedling stage. As a result, phosphate fertilizer must be applied each year whereas lime only needs to be applied every five to eight years. On the other hand, buildup of soil test P above crop needs may lead to increased P in the runoff.

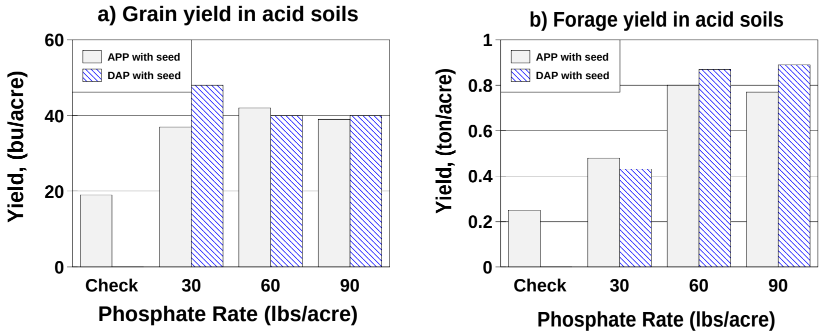


Figure 3.7. Responses of wheat grain and forage yields to seed-applied phosphate fertilizers (APP: ammonium polyphosphate; DAP: diammonium phosphate in a strongly acidic soil.

When to Use Phosphate

As stated earlier, acid soil is best neutralized by adding aglime. However, seed-applied phosphate (either ammonium polyphosphate or diammonium phosphate) should be considered for acid wheatland soils when

1. the land is owned by someone else who will not provide a long-term lease or pay some of the cost for liming.
2. the soil acidity problem is discovered too late for lime application in a given season.
3. the soil has a low soil test value for phosphorus.

It is important to remember that this use of phosphate fertilizer is very different from normal. Banding phosphate on acid soils can increase yields even when the phosphate soil test value is very high (>65); not because more phosphate is provided to the plant, but because metal toxicity is reduced. Also, it is important to remember that the soil continues to become more acid with time. Eventually lime must be added to the soil to neutralize acidity.

SALINE AND ALKALI SOIL

Two other problem soils are salty (saline) soils and slick-spot (alkali or sodic) soils. A third problem soil often develops from slick-spots when they are poorly managed. This is the saline-alkali soil which results when slick-spots become salty.

Although all problem soils may be identified with poor crop production, these soils have other similarities and differences which are important to know before attempting to improve or reclaim them.

Saline soils are soils which contain at least 2600 ppm soluble salts in the solution from a soil saturated with water. The salt content is estimated by laboratory measurement of how well the soil water conducts electricity, and saline soils are those with an electrical conductivity (EC) of 4,000 micromohs/cm (about 2600 ppm). This level of salts is great enough to reduce production of salt-sensitive crops. Normal, productive agricultural soils commonly have electrical conductivity values below 1000.

Alkali soils are soils which contain enough sodium (Na) to cause 15% of the cation exchange sites to be occupied by Na (exchangeable sodium percentage, ESP). Sodium in the soil, prevents clay particles (and other very small, colloidal sized particles such as humus) from coming together and forming large soil aggregates. When soils contain 15% or more of exchangeable sodium most of the clay and humus particles are unattached or dispersed. These soils commonly have a pH of 8.5 or above (alkali). Some Oklahoma soils become dispersed when the exchangeable sodium is as low as 7 percent. Productive agricultural soils often have less than 1 percent exchangeable sodium. Soils can be classified into 4 groups based on the EC and ESP of saturated paste extract. They are illustrated in Fig. 3.8.

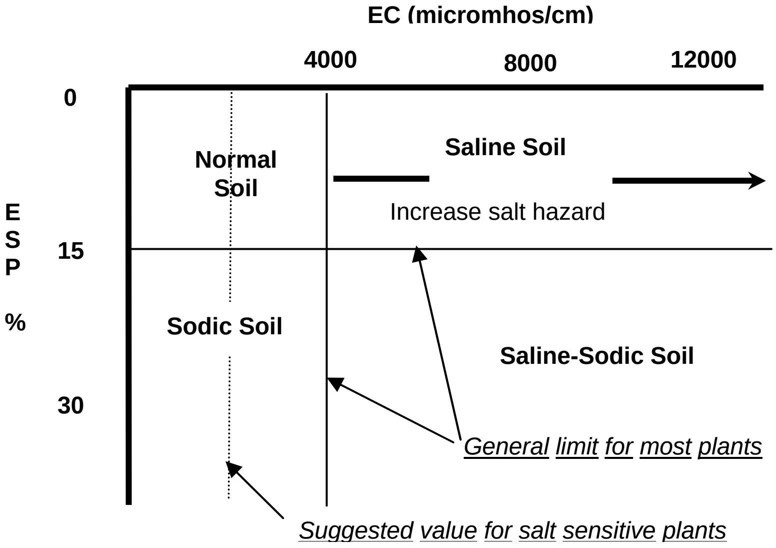


Figure 3.8. General classification of salt affected soils.

Characteristics of Saline Soils

Small, Growing Areas Affected. Naturally developed saline soils usually represent only small areas of a field. Often these are low lying parts of the field which may have poor internal soil drainage. Other small areas occur on slopes where erosion has exposed saline or alkali subsoil. Because low areas are frequently wet when the rest of the field is dry enough for cultivation, these small areas frequently are cultivated when the soil is too wet. This results in the soil becoming compacted in and around the area. Water does not move easily through the compacted soil so more water evaporates, leaving salts from the water to accumulate. As a result, the affected area increases with time.

Poor Yield. Crop production is usually less than normal in salt affected areas. Yield reduction is greatest in years of less than normal rainfall or when water stress has been a yield limiting factor. Salts "tie-up" much of the water in the soil and prevent plants from absorbing it. Seedlings are the most sensitive to water stress and crop stand is reduced because of seedling death and poor yield results.

White Surface Crust. As water evaporates from saline soils, salts which were in the water are left behind to accumulate on the soil surface. Salts are light colored and when accumulation has continued for several days they form a very thin white film on the soil surface. During hot, dry weather, the light film will show up first along edges of the salt problem areas. The center of these areas usually has the most salt and will dry out last.

Good Soil Tilth. Saline soils generally have excellent physical conditions throughout the tillage depth. This is caused by salts effectively neutralizing the negative charge of clay particles, allowing them to attach to one another. When these soils are not too wet, the soil is friable, mellow, and easily tilled. The appearance after tillage is that of a very productive soil.

High Soil Fertility. Soil which has been saline for several years will usually be very fertile, and high N, P, and K soil test values are often a clue of a problem salty soil. These nutrients build up in salty areas when there is little crop nutrient removal and the area is fertilized each year. Soil pH does not change in relation to salt content and it cannot be used as an indicator.

CHARACTERISTICS OF ALKALI SOILS

Except as noted, alkali soils have characteristics similar to saline soils. For this reason, one problem soil may be confused with another. Their differences, however, are important to note as they relate to correcting the problem soils.

Poor Soil Tilth. The excess sodium in alkali soils does not allow soil particles to easily attach to one another. As a result, alkali soil is dispersed and not friable and mellow like saline soil. Instead, alkali soil is greasy when wet ("slick-spot"), especially if it is fine textured, and often very hard when dry. This poor physical condition makes these soils difficult to manage. They are often either too wet or too dry for tillage. Poor seed germination and stand establishment are common because good seedbed preparation is seldom accomplished. As a result, yields are usually lower than the rest of the field and fertility may build up.

Dark or Light Colored Surface. Soil colloids which are floating in the soil water are left as a thin film on the surface after water evaporates. The surface color will be darker than the rest of the field (black-alkali) when the particles are mainly humus since humic acid dissolves in alkali solution and lighter (white-alkali) when the particles are mainly clay and salts. The salts show up as a film when the surface dries.

Droughty But Pond Water. Large pores or channels in the soil which allow water entry and penetration become plugged with dispersed clay and humus. As a result, the subsoil may be very dry even though water is ponded on the surface. Plants that do become established often suffer water stress and may eventually die from lack of water and/or oxygen.

Reclamation

In many instances saline soils and alkali soils can be reclaimed by following a definite series of management steps designed to leach or "wash out" the salts or sodium. The order and description of these steps follows.

Verify Problem. The first step to solving the problem is clearly identifying it. This is best done by having the soil tested. Suspected areas should be sampled separate from the rest of the field. It is best to sample during a dry period of the growing season when affected areas of the field can easily be identified by poor crop growth. Samples should be taken at least one week from the last rain or irrigation and only the top three inches of soil should be sampled. Several small samples of the affected area should be combined in a plastic bucket and mixed to get a good sample.

About one pint of soil is required for the test which is done by the OSU Soil Testing Laboratory. Samples should be submitted through your local OSU County Extension Office requesting a Salinity Management test. Testing takes about a week and a small fee is charged to cover costs. This test will identify the type and severity of the problem.

Identify Cause. Whenever possible, it is important to find out what has caused the problem soil to develop. Knowing the cause can help in modifying the remaining reclamation practices and sometimes provide a clue as to how long it may take to complete the reclamation. The four most common causes of saline and alkali soils in Oklahoma are:

a) naturally poor drainage;
b) poor irrigation water;
c) brine spills;
d) exposure of saline or alkali subsoil due to erosion.

Poorly drained soils are simply soils which water does not easily penetrate. This condition may be a result of the soil having a high clay content, having a water table near the surface (within 10 feet), or existing in a low lying area of the field. In the latter situation, normally adequate internal drainage may not be able to handle runoff from the surrounding area. In some instances internal soil drainage is greatly reduced as a result of compacting the surface soil.

Use of poor quality irrigation water may cause problem soils to develop if special precautions are not taken. The problem develops most rapidly during extremely dry years when evaporation and the amount of irrigation are high. Internal soil drainage may be a contributing factor.

Problem soils sometimes develop "overnight" when brine solutions associated with oil and gas well activities spill onto the soil. Depending on the amount of brine solution spilled and the size of the area, the problem may be slight or very severe.

Whenever the source of salt or sodium causing the problem is the result of addition from runoff, seeps, irrigation water or spilled brine, it is important to eliminate that source as soon as possible.

Improve Internal Soil Drainage. There are no chemicals or soil amendments that can be added to the soil to "tie-up" or somehow inactivate soluble salts or sodium. Hence, the only way of lowering their concentration in the soil is to remove them. This can only be done by leaching (washing out) the salt or sodium downward out of the root zone. In order for this to happen, internal drainage must be good so water can easily pass through the soil.

There are a number of ways internal drainage can be improved. Most are expensive, but when the problem is severe many will pay for themselves with time. Tile drains and open ditches are effective for removing subsoil water that accumulates due to a restrictive layer such as compacted clay or bed rock. Compacted soil layers near the surface can be broken up by subsoiling. This is effective only if done when the soil is dry enough to have a shattering effect and at best provides only temporary benefit.

Problem soils which have developed from use of poor irrigation water or brine spills may already have good internal soil drainage.

Add Organic Matter. Once internal drainage has been assured, the next important step is to improve water movement into the soil. Incorporating 20-30 tons per acre of organic matter into the top six inches of soil creates large pores or channels for water to enter. Even rainfall from intense storms is more effective because there is less runoff. In addition to improving water movement into the soil, the large pores lessen the capillary or wick-like upward water movement during dry periods. Any coarse organic material such as barn yard manure, straw, rotted hay, or crop residue is suitable.

Add Gypsum to Slick-Spots. Up to this point the reclamation practices are the same for both saline and alkali soils. In either situation, leaching is critical to remove salt or sodium. However, since high amounts of sodium absorbed to the soil are the cause of alkali problems, sodium must be loosened from the soil before it can be leached out. Gypsum is the most effective soil amendment for removing sodium from the soil particles. Gypsum is a slightly soluble salt of calcium sulfate. This means that gypsum will slowly react in the soil, but for a long time. The reaction is illustrated in Figure 3.9.

Gypsum applications are needed when the exchangeable sodium percentage (ESP) approaches 15 percent. Calcium ions (Ca^{2+}) in gypsum replace sodium ions (Na^{+}) on the colloids which results in improved soil conditions. The amount of gypsum required will vary widely depending upon the percentage of exchangeable sodium and the soil texture, as determined by the soil test. This relationship is shown in Table 3.4.

When the required amount of gypsum exceeds five tons per acre, the rate should be split into two or more applications of no more than five tons at one time. Successive applications should not be made until time has allowed for some leaching to occur, and the need has been verified by a second soil test. The gypsum should be incorporated only to a depth of about one or two inches, enough to mix it well with the surface soil and keep it from blowing away.

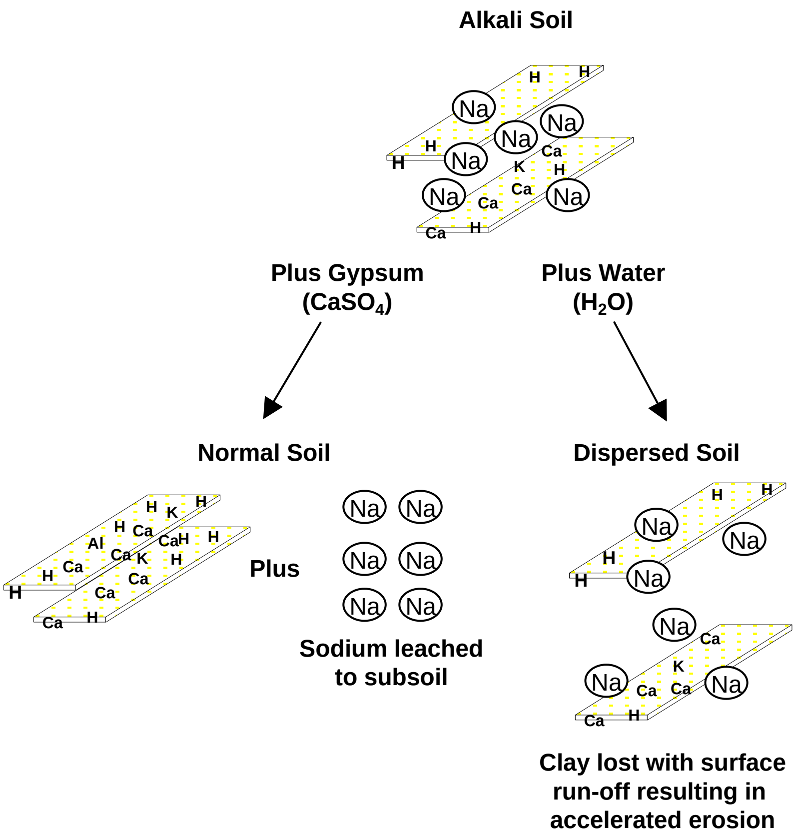


Figure 3.9. Alkali soil reacting with gypsum to form normal soil.

Table 3.4. Gypsum requirement in tons per acre as related to soil texture and sodium percentage.

	------------ Exchangeable Sodium Percentage ------------				
Texture	15	20	30	40	50
	------------------------ gypsum (ton/ac) ------------------------				
Coarse	2	3	5	7	9
Medium	3	5	8	11	14
Fine	4	6	10	14	18

Leach Soil. Leaching (or washing out) the soil is essential to reduce the amount of salts or sodium in the soil. In order for this leaching process to occur, water must enter the soil in excess of what is used by growing crops and lost by evaporation. How fast and to what extent the reclamation is successful will depend on how much good quality water passes through the soil in a given period of time. The shorter the time interval over which excess water is applied, the more effective that amount of water is in reclamation. For this reason, rainfall is most effective when it falls on soil which is already wet.

Avoid Deep Tillage and Establish Cover. Once the leaching process has been started, deep tillage such as moldboard plowing should be avoided for several years to promote uninterrupted downward movement of the salts. Such tillage will bring salt back up to the soil surface, and leaching is then again required. As soon as the salt level in the soil is low enough, a salt tolerant crop such as barley or bermudagrass should be established on the problem area to provide a cover for as much of each growing season as possible. It is especially important to have the cover crop during midsummer when evaporation is high. Adequately fertilized bermudagrass does a good job of drying the soil. To minimize soil compaction it should be cut for hay instead of pastured, make sure to keep heavy equipment off the area when it is wet.

Some problem areas may be too salty to establish a cover crop until some salts have been leached out. A cover crop can be established when there is no longer a white salty film on the soil surface, following a week or two of dry weather, or when weeds begin to grow.

Wait. The final step in reclamation is simply to wait for the previous practices to work. Except for brine spills, these problem soils developed over a period of several years. Reclamation may not take as long, but, depending on how well reclamation practices can be carried out, may take one or more years.

Alternative to Drainage – Reclamation

Learn to Live With It. The key to successful reclamation is good internal soil drainage. If salts or sodium cannot be leached out, the soil cannot be reclaimed by conventional methods. However, most soils have some internal soil drainage, and although drainage may not be good, over several years time it may be sufficient to lower the salt concentration to near normal. During this time it will be important to practice some of the same steps outlined above. Especially important are the following:

1. Avoid excessive fertilization.
2. Avoid traffic on field when wet.
3. Apply gypsum to slick spots.
4. Establish cover crop.
5. Maintain high level of crop residue.
6. Be patient!

Depending on the severity of the problem it may be necessary to select a different crop than has been grown in the past. A list of crops and their relative tolerance to salt is provided in Table 3.5.

Table 3.5. The relative salt tolerance of crops.*

Tolerant	Moderately Tolerant	Sensitive
	In Increasing Order of Tolerance	
	FIELD CROPS	
7,800-10,400 ppm	3,900-7,800 ppm	2,600 ppm
Cotton	Sunflower	Field beans
Sugar beet	Corn	
Barley (grain)	Soybeans	
	Grain sorghum	
	Oats (grain)	
	Wheat (grain)	
	Rye (grain)	
	FORAGES	
7,800-11,700 ppm	2,600-7,800 ppm	1,300-2,000 ppm
Wheatgrass	Smooth bromegrass	Ladino clover
Birdsfoot trefoil	Fescue	Red clover
Barley (hay)	Blue grama	White Dutch clover
Rescue grass	Oats (hay)	Peanuts
Rhodesgrass	Wheat (hay)	
Bermudagrass	Rye (hay)	
Saltgrass	Alfalfa	
Alkali sacaton	Sudangrass	
	Dallisgrass	
	Perennial ryegrass	
	Yellow sweetclover	
	White sweetclover	
	VEGETABLE CROPS	
6,500-7,800 ppm	2,600-6,500 ppm	1,950-2,600 ppm
Spinach	Cucumber	Green beans
Asparagus	Squash	Celery
Kale	Peas	Radish
Garden beets	Onion	
	Carrot	
	Bell pepper	
	Sweet potato & yam	
	Potato	
	Sweet corn	
	Lettuce	
	Cauliflower	
	Cabbage	
	Broccoli	
	Tomato	
	FRUIT CROPS	
	Cantaloupe	Strawberry
	Grape	Peach
		Apricot
		Plum
		Apple
		Pear

* Salt tolerance values at which 50% yield reduction may be expected compared to nonsaline conditions. Salt concentrations are for a soil saturated paste extract.

Chapter 4 Determining Fertilizer Needs

Determining fertilizer and lime needs for selected fields and crops are critical management decisions that often mean the difference between profit and loss for farmers. Applying too little fertilizer or lime when deficiencies exist hurts yields and profit potential. Too much fertilizer reduces nutrient use efficiency, cutting into profits and in some cases, negatively impacting the environment. In today's economic and political atmosphere, farmers must be concerned about both effects.

At one time, determining fertilizer and lime requirements of Oklahoma crops was simple. If a fertilizer contained phosphate, it was good because almost all Oklahoma soils were low in phosphorus. Because of this, in the early days of fertilizer use, 10-20-10 was an effective fertilizer that gained popular use. This thinking no longer applies. Many soils have been fertilized for many years, increasing soil fertility much above native levels. In other soils, continuous cropping has decreased soil pH values to yield-robbing levels or depleted once abundant supplies of nutrients. Farmers can no longer afford to guess about their fertilizer and lime needs. The fertility levels of each field must be known in order to best manage the entire farm.

There are three approaches to determining fertilizer needs: (1) soil testing, (2) scouting for nutrient deficiency symptoms, and (3) plant analysis. Soil testing is by far the most successful method. To obtain maximum benefit, it must be done on a regular basis and should therefore be viewed as a routine component of an overall soil fertility program. A soil fertility program can be enhanced by scouting for nutrient deficiency symptoms and by using plant analysis when applicable, but soil testing remains as the foundation.

USE OF SOIL TESTING

Soil testing evolved from an understanding by soil scientists that plants require chemical elements as nutrients. Thirteen of the essential nutrient elements for plants come from the soil. The soil's nutrient supplying capacity is a chemical characteristic of the soil, and therefore, is most reliably measured or estimated by chemical tests (e.g., soil testing). The concept of soil testing is not new. Even in ancient times, farmers had a limited understanding of basic soil fertility concepts as can be gathered from the ancient agricultural practices documented in Table 4.1. Modernization of soil fertility principles and the refinement of soil testing began in the mid 1800's with advances continuing to this day (Table 4.2).

Table 4.1. Ancient agricultural practices related to soil testing.

Date	Location	Agricultural practice
2500 B.C.	Mesopotamia	First recorded writings mentioning soil fertility. Barley yields observed to range from 86 to 300 times that planted depending on the area in which the crop was grown.
900 B.C.	Greece	Manuring was an agricultural practice known to improve soil productivity.
300 B.C.	Greece	Various sources of manure were classified according to their value as a soil amendment. Green manure crops, especially legumes, were also known to enrich the soil.
100 B.C	Rome	The value of using marl and other liming materials as soil amendments was recognized.
50 B.C.	Rome	That which may be considered the first soil fertility test was developed. Columella recommended using a taste test to measure the degree of acidity and salinity of soils.

Soil testing in Oklahoma first became popular in the 1950's. Soil testing for farmers was primarily performed by county extension agents who operated small laboratories out of their county offices. Samples were periodically analyzed by researchers at the Oklahoma State University campus to verify their accuracy. In the 1960's, Dr. Billy Tucker, an extension soil fertility specialist, and Dr. Lester Reed, a soil chemist, helped analyze approximately 200-300 samples per year for the county agents.

After several years, Dr. Tucker realized that advances in research and technology were causing the county soil testing laboratories to become outdated. In order to maintain a quality soil testing/soil fertility program at OSU, a centralized state soil testing laboratory was needed that used standardized methods and interpretations based on statewide research.

The task was easier said than done. Much resistance was met from the county agents, who took pride in their soil testing skills and also saw their laboratories as a means of making contacts with farmers and generating extra income for other extension programs. After much public and private debate, Dr. Tucker finally convinced the director of extension and most county agents to support the establishment of a centralized soil testing laboratory on the OSU campus. Since that time (1969), sample activity at the OSU laboratory has grown to approximately 25,000 soil samples per year.

Table 4.2. Modernization of soil testing.

Date	Location	Event
1842	Germany	Justus von Liebig states his “law of the minimum”.
1843	England	J.B. Lawes and J.H. Gilbert establish the Rothamsted Experimental Station.
1892	U.S.A.	Magruder Plots established by Alexander C. Magruder in Stillwater, Oklahoma.
Late 1800’s	U.S.A.	E.W. Hilgard promotes the use of hydrochloric acid as an extractant for determining fertility status of soils.
1909	Germany	E.A. Mitscherlich develops his equation relating growth to the supply of plant nutrients.
Early 1900’s	U.S.A.	C.G. Hopkins promotes the importance of monitoring changes in soil fertility status to prevent decreases in productivity as a result of nutrient depletion.
1940’s and 50’s	U.S.A.	Introduction of new crop varieties and hybrids and increases in the availability and use of fertilizers spur interest in soil testing as a management tool.
1960’s to present	U.S.A.	Evolution of soil testing continues on all fronts as technological advances allow improvements in the areas of analysis, correlation, calibration, and interpretation.

VALUE OF SOIL TESTING

Soil tests are designed to estimate plant-available fractions of selected nutrients, that is, that portion of a nutrient present in the soil that a plant can remove for food. Soil fertility tests do not measure total amounts of nutrients in the soil because not all chemical forms of the nutrient can be used by the plant. As a soil test level increases for a particular nutrient, the ability of the soil to supply that nutrient also increases and less fertilizer needs to be added to adequately supply food for the plant.

Much field and laboratory research must be conducted to accurately interpret soil tests so proper amounts of fertilizer are recommended for application. This process is called calibration. During the calibration process, a relationship is established between the soil test value and the amount of fertilizer needed by the plant. Soil tests are calibrated by establishing fertilizer rate experiments on soils with different soil test levels to determine the best fertilizer rate for each level. Once a number of fertilizer experiments have been conducted, the data can be summarized and fertilizer recommendation guides can be developed. Agricultural Experiment Stations provide this information.

SOIL SAMPLING

Producers and fertilizer dealers must remember that a good soil sample is obtained by sampling a uniform field area. Avoid sampling "odd-ball" areas. Sample each field separately, as well as dissimilar soil types within the same field. A core or slice from the surface to a depth of 6 should be taken from 15-20 locations in the field and composited into one representative sample to be tested.

Subsoil samples for nitrates are valuable for estimating fertilizer nitrogen carryover. The nitrogen fertilizer rate is easily adjusted to take advantage of "leftover" nitrate. The subsoil test should be taken from 6 to 24 inches. Sample depth should be indicated when submitting subsoil samples for the nitrate test. Subsoil sample analysis can help provide a more reliable estimate of other nutrients that are mobile in the soil, such as boron, sulfur, and chlorine.

Soil samples may be submitted to your county OSU extension office. They will send the samples to the Soil, Water and Forage Analytical Laboratory for testing, and then send the results back to you with fertilizer recommendations. Soil samples are analyzed routinely for pH, nitrate nitrogen, phosphorus, and potassium, while calcium, magnesium, sulfur, zinc, iron, and boron are tested on request. The subsoil is only analyzed for nitrate unless otherwise requested. A number of other tests are also available through the lab.

LABORATORY SOIL TESTS

A brief description of laboratory tests currently used at the OSU lab follows.

pH

This test measures the active soil acidity or alkalinity. A pH of 6.9 or less is acid. Soils with a pH of 7.0 are neutral; values higher than 7.0 are alkaline. Under normal conditions, most plants grow well when soil pH is in the range of 6.0 to 7.5. An application of lime should be considered for most non-legume crops when soil pH is 5.5 or less. Legumes usually grow best when the pH is 6.0 or higher.

Buffer Index

When soil pH is less than 6.3 a buffer index reading is obtained. This value estimates the amount of lime required to correct soil acidity. The buffer index value is not a standard pH reading and means nothing without a calibration table that relates it to the amount of lime to apply. The lower the buffer index, the higher the lime requirement.

Nitrate

The nitrate soil test measures the actual amount of nitrate-nitrogen in the soil, which is available to plants. The nitrogen fertilizer requirement can be determined by subtracting the pounds of nitrate-nitrogen in the soil from the total nitrogen requirement for a selected yield goal.

Phosphorus

The phosphorus (P) soil test estimates the amount of available soil P. The actual amount cannot be measured because of chemical reactions occurring in the soil. The estimated availability is reported as a percent sufficiency in the soil. A soil test with 40 percent sufficiency means 40 percent of plant P needs will be supplied by the soil. The remainder must be provided by adding fertilizer. If no P is added, the yield will only be 40 percent of its potential. Much field calibration work must be done to correctly interpret this type of test. The Mehlich-3 procedure is used for extraction of soil P and K in Oklahoma. Other labs may use different procedures. Oklahoma calibration may not be appropriate if soils are tested with a different method.

Potassium

Like P, K soil tests estimate availability and the tests indicate a certain percent sufficiency.

Calcium and Magnesium

These two elements and K are referred to as exchangeable cations and are found on the cation exchange sites of the soil. The soil tests measure the exchangeable portion of the cations. Oklahoma research has found that Ca and Mg additions can increase yields when individual tests are low. Percent of base saturation or ratios of Ca/Mg, K/Mg, Ca/K or Ca/Mg/K have not been useful in depicting deficiencies on most Oklahoma soils.

Sulfur

The sulfur soil test measures the amount of available sulfate-sulfur. The amount found in the soil test can be subtracted from crop requirements based upon a yield goal similar to the approach used for nitrogen. Unlike N, most soils contain adequate available S for most crops. Additionally, annual contributions from rainfall are high enough to meet the needs of a 60 bushel wheat crop.

Zinc, Iron, and Boron

Availability of these trace or micronutrient elements can be estimated from soil tests. Trace element deficiencies occur only on certain soils and with certain crops. Knowledge of crop needs and soil deficiencies will help determine when trace element tests need to be run.

SOIL TEST INTERPRETATIONS

After soil samples have been tested, the results need to be examined to see if they identify nutrient deficiencies in any of the fields. This step is called interpreting the test results. Interpretation can only be done reliably if the soil test has been calibrated by field research. Usually calibration research is on-going at Land Grant Universities, such as OSU, and has its best application for soils in that state. The calibration should identify the deficiency and estimate its severity.

Oklahoma State University interpretations are based on research calibration tables published in OSU Extension Facts No. 2225. The same calibration tables are included here as a reference (Tables 4.3-4.10). The tables are updated periodically as determined by current research results.

PRIMARY NUTRIENT INTERPRETATIONS

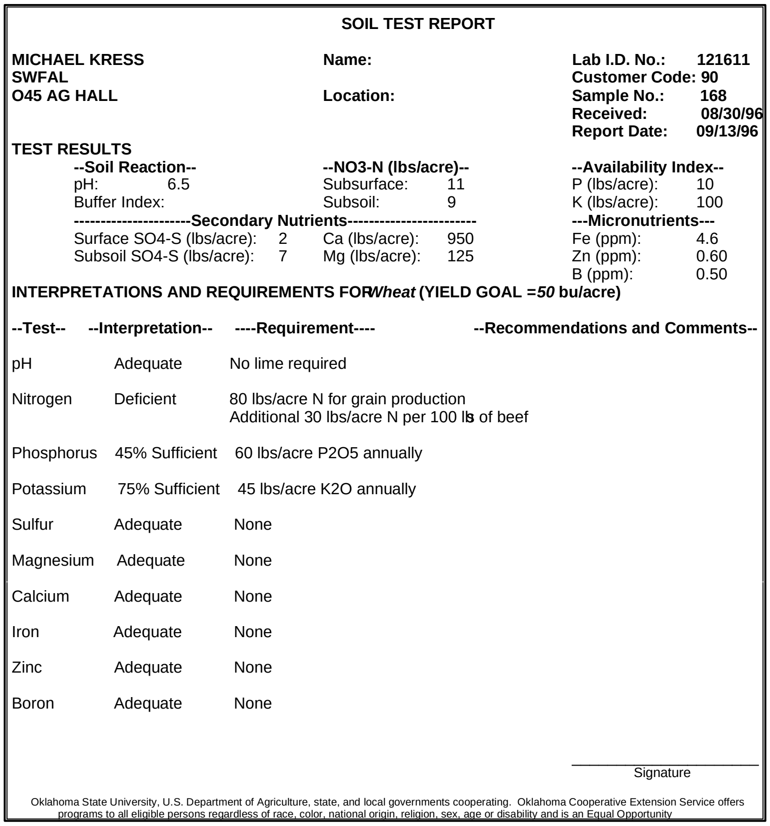
Soil test interpretations for N, P and K are presented in Tables 4.3-4.6. Fertilizer requirements for common Oklahoma crops and forages can be determined from these tables. Nitrogen requirements are based on yield goal, while P and K requirements are based on soil test values and their corresponding sufficiency levels.

Interpretations of soil test reports obtained from OSU are automatically generated by computer using data from these calibration tables. An example report is shown in Fig. 4.1. The report lists the name and address of the sender at the top, and presents the sample identification numbers and soil test results in designated boxes below. The soil test interpretation is printed in an area underneath the test results. If no cropping information is provided with a soil sample, then no computer interpretation is generated and fertilizer requirements must be determined by use of the calibration tables in Fact Sheet 2225 or an interactive program on the lab's website (http://www.soiltesting.okstate.edu). A yield goal is also needed to make N recommendation.

In the example report, wheat was selected as the crop and 50 bu/A was selected as the yield goal. Both selections are listed at the beginning of the interpretation. The pH of the sample was 6.5 which is satisfactory for wheat, therefore no lime was required.

The nitrate test for this sample showed 20 lb N/acre in the soil. According to the calibration tables (Table 4.3), 50 bu/acre of wheat requires 100 lb/acre of N. Subtracting 20 from 100 results in a deficiency of 80 lb N/acre which must be supplied using N fertilizer.

The phosphorus test index for this sample was 10. The calibration table for wheat (Table 4.3) shows that a P index of 10 corresponds to a sufficiency level of 45%. The corresponding P_2O_5 fertilizer requirement to offset this insufficiency is shown on the report or can be read directly from the calibration table as 60 lb/acre. This rate of P_2O_5 must be applied annually to prevent P deficiency until another soil test is performed.



SOIL TEST REPORT

MICHAEL KRESS
SWFAL
O45 AG HALL

Name:
Location:

Lab I.D. No.: **121611**
Customer Code: **90**
Sample No.: **168**
Received: **08/30/96**
Report Date: **09/13/96**

TEST RESULTS

--Soil Reaction--		**--NO3-N (lbs/acre)--**		**--Availability Index--**	
pH:	6.5	Subsurface:	11	P (lbs/acre):	10
Buffer Index:		Subsoil:	9	K (lbs/acre):	100
----------------------Secondary Nutrients------------------------				**---Micronutrients---**	
Surface SO4-S (lbs/acre):	2	Ca (lbs/acre):	950	Fe (ppm):	4.6
Subsoil SO4-S (lbs/acre):	7	Mg (lbs/acre):	125	Zn (ppm):	0.60
				B (ppm):	0.50

INTERPRETATIONS AND REQUIREMENTS FOR *Wheat* (YIELD GOAL =*50* bu/acre)

--Test--	**--Interpretation--**	**----Requirement----**	**--Recommendations and Comments--**
pH	Adequate	No lime required	
Nitrogen	Deficient	80 lbs/acre N for grain production Additional 30 lbs/acre N per 100 lbs of beef	
Phosphorus	45% Sufficient	60 lbs/acre P2O5 annually	
Potassium	75% Sufficient	45 lbs/acre K2O annually	
Sulfur	Adequate	None	
Magnesium	Adequate	None	
Calcium	Adequate	None	
Iron	Adequate	None	
Zinc	Adequate	None	
Boron	Adequate	None	

Signature

Figure 4.1. Example soil test report from the OSU Soil, Water and Forage Analytical Laboratory.

The potassium test index for this sample was 100. This value is not listed in the potassium calibration table for wheat, so the fertilizer requirement must be estimated using the requirements recommended for the index values, 75 and 125 (Table 4.3). Since 100 is halfway between 75 and 125, the potassium index of 100 corresponds to a sufficiency level of approximately 75% (halfway between 70 and 80) and a K_2O requirement of approximately 45 lb/acre (halfway between 50 and 40). The computer calculated this value and listed the potassium fertilizer requirement as a "75% sufficiency, 45 lbs/acre K_2O ". This rate of K_2O, like P_2O_5, must be applied annually to prevent K deficiency until another soil test is performed.

Table 4.3. Primary nutrient soil test calibration tables for small grains and row crops.

NITROGEN REQUIREMENTS

SMALL GRAIN				GRAIN SORGHUM		CORN		COTTON	
Yield Goal Bu/A			N	Yield Goal	N	Yield Goal	N	Yield Goal	N
Wheat	Barley	Oats	lb/A	lb/A	lb/A	bu/A	lb/A	bales/A	lb/A
15	20	25	30	2000	30	40	40	½	30
20	25	35	40	2500	40	50	50	¾	45
30	35	55	60	3000	50	60	60	1	60
40	50	70	80	4000	70	85	85	1¼	75
50	60	90	100	4500	85	100	110	1½	90
60	75	105	125	5000	100	120	130	1¾	105
70	90	125	155	7000	160	160	190	2	120
80	100	140	185	8000	195	180	215	2¼	135
100	125	175	240	9000	230	200	240	2½	150

PHOSPHORUS REQUIREMENTS

P SOIL	SMALL GRAIN		GRAIN SORGHUM		CORN		COTTON	
TEST INDEX	Percent Sufficiency	P_2O_5 lb/A	Percent Sufficiency	P_2O_5 lb/A	Percent Sufficiency	P_2O_5 lb/A	Percent Sufficiency	P_2O_5 lb/A
0	25	80	40	60	30	80	55	75
10	45	60	60	50	60	60	70	60
20	80	40	80	40	80	40	85	45
40	90	20	95	20	95	20	95	30
65+	100	0	100	0	100	0	100	0

POTASSIUM REQUIREMENTS

K SOIL	SMALL GRAIN		GRAIN SORGHUM		CORN		COTTON	
TEST INDEX	Percent Sufficiency	K_2O lb/A	Percent Sufficiency	K_2O lb/A	Percent Sufficiency	K_2O lb/A	Percent Sufficiency	K_2O lb/A
0	50	60	40	100	40	120	40	110
75	70	50	65	75	60	80	60	80
125	80	40	80	50	75	60	75	60
200	95	20	95	30	90	40	90	40
250+	100	0	100	0	100	0	100	0

Table 4.4. Primary nutrient soil test calibration tables for selected grasses and silage.

NITROGEN REQUIREMENTS

COOL SEASON GRASSES (fescue, orchard, rye) Yield Goal Tons/A	COOL SEASON GRASSES (fescue, orchard, rye) N lbs/A	WEEPING LOVEGRASS Yield Goal Tons/A	WEEPING LOVEGRASS N lbs/A	BLUESTEM Yield Goal Tons/A	BLUESTEM N lbs/A	BERMUDAGRASS Yield Goal Tons/A	BERMUDAGRASS N lbs/A	FORAGE SORGHUM, CORN-ENSILAGE Yield Goal Ensilage	FORAGE SORGHUM, CORN-ENSILAGE Tons/A Hay	FORAGE SORGHUM, CORN-ENSILAGE N lbs/A
1	60	1	35	1	35	1	50		1.0	18
2	120	2	70	2	70	2	100	5	2.5	45
3	180	3	110	3	110	3	150	10	5.0	90
4	240	4	160	4	150	4	200	15	7.5	135
5	300	5	220	5	200	5	260	20	10.0	185
						6	320	25	12.5	240
						7	400	30	15.0	300

PHOSPHORUS REQUIREMENTS

P SOIL TEST INDEX	COOL SEASON GRASSES (fescue, orchard, rye) Percent Sufficiency	COOL SEASON GRASSES (fescue, orchard, rye) P_2O_5 lbs/A	WEEPING LOVEGRASS Percent Sufficiency	WEEPING LOVEGRASS P_2O_5 lbs/A	BLUESTEM Percent Sufficiency	BLUESTEM P_2O_5 lbs/A	BERMUDAGRASS Percent Sufficiency	BERMUDAGRASS P_2O_5 lbs/A	FORAGE SORGHUM, CORN-ENSILAGE Percent Sufficiency	FORAGE SORGHUM, CORN-ENSILAGE P_2O_5 lbs/A
0	30	80	50	60	50	60	50	75	30	100
10	50	60	70	40	70	40	65	60	60	75
20	70	40	85	30	85	30	80	40	80	45
40	95	30	95	20	95	20	95	20	95	25
65+	100	0	100	0	100	0	100	0	100	0

POTASSIUM REQUIREMENTS

K SOIL TEST INDEX	COOL SEASON GRASSES (fescue, orchard, rye) Percent Sufficiency	COOL SEASON GRASSES (fescue, orchard, rye) K_2O lbs/A	WEEPING LOVEGRASS Percent Sufficiency	WEEPING LOVEGRASS K_2O lbs/A	BLUESTEM Percent Sufficiency	BLUESTEM K_2O lbs/A	BERMUDAGRASS Percent Sufficiency	BERMUDAGRASS K_2O lbs/A	FORAGE SORGHUM, CORN-ENSILAGE Percent Sufficiency	FORAGE SORGHUM, CORN-ENSILAGE K_2O lbs/A
0	60	70	40	80	40	80	50	140	40	180
75	70	60	65	60	60	60	65	80	60	130
125	80	50	80	40	80	40	80	50	75	90
200	95	30	95	20	95	20	95	30	90	60
250+	100	0	100	0	100	0	100	0	100	0

Table 4.5. Primary nutrient soil test calibration tables for selected forages.

NITROGEN REQUIREMENTS

SMALL GRAINS FOR GRAZING		LEGUMES IN PASTURE	NEW SEEDING OF INTRODUCED GRASSES	VIRGIN NATIVE HAY MEADOWS	
Yield Goal tons/A	**N lb/A**	Legumes will produce nitrogen for their growth. Very little nitrogen remains for the grasses after legume growth stops unless the legume growth is not harvested but is allowed to decay.	40 lb of nitrogen needed to establish a grass. Refer to other table for N requirement for production.	**Yield Goal tons/A**	**N lb/A**
½	30			1.0	0
1	60			1.5	50
1½	90			2.0	100
2	120				
2½	150				
3	180				

PHOSPHORUS REQUIREMENT

P SOIL TEST INDEX	SMALL GRAINS FOR GRAZING		LEGUMES IN PASTURE		NEW SEEDING OF INTRODUCED GRASSES		VIRGIN NATIVE HAY MEADOWS	
	Percent Sufficiency	P_2O_5 lb/A	Percent Sufficiency	P_2O_5 lb/A	Percent Sufficiency	P_2O_5 lb/A	Percent Sufficiency	P_2O_5 lb/A
0	25	80	50	75	30	80	50	40
10	45	60	65	60	50	60	80	20
20	80	40	80	40	70	40	95	0
40	90	20	95	20	95	20	100	0
65+	100	0	100	0	100	0	100	0

POTASSIUM REQUIREMENT

K SOIL TEST INDEX	SMALL GRAINS FOR GRAZING		LEGUMES IN PASTURE		NEW SEEDING OF INTRODUCED GRASSES		VIRGIN NATIVE HAY MEADOWS	
	Percent Sufficiency	K_2O lb/A	Percent Sufficiency	K_2O lb/A	Percent Sufficiency	K_2O lb/A	Percent Sufficiency	K_2O lb/A
0	50	60	50	80	50	80	40	40
75	70	50	65	60	65	60	70	30
125	80	40	80	40	80	40	85	20
200	95	20	95	20	95	20	95	0
250+	100	0	100	0	100	0	100	0

Table 4.6. Primary nutrient soil test calibration tables for legumes.

NITROGEN REQUIREMENTS

ALFALFA	PEANUTS	SOYBEANS	MUNGBEANS COWPEAS, GUAR
10-20 lb/A for establishment. None needed for maintenance.	10-20 lb N/A with P & K.	10-20 lb N/A with P & K. Inoculate seed.	10-20 lb N/A with P & K. Inoculate seed.

PHOSPHORUS REQUIREMENT

P SOIL TEST INDEX	ALFALFA		PEANUTS		SOYBEANS		MUNGBEANS COWPEAS, GUAR	
	Percent Sufficiency	P_2O_5 lb/A	Percent Sufficiency	P_2O_5 lb/A	Percent Sufficiency	P_2O_5 lb/A	Percent Sufficiency	P_2O_5 lb/A
0	20	200	40	80	40	70	40	70
10	50	150	60	60	60	50	60	50
20	70	100	80	40	80	30	80	30
40	90	60	95	20	95	20	95	20
65+	100	0	100	0	100	0	100	0

POTASSIUM REQUIREMENT

K SOIL TEST INDEX	ALFALFA		PEANUTS		SOYBEANS		MUNGBEANS COWPEAS, GUAR	
	Percent Sufficiency	K_2O lb/A	Percent Sufficiency	K_2O lb/A	Percent Sufficiency	K_2O lb/A	Percent Sufficiency	K_2O lb/A
0	20	280	40	80	40	100	50	80
75	50	210	60	60	60	70	60	60
125	70	140	75	40	75	60	80	45
200	90	80	90	30	90	40	90	30
275	95	40	100	0	100	0	100	0
350+	100	0	100	0	100	0	100	0

SECONDARY AND MICRO-NUTRIENT INTERPRETATIONS

Calcium

Calcium deficiency has not been observed in any crop in Oklahoma. Gypsum is sometimes applied over the pegging zone of peanuts during early bloom stage to improve quality. Appropriate rates are listed in Table 4.7.

Table 4.7. Calcium soil test interpretation for peanuts.

Ca Soil Test Index	Gypsum Needed lb/A
0	750
150	500
300	400
450	300
600	200
>750	0

Magnesium

Magnesium deficiencies are indicated by soil test index values less than 100 lb/A. Deficiencies can be corrected by applying 30-40 lb of magnesium fertilizer per acre or by using dolomite limestone if lime is needed.

Sulfur

Sulfur is a mobile element in the soil, therefore, plant requirements are based on yield goal similar to that for N. Sulfur requirements for non-legumes are calculated by dividing the nitrogen requirement by 20. The available sulfur measured by the sulfur soil test for both the surface and subsoil is subtracted from the sulfur requirement to determine the fertilizer rate. The rate may also be reduced by an additional 5 to 6 lb/acre due to sulfur supplied through rainfall and other incidental additions such as N, P, and K fertilizer impurities. Following is an example of sulfur interpretation for bermudagrass:

Crop: bermudagrass   Yield goal: 6 tons/acre

N requirement (Table 4.4) = 320 lb/acre
S requirement = N req./20 = 320/20 = 16 lb/acre
Sulfur soil test values: surface = 2 lb/acre
subsoil = 7 lb/acre
total = 9 lb/acre

Incidental sulfur additions: 5 lb/acre

Sulfur fertilizer rate = 16 - 9 - 5 = 2 lb S/acre

A similar calculation is used to determine the sulfur fertilizer rate for legumes, with the exception that the sulfur requirement is obtained from Table 4.8 rather than dividing the nitrogen requirement by 20.

Table 4.8. Sulfur requirements for legumes.

ALFALFA		PEANUTS		SOYBEANS	
Yield Goal tons/A	S lb/A	Yield Goal cwt/A	S lb/A	Yield Goal bu/A	S lb/A
2	6	6	2	10	3
4	11	12	3	20	6
6	17	18	5	30	9
8	22	24	7	40	12
10	28	30	9	50	15
		36	11	60	18

MUNGBEANS		COWPEAS		GUAR	
Yield Goal cwt/A	S lb/A	Yield Goal cwt/A	S lb/A	Yield Goal bu/A	S lb/A
5	1.5	5	1.5	6	2
10	3.0	10	2.5	12	3
15	4.5	15	4.0	18	5
20	6.0	20	5.5	24	7

Zinc

The soil test interpretation for zinc is presented in Table 4.9. Zinc soil test values less than 0.30 ppm are considered deficient for all crops except small grains, cool season grasses (fescue, orchardgrass, and ryegrass) and new seedings of introduced grasses. The recommended rates are enough to correct a deficiency for several years. Fertilizer applications should not be repeated until a new soil test is taken. Some producers may wish to apply 2 pounds of zinc per year until the total recommended amount is applied.

Table 4.9. Zinc soil test interpretation.

SOIL TEST Zn (ppm)	INTERPRETATION	ZINC RATE lb/A
0-0.30	Deficient for all crops except small grains, cool season grasses (fescue, orchard, and rye) and new seedings of introduced grasses	6-10
0.30-0.80	Deficient for corn and pecans only	2-5
0.80-2.00	Deficient for pecans only	Foliar only
2.00+	Adequate for all crops	None

Iron

Iron soil test values less than 2.0 ppm are considered low and may cause iron chlorosis in crops which are moderately sensitive such as wheat, soybeans and peanuts. Soil test values in the medium range, 2.0-4.5 ppm, may cause chlorosis in sensitive crops such as sorghum and sudan. Levels above 4.5 ppm are usually adequate for all crops. Crop sensitivity is increased when soil pH increases above 8.2 and soil test manganese levels are high (above 50 ppm). Foliar application of a 3% ferrous sulfate (or ammonium ferrous sulfate) solution is effective for correction. Severe chlorosis may require several applications. Effective control can be obtained by applying 2 lb of iron per acre in chelated form or 8 lb of ferrous sulfate per acre with ammonium polyphosphate solution in a band near the seed. It is important to apply the polyphosphate and ferrous sulfate solutions in the same band.

Boron

Boron deficiency in Oklahoma is of concern only in legumes, particularly alfalfa and peanuts. The soil test interpretation for boron is presented in Table 4.10.

Table 4.10. Boron soil test interpretation.

SOIL TEST	BORON RATE (lb/A)	
B (ppm)	PEANUTS	ALFALFA
0.0-0.25	1	2
0.25-0.50	0.5	1
0.50	0	0

NUTRIENT DEFICIENCY SYMPTOMS

Identifying nutrient deficiency symptoms is sometimes helpful in assessing fertility problems that need correction. Plant analysis may be used to confirm deficiency symptoms or monitor fertilizer effectiveness.

Recognizing nutrient deficiency symptoms and obtaining plant analysis are good approaches for identifying fertility problems but are not suitable parameters for making fertilizer recommendations. These two approaches are useful for identifying problem areas that need to be soil tested to measure the severity of the deficiency and the fertilizer requirements.

Plants deficient in one or more essential nutrients become "sick" and exhibit different leaf colors and growth disorders that are indicative of the deficiency. With practice one can identify symptoms and make suggestions for remedies. The problem for most is identifying the deficiency symptom correctly. The key presented in Table 4.11 should be helpful. A more complete description of deficiency symptoms that may be observed in Oklahoma is given below.

Nitrogen

Nitrogen is the most universally deficient nutrient in nonlegumes. A deficient field will possess a light green appearance. When N deficiency occurs later in plant growth, yellowing begins at the leaf tip and follows up the leaf midrib in a V-shaped pattern of the oldest leaves. Eventually, the entire lower leaf of plants, e.g., corn. will turn yellow and then brown (necrosis or death of tissue). As this happens, the second and third leaf will show chlorosis of the tip and midrib tissue as N is translocated to new leaves. A few days after the leaf tissue turns yellow, it dies and dries up.

Table 4.11. Key to nutrient deficiency symptoms

Symptom	Deficient Nutrient
A. Color change in lower (older) leaves.	
1. Plants light green - lower leaves yellow from tip along midrib towards base.	Nitrogen
2. Plants dark green, some purple coloring on base of stem - leaves and plants small.	Phosphorus
3. Brown discoloration and scorching along outer margins of lower leaves.	Potassium
4. Lower leaves have yellow discoloration between veins - reddish-purple cast from edge inward in some plants.	Magnesium
B. Color changes in upper (newer) leaves.	
1. Terminal bud dies.	
a. Emergence of primary leaves delayed - terminal buds deteriorate.	Calcium
b. Leaves near growing point yellowed - growth buds appear as white or light brown dead tissue.	Boron
2. Terminal bud remains alive.	
a. Leaves including veins turn pale green to yellow - young leaves first.	Sulfur
b. Leaves yellow to almost white - interveinal chlorosis to tip of leaf.	Iron
c. Shortened internodes – pale yellow or bronze coloration between leaf margin and midrib.	Zinc
d. Leaves yellowish-gray or reddish-gray with green veins.	Manganese
e. Young leaves uniformly pale yellow - may wilt and wither without chlorosis.	Copper
f. Wilting of upper leaves - followed by chlorosis.	Chlorine
g. Young leaves wilt and die along the margins.	Molybdenum

Phosphorus

Mild P deficiencies are characterized by stunted growth and an abnormally green appearance. In the advanced stages, phosphorus deficiencies cause purpling of the leaves. As in the case of N, the symptoms start with the older leaves and progress upward toward the younger leaves. Eventually leaf tips die and turn brown. Phosphorus deficiencies are more pronounced in young plants. Absorption of P by plants is slowed by cool soil. Often P deficiencies dissipate as the soil warms if sufficient P is present in available forms.

Whenever sorghum, corn, and cereals are damaged by certain insecticides, a purple pigmentation develops in the leaves. This leaf discoloration should not be confused with phosphate deficiency.

Potassium

Potassium deficiency causes shorter plants, weaker stems or stalks and a general loss of green color. Severe deficiencies produce a discoloration of the leaf tip and edges. In sorghum, corn, cotton, and other large leafed plants, the discoloration on the leaf edges is continuous. Potassium deficiency of grains and legumes is a general yellow mottling as well as numerous brown specks which occur at leaf tips, around margins and between the veins. As symptoms progress, the yellow mottled spots on leaf edges die and finally the dead tissue sloughs off giving leaves an extremely ragged appearance. The dying of the lower leaf is referred to as "firing". The condition known as "firing" is usually caused by potassium deficiency but other conditions such as dry and hot weather can also bring about dead tissue in the leaves and can be confused with potassium and nitrogen deficiency.

Potassium deficiency symptoms are rarely seen on peanuts. Fruit crops and many ornamental plants are highly susceptible to potassium deficiencies, and broad-leafed trees and ornamental plants readily show potassium deficiencies. Potassium deficiency in bermudagrass increases its susceptibility to "winter kill".

Sulfur

Sulfur deficiencies usually result in stunted growth, delayed maturity and a general yellowing of the foliage. Since it is easy to mistake sulfur deficiency for nitrogen deficiency, one must know the nitrogen status before diagnosing a sulfur deficiency. Sulfur deficiency is more pronounced on the young leaves.

In many sulfur deficient plants the veins remain green even though the tissue between the veins becomes chlorotic giving the leaf a mottled appearance. These mottled leaves resemble iron and zinc deficiencies.

Magnesium

Magnesium deficiency occurs first on the lower leaves as a general yellowing. Eventually the areas between the veins of the leaves become light yellow giving rise to a striping on grass-type plants and mottling on broad-leaf plants. In some plants, like soybeans, rusty specks and necrotic blotches may appear between the veins and around the edges of the newest leaflets. In cotton, magnesium deficient plants are purplish-red with green veins. Late in the season it is difficult to distinguish between magnesium deficiency and normal maturity in cotton which produces a purplish-red leaf.

Zinc

Zinc deficiency symptoms are usually seen during the plant seedling stage. It is characterized by a broad band of bleached tissue on each side of the midrib beginning at the base of the leaf. The midribs and leaf edges remain green. On broad-leaf plants a general bronzing may occur with a pronounced interveinal chlorosis. The leaves become thick and brittle and their margins are cupped upward. In grain sorghum, heads from severely zinc deficient plants are blasted. Most crops fail to develop normal internode length resulting in severe stunting and an appearance of all leaves coming from the same node.

Iron

Iron deficiency can be detected by yellowing between the veins with the veins remaining green. This gives a striping appearance. In contrast to zinc deficiency, the stripes are much narrower and extend the full length of the leaf.

Iron is not mobile within the plant, therefore, a deficiency is first observed on the younger (top) leaves with the older part of the plant remaining green. In severe cases the terminal portion of the plant turns white and eventually dies.

Boron

Boron deficiencies develop first on the youngest growth. The upper internodes are shortened and plants develop a rosette appearance. Upper leaves near the growing point turn yellow and in some legumes are reddened. The lower leaves remain green and healthy. In severe cases the terminal leaves become white.

In cotton, boron deficiency is described as having thick and leathery older leaves. Leaf petioles are often twisted with small ruptures appearing over their surfaces. A constriction near the base of the petiole may occur giving a "ringed" condition. Severe boron deficiency in cotton results in half opened bolls and plants which are hard to defoliate.

Boron deficient peanut plants possess the typical yellowing and rosetting, but even before the symptoms are noted on the vines, the nuts may have internal damage. The center of the nut will be somewhat hollow and discolored. Nuts with "hollow-heart" are severely downgraded upon marketing.

Other Deficiency Symptoms

Other nutrients exhibit characteristic deficiency symptoms, but the expected occurrences of these deficiencies in Oklahoma are rather remote.

Assistance should be obtained from a qualified person and/or plant analysis and soil tests to confirm the symptom, since chlorosis or yellowing and brown spots can result from factors other than nutrient deficiency. Herbicide damage and excess amounts of elements can cause similar visual symptoms. The deficiency must be confirmed before attempting to correct it.

Sometimes the knowledge of environmental conditions is useful in diagnosing the nutrient problem. These conditions should be checked:

Root zone - The soil should be granular and permeable so roots may expand and feed extensively. Crops normally develop a root system to a depth of 3 to 5 feet from which they extract water and nutrients. A shallow or compacted soil does not offer this root feeding zone.

Temperature - Cool soil temperatures reduce organic matter decomposition and the amount of nitrogen and other nutrients being released. Solubility of elements is lower in cool temperatures, thus creating more deficiencies.

Soil pH - The availability of some plant nutrients is greatly affected by soil pH. Molybdenum availability is reduced by acid soil conditions, while iron, manganese, boron, copper, and zinc availabilities are increased by soil acidity. Nitrogen and phosphorus availabilities are highest between a pH of 5.5 and 7.2. Aluminum toxicity may occur in very acidic soils, which also result in a purple leaves.

Insects - Insect damage may look like deficiency symptoms. Roots should be examined for insect damage that may project itself as a nutrient deficiency.

Diseases - Close study will reveal differences between plant diseases and nutrient deficiency symptoms. The organisms can usually be found upon close examination.

Moisture conditions - Dry soil conditions may create deficiencies. However, nutrient deficiencies during drought must be correctly identified and not attributed to the drought. Crop "firing" attributed to the drought may actually be nitrogen or potassium deficiency.

Soil salinity problems - In some areas of Oklahoma soluble salts and alkali are problems. These areas usually cover only a portion of the field. The salty areas usually occur where a high water table exists, salt-water well contamination has occurred or poor quality water has been used for irrigation.

Nutrient deficiency symptoms indicate severe starvation problems but have the shortcoming of not indicating slight to moderate starvation. Many crops exhibit yield reductions from a lack of nutrition before actually showing visual signs of a deficiency. "Hidden hunger" is the term used to describe this phenomenon. Hidden hunger may reduce yields and quality of crops without the plants showing deficiency symptoms.

PLANT ANALYSIS

The term plant analysis means the chemical analysis of plant tissue to determine the concentration of essential plant nutrients, excluding carbon, hydrogen and oxygen. The level of nutrients in the plant tissue is compared to established sufficiency levels to determine possible deficiencies and hidden hunger. In some cases poor-growth plant tissue may be compared to adjacent good-growth plant tissue to draw conclusions about the problem area.

Plant analysis can be used to measure the level of plant nutrients that are difficult to test by soil testing procedures, such as molybdenum. It is a good tool for researchers to use when evaluating fertilizer sources or fertilizer placement and when confirming nutrient deficiency symptoms. Plant analysis cannot be used to make fertilizer recommendations because the soil pH and soil nutrient level must be known. It can be used to adjust the fertilizer recommendation once the soil level is known. The same factors that interfere with identifying nutrient deficiency symptoms must be considered when interpreting plant analysis.

A proper plant sample must be taken for plant analysis to be reliably interpreted. Sufficiency levels have been established for certain plant parts as shown in Table 4.12.

Table 4.12. Sufficiency levels of plant nutrients for several crops at recommended stages of growth shown in Table 4.13.

Element	Sufficiency Levels						
	Corn	Grain sorghum	Soybeans	Small grains	Peanuts	Alfalfa	Bermuda-grass
N, %	2.7-3.5	3.3-4.0	4.2-5.5	1.7-3.0	3.5-4.5	4.5-5.0	2.5-3.0
P, %	.25-.40	.20-.35	.26-.50	.20-.50	.20-3.5	.26-.70	.26-.32
K, %	1.7-2.5	1.4-2.5	1.7-2.5	1.5-3.0	1.7-3.0	2.0-3.5	1.8-2.1
Ca, %	.21-1.0	.30-.60	.36-2.0	.20-.50	1.25-1.75		.50-3.0
Mg, %	.21-.60	.20-.50	.26-1.0	.15-.50	.30-.80		.30-1.0
S, %	.20-.30	.26-.50	.15-.20				
B, ppm	4-25	1-10	21-55	5-10	20-50	30-80	
Cu, ppm	2-6	2-7	10-30	5-25	10-50	7-30	
Fe, ppm	21-25	65-100	51-350	50-150	100-350		
Mg, ppm	20-150	8-190	21-100	25-100	100-350	31-100	
Zn, ppm	20-70	15-30	21-50	15-70	20-50	21-70	

Select plant tissue so it represents the field as much as possible. Take the composite sample by sampling the number of plants shown in Table 4.13. The same procedure should be used when sampling abnormal growth areas in a field (i.e. take the required number of plants throughout the trouble spot and select an equal-size area of normal plants to sample for comparative purposes).

Keep in mind that disease- or insect-infected plants, drought-stricken plants, and frost-damaged plants should not be sampled.

Allow samples to partially dry before mailing. Send samples in paper bags or envelopes, not in plastic bags. Damp or wet plant tissue will deteriorate if mailed in plastic or air-tight containers. Do not send soil or roots in the same container. Soil contaminates the plant tissue and makes it difficult to clean at the laboratory.

It is a good idea to take a soil sample in the same vicinity as the plant sample. Soil tests may help interpret the plant analysis results. Plant tissue sufficiency levels for several crops are presented in Table 4.12. Whenever nutrient levels in the plants fall below the sufficiency range, a deficiency is expected. The lower the concentration is below the sufficiency range, the greater the nutrient deficiency.

Some laboratories and researchers have tried to use ratios between 2 or more elements for interpretation. At the present time, the N/S ratio appears to be a good method for diagnosing sulfur deficiency. Sulfur is sufficient when the ratio is 15:1 or less and deficient when the ratio is greater than 20:1. Other combinations or ratios have not shown any benefit over the sufficiency levels shown in Table 4.12.

Remember to use plant analysis along with other data, including soil tests. Interpretation must be logical. Be suspicious of far-fetched diagnosis. Growers have frequently been disappointed by applying some otherwise illogical nutrient to their soil and obtaining no benefit. The OSU Soil, Water and Forage Analytical Laboratory conducts plant analysis on request but does not offer interpretations.

Table 4.13. Guide to plant sampling for tissue analysis.

Crop	Plant part to sample	Stage of growth	Number of plants
Corn or Grain sorghum	All above-ground	Seedling stage (less then 12')	20-30
Corn or Grain sorghum	Top fully developed leaf	Prior to tasseling	15-25
Corn	Leaf at ear node	Tasseling to early silk*	15-25
Grain sorghum	Second leaf from top	At heading	15-25
Soybeans	All above-ground	Seedling stage (less than 12")	20-30
Soybeans	Top fully developed trifoliate leaves	Prior to or during initial flowering*	20-30
Small grain	All above-ground	Seedling stage (prior to tillering)	50-100
Small grain	All above-ground	As head emerges from boot*	15-25
Peanuts	All above-ground	Seedling stage	20-30
Peanuts	Upper stems and leaves	Early pegging*	15-25
Alfalfa	All above-ground	Prior to bloom	30-40
Alfalfa	Top 1/3 of plant	At bloom*	15-25
Bermudagrass	Whole plant top	4 to 5 weeks after clipping*	15-25
Cotton	Whole plants	Early growth	20-30
Cotton	Petioles of youngest fully expanded leaves	During bloom*	20-30

*Recommended sampling period for fertilizer evaluation.

Chapter 5 Fertilizer Use in Oklahoma

HISTORICAL BACKGROUND AND DEVELOPING TRENDS

Fertilizer Use

It was not until 1945 that fertilization became a common practice for grain production in Oklahoma. This is illustrated in Figure 5.1 along with the average wheat yields from 1890 to 2004. Fertilizer use did not increase dramatically until the early 1960's. From 1960 to 1980, the total tonnage of fertilizer sold in Oklahoma increased from 100,000 to 700,000 tons. Presently, almost 1,000,000 tons of fertilizers are sold annually in Oklahoma (Figure 5.1). It is important to note that this represents the total amount of fertilizer sold in Oklahoma and does not represent the amount used per acre.

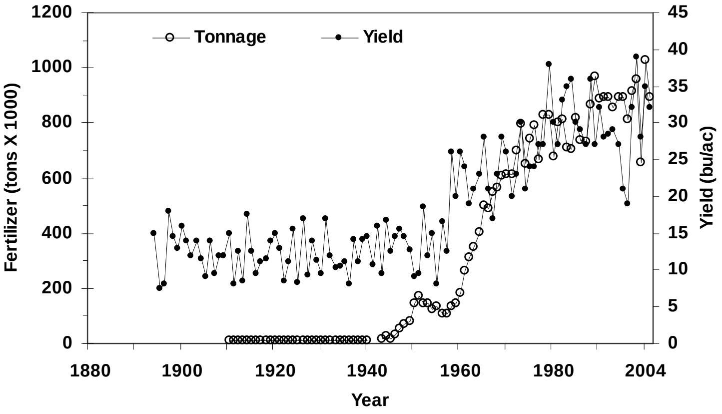


Figure 5.1. Total fertilizer sold (tons) and average wheat yields in Oklahoma from 1890-2004.

Since the early 1920's, total wheat acreage has fluctuated between 4 and 7 million acres. The general trend within that time period has been for wheat acreage to increase by 28000 acres per year (Figure 5.2). Average wheat prices from 1900 to 2004 illustrate drastic fluctuations especially during the depression in the 1930's and during World War II. Since the early 1970's to present, wheat prices have averaged above $2.25/bushel (Figure 5.2).

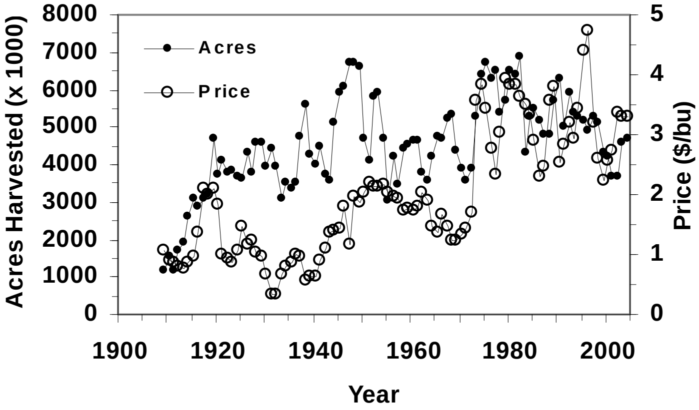


Figure 5.2. Relationship of harvested acres of wheat and average price per bushel in Oklahoma, 1890-2004.

The use of phosphorus and potassium fertilizers have not increased to any great extent since 1970, however, nitrogen fertilizer use has continued to increase since the early 1960's (Figure 5.3). This demonstrates the importance of nitrogen fertilizers in the state and the relative use of nitrogen compared to phosphorus and potassium.

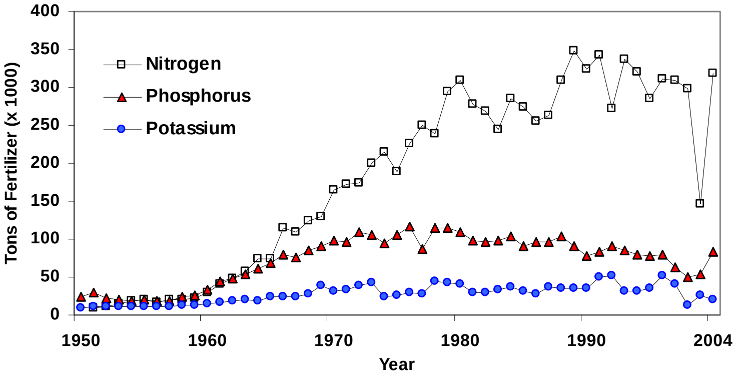


Figure 5.3. Fertilizer nitrogen, phosphorus and potassium sold in Oklahoma, 1951-2004.

Presently, bulk fertilizer sales represent the largest fraction of nutrient use in Oklahoma (Figure 5.4). From 1965 to 2004, the use of liquid fertilizers has increased substantially, largely due to the present popularity of urea ammonium-nitrate solution (UAN, 28-0-0). Alternatively, bagged fertilizers have decreased substantially for this same time period (Figure 5.4).

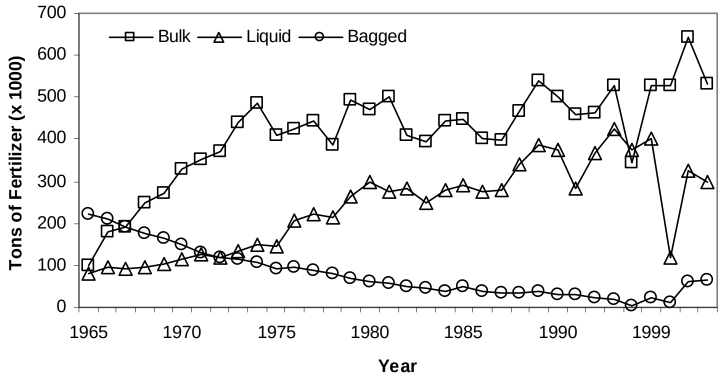


Figure 5.4. Forms of fertilizer sold in Oklahoma, 1965-2004.

From 1977 to the mid 1990's, anhydrous ammonia (82-0-0) was the major source of N used in the state of Oklahoma. Since that time period there has been a marked increase in the use of urea ammonium-nitrate and urea sources of N, with urea being the top seller in recent years (Figure 5.5). The use of ammonium-nitrate has decreased over this same time period while the contribution of N from diammonium phosphate has remained constant. Similar to anhydrous ammonia as an N source, diammonium phosphate (DAP) has remained the principle source of P (Figure 5.6). All other P sources combined contribute less than one third of the total P used in Oklahoma (Figure 5.6). However, there has been a tendency for ammonium polyphosphate (APP) to increase in the last five years.

NATIVE FERTILITY

The lack of commercial fertilizer use before 1950 was largely due to the native fertility of the Oklahoma prairie soils which were not cultivated until the late 1800's. Many of these soils were very fertile and required no added fertilizers in the first years of wheat production.

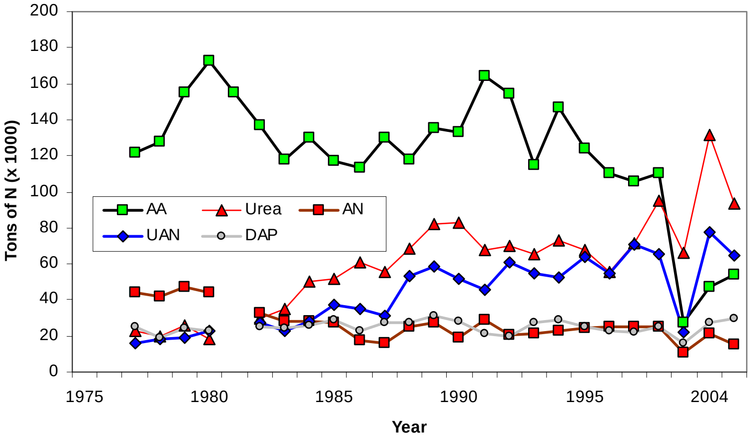


Figure 5.5. Tonnage of fertilizer N sold in Oklahoma for the major sources available, 1975-2005.

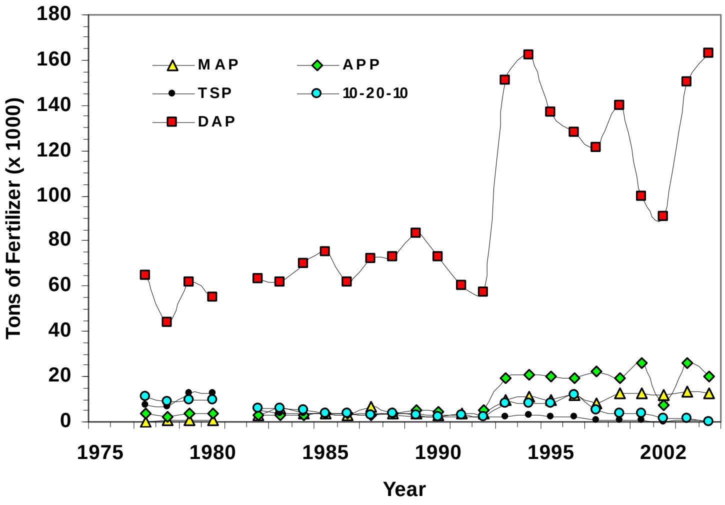


Figure 5.6. Tonnage of fertilizer P sold in Oklahoma for the major sources available, 1975-2005.

However, with time nutrients were continually depleted from the organic matter pool thus requiring fertilizers additions in later years. The demand for fertilizers was essentially a function of need. Continuous cultivation of these soils lowered soil organic matter levels from 4% (grass first turned over) to their present level of about 1%. Under continuous wheat production, this represented an annual depletion of the soil organic matter by 0.04%. However, this lowering of the soil organic matter was much greater in magnitude in early years and much less in later years. It is important to note that soils with 1% organic matter have about 2000 pounds of actual N in the top foot of soil. Therefore, almost 8000 pounds of N were present in these soils when they were first plowed. At that level one would think that there would never be a need for N, however, it must be remembered that this was N in an organic fraction. The amount of N that would be mineralized (biologically and chemically transformed to an available form for the plant) in the first 10 years was much greater than it is today. In addition, the crop needs for N were much less in the early 1900's since varieties had much lower yield potentials and thus removed less N from the soil (Figure 5.1). Soils with 1% organic matter will mineralize less than 20 pounds of N per year and as such will not make a major contribution to the N needs for wheat grain production. However, in earlier years, demands for fertilizer N were less since the organic matter decay provided for most of the crop N needs.

Although this discussion has focused on nitrogen, it should also be noted that with time, the organic matter nutrient pool was also depleted of the other essential elements required for plant growth. With time, micronutrient deficiencies are expected to appear in isolated regions where continuous cropping has taken place for long periods of time.

IMPORTANCE OF FERTILIZER USE

It is important to realize that many farmers in the developing world still do not apply fertilizers. In many of these impoverished areas, farmers burn down the forested areas, plant and produce crops for 10 to 20 years and then move on to another area of land. These are migrant farmers that have an average farm size of 2 acres, and who are extremely poor. The importance of this type of 'slash and burn' agriculture is that it only lasts until the nutrient supplying power of the ash from burned trees and brush, and the organic matter pool is depleted to the point where crops can no longer be produced. Not having availability to fertilizers, or more importantly the funds to apply any inputs to their farming techniques, they moved on to another forested area where they would cut down the trees, burn them, and produce crops for another 20 years or so until production was again stifled by depleted nutrient levels. Our agricultural systems are obviously much different from that of third world countries, however, organic matter depletion in this country is the same as that found elsewhere. Our farmers cannot move from one area to the next simply because the lands became increasingly unproductive with time, but rather must search for the methods and techniques to sustain production on the same lands.

CONVENTIONAL MATERIALS AND SOURCES

Before World War II nearly all commercial fertilizer materials sold in the U.S. were dry materials. Dry fertilizer materials are either straight materials (those containing only one nutrient) or mixtures (those containing two or more nutrients). Mixed dry materials are available in two forms: 1) chemical compounds in which 2 of the major fertilizer elements are combined together in the granule and 2) bulk blends in which straight materials and/or chemical compounds are physically blended to make various grades.

Bulk blending increased rapidly in Oklahoma during the early 1960's and was readily accepted by growers because the proper ratio of fertilizer elements can be blended to fit soil test requirements. In Oklahoma, most dry blends are made from combinations of the following: ammonium nitrate, urea, diammonium or monoammonium phosphate and/or concentrated superphosphate, and muriate of potash. A blender with 4 to 5 bins of bulk, straight materials can blend most any ratio of material needed. A computer program is available to assist in the calculation of the needed ingredients for a particular blend at: http://www.soiltesting.okstate.edu/Interpretation.htm.

The major dry and liquid fertilizer materials available in Oklahoma are listed in Table 5.1.

Nitrogen Fertilizers

Anhydrous Ammonia, NH_3, 82% N. Nitrogen was one of the first nutrients to be produced in a liquid form (liquid under pressure). Nitrogen is taken from the air and reacted with a hydrogen source in the presence of a catalyst to produce anhydrous ammonia. Virtually all nitrogen manufacturing facilities use natural gas as a source of hydrogen. Approximately 33,000 cubic feet of natural gas are required to produce a ton of ammonia.

Under pressure, anhydrous ammonia becomes a liquid that returns to a gas when released from the storage container. To prevent excessive loss of N, it must be injected into the soil and sealed until ammonium (NH_4^+) is formed. Anhydrous ammonia is a hazardous material and care must be taken in handling to avoid exposing human, animal or plant life to direct contact with liquid or gaseous forms. In nitrogen producing plants, anhydrous ammonia is the basic material used to produce other kinds of nitrogen fertilizers.

Urea ammonium-nitrate, 28-32% N. A common liquid N fertilizer is made from soluble urea and ammonium nitrate mixed in equal parts with water to form non-pressure N solution containing 28 to 32 percent nitrogen. Ammonium nitrate or urea solution, alone, can only be handled satisfactorily in the field, in approximately 20% N concentrations.

Table 5.1. Major fertilizer sources of nitrogen, phosphorus and potassium sold in Oklahoma.

	Nutrient Composition						
Source	N	P_2O_5	K_2O	CaO	MgO	S	Cl
	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	%	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -
Nitrogen							
Ammonium sulfate	21	-	-	-	-	24	-
Anhydrous ammonia	82	-	-	-	-	-	-
Ammonium nitrate	33-34	-	-	-	-	-	-
Calcium nitrate	15	-	-	34	-	-	-
Urea	45-46	-	-	-	-	-	-
Urea-ammonium nitrate (solution)	28-32	-	-	-	-	-	-
Phosphorus							
Monoammonium phosphate (MAP)	11	48-55	-	2	0.5	1-3	-
Diammonium phosphate (DAP)	18-21	46-54	-	-	-	-	-
Ammonium poly-phosphate (solution) (APP)	10-11	34-37	-	-	-	-	-
Urea-phosphate	17	43-44	-	-	-	-	-
Ordinary super-phosphate*	-	16-23	-	18-21	-	11-12	-
Conc. (triple) super-phosphate (TSP)	-	44-53	-	12-14	-	0-1	-
Rock phosphate*	-	25-40	-	33-36	-	-	-
Potassium							
Potassium chloride	-	-	60-62	-	-	-	47
Potassium sulfate	-	-	50-52	-	-	17	-

* - no longer important sources in Oklahoma

Like any salt solution, nitrogen solutions will salt out. Salting out is simply the precipitation of the dissolved salts when the temperature drops to a certain degree. The salting out is determined by the amount and kind of salts in solution. As a general guide, 28% non-pressure solution salts out at about 0°F and 32% salt out at about 32°F, although this can vary between the materials produced by different manufacturers.

Corrosion inhibitors and a pH near 7.0 in nitrogen solutions reduce corrosion of carbon (mild) steel. The following materials are satisfactory for storing and handling nitrogen solutions: aluminum, stainless steel, rubber, neoprene, polyethylene, vinyl resins, glass and carbon steel. Materials that will be destroyed rapidly include copper, brass, bronze, zinc, galvanized metal, and concrete.

Nitrogen solutions that do not contain free ammonia can be applied to the soil surface without loss of N, although incorporation is recommended where ammonia volatilization loss from urea may be a problem. Ammonia free N solutions can also be applied in sprinkler irrigation systems with good success. Non-pressure N solutions are probably the most versatile of all N materials for application to a broad range of crops with a wide variety of application equipment.

Ammonium Nitrate, NH_4NO_3, 33.5-34% N. Ammonium nitrate is made by reacting anhydrous ammonia and nitric acid. Half of the total nitrogen in the material is in the nitrate form and half is in the ammoniacal form. Most ammonium nitrate is prilled and coated.

Urea, $(NH_2)_2CO$, 45-46% N. Urea is formed by reacting ammonia and carbon dioxide. All of the nitrogen in urea is in the ammoniacal form. Urea is produced in both prilled and granular forms. It is classed as an organic compound since it contains carbon.

Ammonium Sulfate, $(NH_4)_2SO_4$, 20.5-21% N. Ammonium sulfate is formed by reacting ammonia with sulfuric acid. All of the material's nitrogen is in the ammoniacal form. Ammonium sulfate is an effective source of sulfur since it contains 24 percent S. It is produced in both crystalline and granular forms.

Phosphorus Fertilizers

Diammonium Phosphate, DAP, $(NH_4)_2HPO_4$, 18% N, 46% P_2O_5. This popular N-P material is produced by reacting ammonia and phosphoric acid. All of the nitrogen is in the ammoniacal form and the P is highly water-soluble. It is produced in the granular form.

Monoammonium Phosphate, MAP, $NH_4H_2PO_4$, 11-12% N, 48-60% P_2O_5. This material is produced by reacting ammonia and phosphoric acid. All of the N is in the ammoniacal form and the P is highly water-soluble. Most MAP is produced in the granular form.

Phosphoric Acid and Superphosphoric Acid, 54-85% P_2O_5. Phosphate rock deposits are the basic source of all phosphate materials. The principal world reserves are located in North Africa, North America and the former Soviet Union. The primary intermediate step in the production of phosphorus fertilizers is phosphoric acid. In some areas, phosphoric acid is applied to the soil as a form of fertilizer; however, the handling problems associated with this acid has limited its use.

In fluid fertilizer production two types of acid are commonly used; ortho phosphoric (phosphoric acid) containing about 54% phosphorus (P_2O_5) and superphosphoric (polyphosphoric acid) containing up to 85% phosphorus (P_2O_5). Being more concentrated, it is possible to produce a higher analysis P fertilizer from superphosphoric acid.

When ortho phosphoric acid is reacted with ammonia, the acid can be neutralized to a pH of about 6.5 to produce a nitrogen phosphorous solution of 8-24-0. This was the basic phosphorous material used in mixed liquid fertilizers for several years. The development of superphosphoric production procedures make it possible to produce the higher analysis nitrogen phosphorous solutions (10-34-0), currently used as the basic phosphorous source in liquid and suspension grades of liquid fertilizer.

Ammonium Polyphosphate Solutions, APP, 10% N, 34% P_2O_5. The ability to produce 10-34-0 ammonium polyphosphate solution played an important role in the rapid growth of liquid N-P-K fertilizers during the 1960's. Improved storage and application equipment and other technical advances have enabled this growth to continue.

Ammonium polyphosphate solutions can contain up to 70 percent of the total P_2O_5 as a poly-P form. The remaining P_2O_5 is as an orthophosphate. All phosphate fertilizers contain some orthophosphate with many being 100% in the ortho form. In fluids, it is generally accepted that high poly content, above 55 percent, improves storage quality and the opportunity to carry low cost sources of micronutrient metals in liquid grades.

Ordinary Superphosphate, 20% P_2O_5. Ordinary superphosphate is made by treating finely ground phosphate rock with sulfuric acid. The P_2O_5 content of this source ranges between 18 and 22 percent. This source has between 11 and 12 percent sulfur as calcium sulfate and is sold as granular form. This low analysis material is no longer readily available in Oklahoma.

Concentrated Superphosphate, 46% P_2O_5. This source is produced by treating ground rock phosphate with phosphoric acid. The product will vary from 42-46 percent P_2O_5 with the most common analysis 46% P_2O_5.

Potassium Fertilizers

Potassium (K) is found throughout the world in both soluble and insoluble forms. The soluble forms are the principal form used in fertilizers. Potassium chloride is by far the most important source of fertilizer K.

Potassium Chloride (Muriate of Potash), KCl, 60% K_2O. This is the K salt of hydrochloric (muriatic) acid. Most potash deposits are in this form. It is the most popular potash material used in fertilizers. Muriate of potash is a crystalline material. It is available in various particle sizes which are chosen to coincide with other materials for bulk blending. Some muriate of potash contains iron coatings, giving it a reddish color. Most muriate of potash is white or translucent. Color or particle size does not affect potassium availability for plant growth since it is a water soluble compound. In addition, potassium chloride is the major source of potash for liquid fertilizers. The fine soluble 0-0-62 grade is used for both liquid and suspension. About 10% K_2O is the maximum that can be dissolved in a liquid but up to 30%K_2O can be carried in a suspension.

Potassium Sulfate, K_2SO_4, 50% K_2O. Like muriate of potash, potassium sulfate occurs naturally in limited deposits. It is extensively used in tobacco fertilizers where there is concern regarding chlorine build-up. It contains 17 percent sulfur and is widely used in areas where both potassium and sulfur are needed. Potassium sulfate has a lower solubility than KCl and is primarily used in suspensions to produce chloride free potassium and sulfur.

Secondary Elements

Calcium (Ca). Calcium fertilizers are not usually needed in Oklahoma. Common sources of supplemental Ca are lime and gypsum.

Calcium Carbonate (Lime)	20-40% Ca
Calcium Sulfate (Gypsum)	23% Ca, (18.6% Sulfur)
Normal Superphosphate	22% Ca, (20% P_2O_5, 12% Sulfur)

Magnesium (Mg). The most common sources of magnesium are magnesium sulfate and dolomitic lime.

Magnesium Oxide	52% Mg
Magnesium Sulfate	16% Mg
Potassium - Magnesium Sulfate (Sul-Po-Mag, K-Mag)	11% Mg, (22% K_2O, 22% Sulfur)
Dolomitic Limestone (varies)	12% Mg

Sulfur (S). Sulfur is most available when supplied in the highly water soluble sulfate form. Ag. sulfur (elemental sulfur) can be used, but requires biological oxidation over time to convert the elemental form to available sulfate.

Calcium Sulfate (Gypsum)	17% S (22% Ca)
Potassium Sulfate	17% S
Sulfate of Potash, Magnesia	22% S
Ammonium Sulfate	24% S
Normal Superphosphate	12% S
Ammonium Thiosulfate	26% S

Boron (B). A sodium borate (solubor) containing about 20% B is the source of B most commonly used in liquids. Boric acid and other soluble forms containing between 14 to 20% B are also suitable for liquid mixes.

Borax	11.3% B

Zinc (Zn), Iron (Fe), Copper (Cu), and Manganese (Mn)

The micronutrient elements can be discussed as a group since their sources are somewhat similar. Industry separates the compounds into two general categories; inorganic and organic. Inorganic include sulfates, oxides, carbonates and chlorides. The term organic applies primarily to chelated products and some sequestered materials. Most chelates, and particularly liquid products, can be mixed with liquid without difficulty.

Zinc	
Zinc Sulfate	25-36% Zn
Zinc Oxide	50-80% Zn
Zinc Chloride	48% Zn
Zinc Chelate	9-14.5% Zn

Iron	
Ferrous Sulfate	20.1% Fe
Ferric Sulfate	19.9% Fe
Ferrous Ammonium Sulfate	14.2% Fe
Ferric Chloride	34.4% Fe
Iron Chelate	10% Fe

Copper	
Copper Sulfate	25% Cu

Manganese	
Manganese Sulfate	23-28% Mn

Molybdenum (Mo). Ammonium molybdate is satisfactory for liquids. Sodium molybdate can also be used although it is less soluble than ammonium molybdate. Since Mo is applied in ounces per acre, liquids are ideal for getting even distribution.

Sodium Molybdate	39.7% Mo
Ammonium Molybdate	54.3% Mo

Chlorine. Chlorine has only recently been found deficient in Oklahoma soils. The deficiency in wheat on deep sandy soils near Perkins, OK can be corrected using muriate of potash (0-0-60). This is the common source of potassium, which is usually also deficient in these sandy soils.

Mixed Fertilizers

Fertilizer mixtures account for a significant portion of the total amount of fertilizer consumed in Oklahoma. These mixtures are either manufactured at large granulation plants and shipped to the dealer as the grade or they are blended by local blend plants. Field research has shown little or no differences between the chemical granulated materials and physical blends unless segregation occurs in the blends.

METHODS OF APPLICATION

Comprehensive evaluation of fertilizer placement research reveals that no single question has been asked so many times for so many different crops and production systems as the question of whether to "band or broadcast". Interestingly, it remains an important question today and may well be in the future. The most common method of applying fertilizers in modern times has been to broadcast, either with or without incorporation. However, the method used depends on various factors including the fertilizer to be applied, tillage, equipment available and crop grown.

Banding

Banding immobile nutrients such as P has become a common method for soils with high fixation capacities. In general, banding is the placement of fertilizer nutrients in a concentrated zone near the seed. Initial reasons for banding were:

1. to reduce the surface area of the fertilizer in direct contact with the soil, and thus minimize fertilizer-soil reactions that reduce chemical availability;
2. to apply the nutrient where there is the greatest chance for root contact.

Banding will likely have little beneficial effect for mobile nutrients such as N and S. Banding P and K has been beneficial where starter effects were desired in cool, wet climates. Recent work has shown banding P with the seed at planting on highly acid soils can reduce aluminum toxicity.

Soluble fertilizers placed in a band may cause germination and/or seedling injury if rates are too high. In general, ***the salt index (applied N + K_2O) should not exceed 30 lb/ac for wheat and 7 lb/ac for corn.*** In extremely arid regions and/or where rapid drying takes place, salt rates less than these can adversely affect wheat and corn seed germination. Although banding P with the seed has become popular for Oklahoma wheat farmers with acid soil, it remains as a temporary alternative to liming.

Unlike broadcasting, there are several variations of band applications including with the seed, below the seed, beside the seed, dribble surface bands, spoke tooth bands, spot placement, point injection, and dual band applications. Accurate characterization of band applications must also consider spacing, form (liquid or solid), and depth of placement. An illustration of plant response to banding is found in Figure 5.7. Roots respond to increased P availability, increasing in growth within the band where the P is placed. If a soil were deficient in P, all roots would not explore the entire soil profile in search of this limiting element. Instead, some roots penetrate the band or localized area where P has been applied, and proliferate in that zone (Figure 5.7).

Broadcast

Broadcast applications of granular fertilizers are most often applied prior to planting. For many grain producers, this method of application can be more economical and requires less time, which can be important when one operator must cover a large acreage. However, poor distribution patterns from bulk dry spreaders can result in uneven stands and lower grain yields. Ultimately, it is up to the farmer to check commercial fertilizer applicators. Using sample pans (8 to 10 pans, 2 ft wide) spread across the application width, one can quickly assess the distribution pattern of the fertilizer applicator. If the weighed amounts in the pans differ by more than 10-15%, the application equipment should be adjusted accordingly. Applicators which can cover a broad width (30-60 feet with each pass), need close monitoring to avoid uneven distribution of the applied fertilizer.

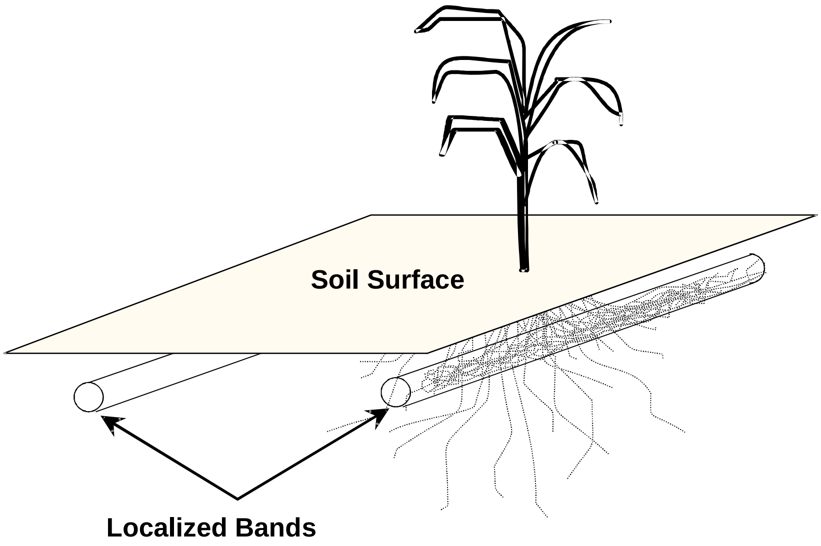


Figure 5.7. Plant root development when P is banded in phosphorus deficient soils (conventional tillage).

Broadcast applications of phosphorus have proven to be satisfactory in minimum tillage crop production since this method of placement effectively reduces the surface area of the soil in contact with the fertilizer (Figure 5.8). The advantages of this method in reduced tillage crop production, at least under humid region cropping conditions is also a function of placing the fertilizer near the zone (surface horizon 0-2 in) where increased moisture and root mass are present. In this regard, broadcast applications of P in minimum tillage systems have been viewed as surface horizontal bands (Figure 5.8). Alternatively, localized band applications of P in conventional tillage have commonly increased uptake efficiencies and grain yields when compared to broadcast methods as a result of effectively reducing soil-fertilizer P fixation.

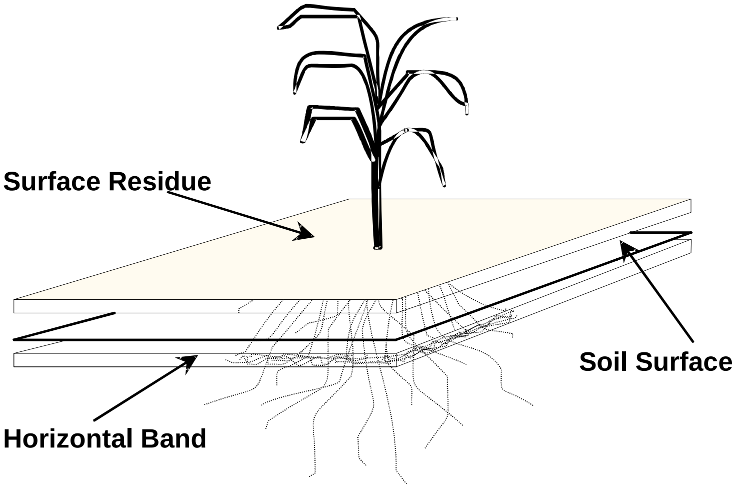


Figure 5.8. Plant root development when P is broadcast applied in minimum/zero tillage production systems.

VOLATILIZATION LOSSES FROM SURFACE APPLIED UREA AND UAN SOLUTIONS

Urea is now the most widely used solid form of N in the world. Methods of applying urea forms of N in minimum tillage systems have been given considerable attention since gaseous losses of N as ammonia gas (NH_3) are known to occur when urea is applied to soils with pH > 7.0 and where surface soil temperatures are high. Because of this problem, various researchers have stressed the importance of banding urea below the surface of the soil.

When urea is broadcast applied to soils where minimum or zero tillage is used, N losses as ammonia gas can increase due to accumulated surface residues. This is due in part to the enzyme urease (found in crop residues) which is responsible for the chemical transformation of urea ($(NH_2)_2CO$) to ammonium (NH_4^+) that can be used by the plant. Ammonium can be chemically transformed to ammonia gas (NH_3) and lost from the soil. This loss is favored by application of urea to wet soil or residue surfaces that remain moist for several hours, followed by good drying conditions (windy, high temperature). Any loss decreases the amount of N available to the crop and increases the fertilizer requirement. Some of the surface applied N will stimulate microbial decay of residue and be "tied-up" in microbial tissue. Because of this, when urea is surface applied in reduced tillage systems, a higher rate of N is generally needed for optimum wheat grain yields when compared to conventional tillage. Sprayed applications of solutions 28 or 32 (UAN) on bermudagrass may also be less effective than other sources of nitrogen because of the high chance for ammonia from the urea to volatilize.

Reduced tillage systems have shown distinct advantages over that of conventional tillage in terms of soil erosion control, increased soil moisture, and higher residual soil mineral N levels. However reduced tillage systems can also increase volatilization losses from surface applied urea when compared to conventional tillage. Other disadvantages associated with reduced tillage systems include increased surface soil acidity, denitrification, immobilization, NO_3-N leaching and higher N requirements for crop production.

In general, urea sources of N should not be broadcast when soil pH exceeds 7.0, and where minimum tillage/reduced tillage practices are employed.

MANAGEMENT STRATEGIES TO INCREASE N USE EFFICIENCY

Fertilizer N use efficiency in crop production has been primarily influenced by volatilization losses, surface immobilization and NO_3-N leaching beyond the rooting zone. Volatilization losses from applied urea have been effectively reduced by surface incorporation of urea-N sources. Other work has focused on the use of urease inhibitors that selectively inhibit the urease enzyme involved in ammonium hydrolysis. Surface immobilization of applied N can be reduced by using various forms of banding (localized placement).

Sidedress or Split Applications

The most practical method of reducing NO_3-N leaching losses is to apply the N when it is needed most by the crop. Split applications can effectively reduce mobile nutrient leaching losses by applying the required amounts during high crop uptake stages. Fertilization practices mirror the initial ideas behind split applications by applying the same actual N rate in smaller quantities over time and in relation to crop need. Nitrate-N leaching has also been reduced in certain areas by the use of nitrification inhibitors which slow down the transformation of NH_4^+ to NO_3^-. This is accomplished by the selective inhibition of the bacteria nitrosomonas sp. involved in the biological oxidation of NH_4^+.

Knife Injection of Anhydrous Ammonia

Depending on the soil, anhydrous ammonia should generally be applied 4 to 8 inches below the soil surface. Slower tractor speeds can favor better ammonia retention by the soil (and less loss of ammonia gas) due to improved soil closure behind the knife applicator. If soils are too dry and large chunks of soil form behind the applicator, or too wet and a trench forms, then the resulting poor seal allows much of the ammonia gas to escape to the air. Spacing of the applicator knifes should be based on the row spacing to be used, rate of application and whether the application is made before planting. The minimum practical spacing is 14 inches and the maximum is 40 inches.

When anhydrous ammonia is applied sidedress within row crops, the knives should be placed to travel 6 to 10 inches to the side of the row. For other crops with extensive root systems, the knives should be spaced to travel between the rows. On soils with extremely high clay contents, and/or very sandy soils, anhydrous ammonia may not be a suitable N source due to gaseous losses which can occur. In general, ammonia losses are minimized when soil moisture content is between 12 and 18% (Figure 5.9). It is also important to note that at the 9 and 12 inch depths of placement, ammonia losses are further reduced. However, it is not advisable to knife anhydrous ammonia at depths greater than 9 inches due to equipment wear and increased fuel costs.

The long-term benefits of knifing anhydrous ammonia preplant compared to other more costly granular and liquid N forms has been noted in wheat, corn and sorghum production. Similar results from using anhydrous ammonia on other crops is largely due to the lower cost per pound of N and economies of scale when considering the cost of anhydrous ammonia versus alternative N sources. Additionally, application costs may be nil when done in conjunction with a planned tillage operation.

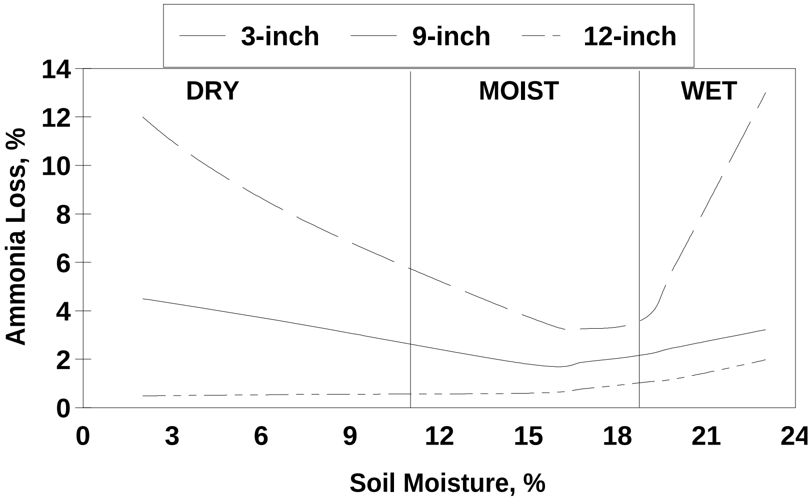


Figure 5.9. Relationship of ammonia loss and soil moisture at the time of application using different depths of placement.

Chapter 6 Nutrient Management and Fertilizer Use Economics

Profitable use of fertilizers is the most common and obvious goal of farmers. Achieving the most profitable use each year is extremely difficult, however, because several factors other than nutrient availability will affect crop yield and thus, profit. The key is knowing first of all whether or not a nutrient is deficient, then how much fertilizer is required to correct the deficiency, how much will the crop yield response be, and finally how much the soil (or soil test level) will change. These factors and associated costs and values all influence profitability.

SOIL TESTING

Soil testing is a good foundation for building a nutrient management program. If a field is soil tested consistently, then over a period of years one will develop a sense of knowing, or knowledge, about the nutrient availability and soil pH for that field. It is especially helpful to examine change in soil test results over time as a way of gaining insight to how nutrient availability may be changing in relation to fertilizer use and crop yield. A new computer program called STRK (Soil Test Record Keeping) developed by OSU is a useful tool to help examine these changes. Examples of output from this computer program are shown in the succeeding figures to illustrate these points.

Table 6.1 shows how soil tests can be stored by the computer in a table of results. New soil test results can be added each year as they are run. It is easy to get a general feel for what is happening in this field just from a glance at the table of soil test results. Soil pH is acid and may have been declining from 1985 to 1990, after which it increased sharply (the field was limed after the 1990 harvest). The field has a moderate phosphorus deficiency (P test <65), but the soil test seems to be increasing in the last few years. Potassium is adequately supplied (K test>250) and test values appear stable at about 265. These changes,

Table 6.1. Soil Test: NW4/Oklahoma COOP.

Date	pH	Buffer Index	Nitrate Nitrogen	Phosphorous Index	Potassium Index
7/15/1985	5.6	6.7	20.0	35.0	267.0
7/10/1986	5.3	6.7	40.0	40.0	260.0
7/12/1987	5.4	6.7	50.0	41.0	280.0
8/3/1988	5.1	6.6	10.0	33.0	265.0
7/12/1989	5.3	6.7	31.0	38.0	270.0
7/15/1990	5.2	6.6	10.0	44.0	268.0
7/10/1991	6.3	7.2	14.0	49.0	270.0

over time, including the nitrate soil test values can be more easily seen from a graphic display of the data as illustrated in Fig. 6.1. From this figure it is easier to see that there did seem to be a gradual pH decrease taking place prior to liming. Also, it is easy to see that soil test nitrogen changes quite sporadically, potassium is relatively stable and phosphorus has changed considerably over the period tested and is now increasing.

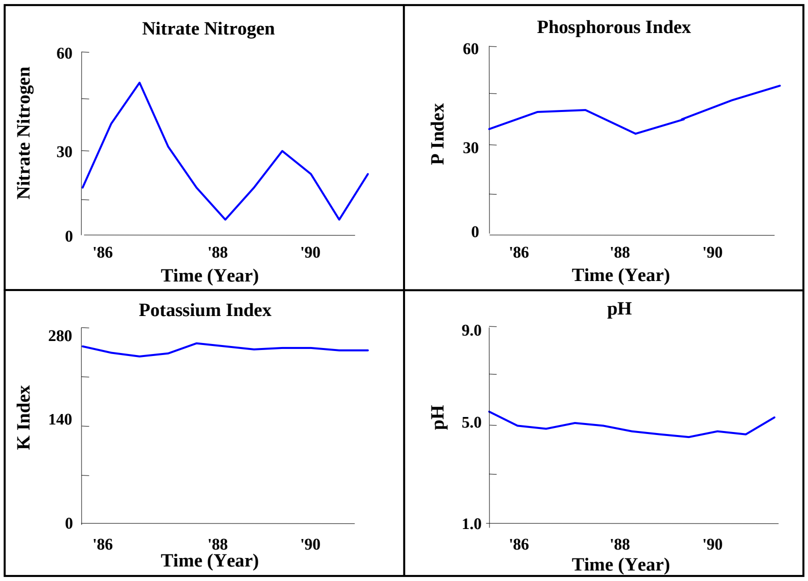


Figure 6.1. Graphic screen display of soil testing results stored by STRK computer program.

Graphs such as these are especially useful for detecting when there may be a problem with a soil sample or test result, causing it to be greatly different from previous tests. In such instances, it is better to use the average of the past two to three years instead of a current soil test that may be incorrect, as a guide to fertilizer use. Subsequent tests will identify whether the test in question was in error or not.

An additional feature of the STRK software is that it will keep track of the balance between nutrient additions and removals when fertilizer and harvest data are input. An example of this output is shown in Fig. 6.2 illustrating changes in nitrate soil test, yield, nutrient balance and cumulative nutrient balance over time. From this display it is seen that more nitrogen is added than is removed over time (cumulative balance). However, since there is no obvious increase in soil test nitrate-nitrogen, the excess nitrogen must be either incorporated into soil organic matter or lost from the surface soil. This feature of the software is useful for a more in depth assessment of nutrient changes and nutrient management than is possible from simply viewing soil test results.

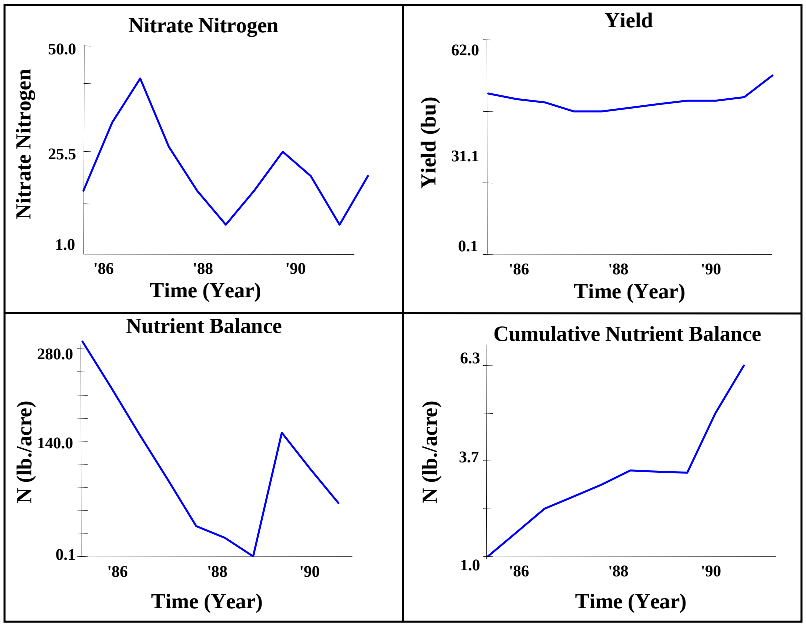


Figure 6.2. Graphic display of nitrate soil test, crop yield, balance between added fertilizer nitrogen and nitrogen removed by crop harvest, and cumulative nitrogen balance for several years as calculated by STRK computer program.

ECONOMICS

A second computer program, developed several years ago by OSU, called NPK$PLUS allows one to examine the economics of alternative fertilizer rates. As shown by an example output illustrated in Table 6.2, this software demonstrates that there is often about a 2 to 1 return from fertilizer investment when fertilizer is applied to a field where there is a true nutrient deficiency.

Table 6.2. Example output from the NPK$PLUS computer program showing projected economics of alternative fertilizer rates for a field with given soil test results.

Top 10 Fertilizer Options with Projected Yield and Return (SCR:2/3)

Option	Yield	N	P	K	Lime	Cost	Return	%Return
1	39.8	50	20	20	0.0	17.60	31.50	179
2	39.4	50	20	10	0.0	16.50	31.12	189
3	38.9	50	10	20	0.0	15.40	30.74	200
4	38.4	50	10	10	0.0	14.30	30.40	213
5	38.7	40	20	20	0.0	15.40	30.30	197
6	38.3	40	20	10	0.0	14.30	30.03	210
7	40.0	60	20	20	0.0	19.80	29.77	150
8	37.8	40	10	20	0.0	13.20	29.76	225
9	37.4	40	10	10	0.0	12.10	29.52	244
10	39.5	60	20	10	0.0	18.70	29.37	157

Soil Test Value for Nitrate Nitrogen: 10
Soil Test P Index: 40 Soil pH: 6.2
Soil Test K Index: 200
Crop: WHEAT
Yield Goal: 40.0 bushels/acre Yield Ave: 30.0 bushels/acre

The NPK$PLUS software projects short-term (one-year) profits from using fertilizer. Long-term profits are much more difficult to illustrate on the basis of specific costs and return. In order to understand long-term profitability of fertilizer use one must recognize that whenever fertilizer is applied to a deficient field, some is used by the crop and some by the soil. The most efficient and economic fertilizer application would be a method that insures all the nutrient is absorbed by the plant and none by the soil. This idealized situation is achieved, or nearly so, when a low rate (usually micronutrient) is applied as a foliar spray to a crop that intercepts all the material (100% crop canopy cover). For the major nutrients and others applied to the soil, crop utilization efficiency is always less than 100%.

All soils have some limit to their capacity to hold nutrients unavailable for crop use. Whether this is positional or chemical unavailability is inconsequential. However, once this capacity has been satisfied, the soil is then fertile and capable of temporarily supplying adequate levels of the nutrient to satisfy crop needs. Long-term profitability of fertilizer use is identified with the crop’s response to residual fertilizer as a result of previous fertilizer application(s).

Phosphorus Build Up

As a general rule, the P soil test index will increase by one, for every 10 to 20 lb of P_2O_5 added that is not taken up by the crop (Table 6.3). When P fertilizer is broadcast and incorporated only 10-15% of the fertilizer P is taken up by the crop, the remaining 85-90% goes toward "fertilizing the soil". Some of this replaces what the crop removed from the soil and the rest contributes to "build-up" or increase in the soil test value. For example, in a Pond Creek Silt Loam with a soil test P index of

20, the OSU calibration would identify a need for applying 40 lb/acre P_2O_5. Yield of 40 bu/acre would take about 20 lb/acre of P_2O_5 from the soil and fertilizer. This would leave about 20 lb/acre of P_2O_5 to build P soil fertility. At this rate it would take about 15-20 years to build the soil test P index from 40 to 65 and reduce the fertilizer requirement from 40 to zero lb/acre. The long-term profitability is that of reducing P fertilizer cost from about \$10/acre to zero. Much of this long-term benefit is incidental to fertilizer P additions needed to correct deficiencies each year that result in short-term or annual profit.

Another way to look at the long-term benefit or build up of available soil P is to consider the cost of "creating" P fertile soil. Extrapolating from the data in Table 6.3, one can calculate that it would take about 900 lb/acre of P_2O_5 to change the P soil test from zero to 65. At an average cost of \$0.25/lb applied, this amounts to a value of \$225. In terms of land value for long-term crop production, one could afford to pay \$225 an acre more for a field of this soil type that tested 65 or above than for one that had a zero P soil test.

Table 6.3. Phosphorus build-up in Grant silt loam in Alfalfa County (continuous wheat production).

Rate of Phosphorus (lb P_2O_5/acre)	Total Applied in 8 years (lb P_2O_5)	Soil Test (lb P/acre)
0	0	32
20	160	37
40	320	48
60	480	73
80	640	97
100	800	110

ENVIRONMENTAL RISK

Although the chemical and biological reactions responsible are different, each of the essential plant nutrients is present in both immediately available and slowly available (or fixed) forms in soil. The slowly available form often provides a huge reservoir of the nutrient that crops can draw upon for many years without a deficiency occurring. Some evidence of this is provided in Table 6.4 which shows the total amount of selected elements in a Hollister clay loam. From this table it is easy to see that only a fraction of the total nutrient content in soils would be removed even by a nutrient demanding crop like alfalfa.

Many nutrients, when added to soil in a fertilizer formulation that is 100% available, revert back to the fixed form already present in soil. Consequently, the amount of nutrient in the soil solution that could migrate to groundwater is usually small or non-existent. This fact is born out by chemical analysis of groundwater that usually shows detectable amounts of only nutrients like nitrogen, calcium, potassium, and magnesium. Phosphorus and iron are usually present in only minute or non-detectable amounts.

Table 6.4. Constituents of a Hollister clay loam.

	Surface Soil Content	
Element	Total	Available*
SiO_2	1,512,000	0
Al_2O_3	212,000	0
Fe_2O_3	62,000	0.5
K_2O	44,000	235
Na_2O	22,000	50
MgO	16,000	30
CaO	14,000	150
P_2O_5	2,000	55

* Amounts removed by a 5 ton yield of alfalfa.

Presence in groundwater of nutrient elements potassium, calcium, magnesium, and iron is a result of them being components of the geologic aquifer and materials such as limestone, sandstone, and shale. Nitrogen, however, is not usually a component of rocks and minerals. Its presence in groundwater is almost certain to have resulted from excess nitrate leaching out of the surface soil. Excess nitrate in surface soils may originate from mismanagement of fertilizer or manure additions, or tillage that stimulated release of organic bound nitrogen when soil organic matter decayed. It is very likely that much of the NO_3-N found in groundwater today came from soil organic matter.

The prairie soils of Oklahoma commonly contained in excess of 2% soil organic matter. Soil in the top six inches in the famed Magruder Plots at OSU contained about 3.5% organic matter and 3200 lb/acre of N in 1892 when they were initiated. Release (mineralization) of organic N is stimulated by aeration, primarily associated with tillage. In the earliest years of cultivated agriculture release of N from soil organic matter was very low because of the minimum tillage provided by horse-powered cultivation. The advancement of tractors brought with it intensive tillage that likely stimulated N release in excess of crop use for many years. Rough calculations indicate the “no fertilizer” Magruder Plots utilized only about 70% of the N released from soil organic matter over the past 100 years. It is very likely that substantial amounts of nitrate nitrogen from soil organic matter release were unused in years of crop failure because of insects, disease, or lack of timely rains and leached below the root zone by subsequent heavy rain. These additions of nitrate-nitrogen cannot be separated from any current additions originating from chemical fertilizer use. Unfortunately, many water quality investigations that report high nitrates draw the conclusion, based upon speculative association, that it is all a result of N fertilizer use.

Calculation of N additions to, and removals from agriculture land provides valuable insight to how prudently N fertilizer is used. In recent years, Oklahoma fertilizer sales have accounted for addition of about 300,000 tons of actual N to farmland each year. Not surprisingly, since most farmers cannot afford to buy unneeded fertilizer, the amount of N removed by harvest of grains and forage each year is almost exactly the same.

All involved in the use of farm chemicals must be sensitive to the environmental risks that may result from misuse. However, especially in the consideration of fertilizer use we must understand that these "chemicals" are naturally occurring, essential for crop production and biological activity, and that common use seldom is a threat to the environment.

ADVANCED CONSIDERATIONS

Nitrogen Fertilizer Response

Soil fertility research and general response of crops to fertilizer has led to some common generalizations and expectations about crop response. For example, it is generally accepted that about 2 lb N/acre are required to produce a bushel of wheat and 50 lb N/acre are required to produce a ton of warm season forage in Oklahoma. However, occasionally the N requirements are much greater and sometimes they are much less. The question then is “how come?” The answer to this question is related to the soil’s capacity to hold available N in an organic matter reservoir.

When more N is applied to a field than is removed by the harvested crop each year, much of the unused N becomes a part of accumulating soil organic matter. If this happens for several successive years, then the result is similar to what happens when wheat follows alfalfa. Nitrogen fertilizer is not needed for the wheat because the mineralization of several years of accumulated alfalfa residue supplies the needed N. Similarly, a good wheat yield can be obtained without N fertilizer if wheat has received adequate or excessive N for several prior years. Usually wheat yields will be less the second year without N fertilizer because much of the stored N will have already been used. In years of exceptionally good weather, yields much above the yield goal may be obtained. The N for the “extra yield” in these years is also a result of N released from the soil organic matter. It is important to realize that whenever some of the N in soil organic matter is used, the amount in this reserve becomes less and cannot as easily make the contribution again without having been restored from addition of a little extra fertilizer N.

If the N fertilizer input is always less than what is generally required to support the yields obtained (e.g., harvest 2 ton forage each year and only apply 60 lb N/acre), then whatever yield is obtained will be partially supported by N released from soil organic matter. Consequently, this organic matter reserve will become partially depleted. A field with this N deficient history will not respond normally to N fertilizer. If the field has the potential to produce four ton/acre of forage, application of 200 lb of N may produce less than the expected yield because some of the N will go toward restoring the normal reserve of organic N in the soil. This “less than expected” crop response may reoccur until organic N levels are back to normal.

Phosphorus and Potassium Fertilizer Response

Significant P and K deficiencies may exist in fields even when crop yields appear excellent. Tables 4.3 to 4.6 show that deficiencies of these nutrients may be expressed as a “Percent Sufficiency”. This means that yields in a nutrient deficient field will be a percentage of the yield potential, or yield that could have been obtained if there was no deficiency. For example, we might expect an alfalfa field that yielded 5.0 ton when fertilized, to yield only 4.5 ton without fertilizer P if the P soil test was 40 (90% sufficient; 0.90 X 5 ton = 4.5 ton). The 0.5 ton yield response from adding the fertilizer would be near impossible to see in a field if a check strip was left because it represents the total response from 4 to 5 cuttings.

In low yielding environments, it is more difficult to see P and K responses than in high yielding environments. A soil test P level of 20 for wheat (80% sufficient) will result in only a 4 bushel loss if the yield potential is 20 bushels (0.80 X 20 = 16), but a 12 bushel loss if the yield potential is 60 bushels (0.80 X 60 = 48).

Fields that test adequate for P and K may still show a response to P or K fertilizer because of field variability. When a field is extremely variable, some of the 15 to 20 cores that make up the composite soil sample will have come from areas of the field that are more deficient than the average. If the average, represented by the composite sample tests adequate (e.g., 65 for P), applying a strip of fertilizer P the length of the field may still show crop response in those low testing areas. This phenomenon has led to interest in the concept of “precision agriculture” that would manage production inputs based on variable needs of fields.

Chapter 7 Utilization of Animal Manure as Fertilizer

INTRODUCTION

Animal production is a large segment of the economy of Oklahoma. The increased numbers of confined animal feeding operations (CAFO) and poultry production facilities produce large quantities of manure requiring proper management. Animal wastes have been used by ancient and modern farmers to enhance crop production. Manure contains valuable plant nutrients as well as potential pollutants. Besides providing valuable major and micronutrients to the soil, manure supplies organic matter to improve soil tilth, improves infiltration of water and retention of nutrients, reduces wind and water erosion, and promotes growth of beneficial organisms. Therefore, manure land application recycles nutrients and improves soil productivity (Figure 7.1).

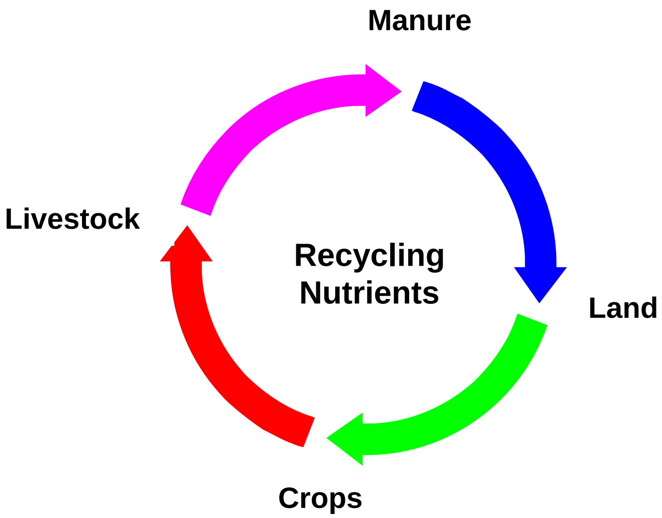


Figure 7.1. Land application of animal manure recycles nutrients back to the land. It is the most economical and environmentally sound method to handle by-products in meat and milk production.

Manure applications, however, may cause surface and groundwater pollution if mismanaged. Surface runoff from manured land may contain plant nutrients and organic materials. Excess nutrients and organic material in surface water often causes algal bloom, which increase the turbidity and biological oxygen demand (BOD) of water. The polluted water may cause odors and result in a fish kill if the dissolved oxygen is significantly lowered. Excessive applications of manure may also cause nitrate-nitrogen (NO_3-N) to accumulate in the soil. The excess NO_3-N can reach the surface water through drainage ditches or groundwater through leaching.

This chapter is to provide agronomic information for the efficient use of manure nutrients for crop production and to help preserve surface and ground water quality. A work sheet is also provided for choosing the optimum rate of manure application depending on your crop yield goal and soil conditions.

MANURE MANAGEMENT FUNCTIONS

An agricultural waste management system designed for a confined animal feeding operation consists of six basic functions: production, collection, storage, treatment, transfer, and utilization (Fig. 7.2). It is important to understand each of these functions since they affect the nutrient contents of the manure.

Production

Production is the function of the amount and nature of manure generated by a feedlot operation. Oklahoma farms produce about 9 million tons of manure from CAFO alone each year. The generation of unnecessary waste should be kept to a minimum. Leaking watering facilities and spilled feed contribute to the production of waste. These problems can be reduced by careful management and maintenance of feeders, watering facilities, and associated equipment.

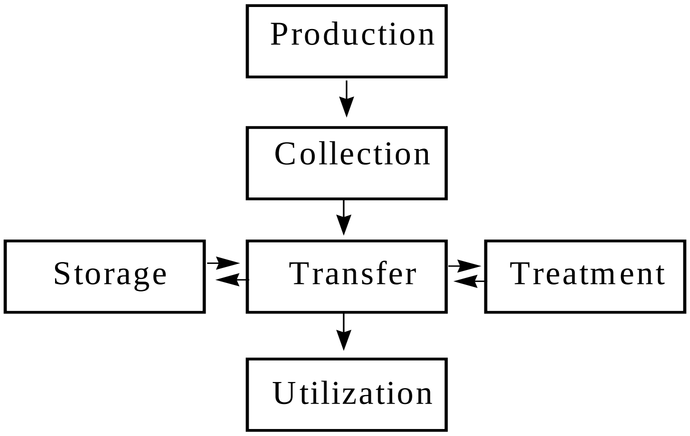


Figure 7.2. Manure Management Functions.

Collection

This refers to the initial capture and gathering of the waste from the point of origin or deposition to a collection point.

Storage

Storage is the temporary containment of the waste. The storage facility of a waste management system is the tool that gives farmers control over scheduling of transfer operation or land application.

Treatment

Treatment is any process designed to reduce pollution potential of the waste, including physical, biological, and chemical treatment. It includes activities that are sometimes called pretreatment, such as the separation of solids.

Transfer

This refers to the movement and transportation of the waste throughout the system. It includes the transfer of the waste from the collection point to the storage facility, to the treatment facility, or to the utilization site. Waste may require transfer as a solid, liquid, or slurry, depending on the total solid concentration.

Utilization

Utilization refers to the recycle of waste products into the environment. Agricultural wastes may be used as a source of energy, bedding, animal feed, mulch, organic matter or plant nutrients. Properly treated, they can be marketable. Most often they are land applied as soil amendments, therefore, utilization of manure as plant nutrients will be discussed here in detail.

VALUE OF ANIMAL MANURE

Animal manure contains valuable nutrients that can support crop production and enhance soil chemical and physical properties. Thus, manure can be an asset to a livestock production operation if its nutrient value is maximized. Nutrient composition of farm manure varies widely even for the same species of animal. In the past, manure was primarily solids, thus application was a problem because it required handling a large tonnage of low-analysis material. Today, an increasing amount of the waste is in a fluid and the analysis is even lower because of the higher water content. The approximate fertilizer values for various manures are shown in Table 7.1. However, the actual value is based on the need for nutrients. For example, crop will not benefit from additional P if the field is already high in soil test P. These nutrients are average values and a chemical analysis on each sample should be obtained before manure is applied to your field. Manure sampling procedures and analysis is available through OSU Soil, Water and Forage Analytical Laboratory (http://www.soiltesting.okstate.edu) will be discussed later.

Table 7.1. Approximate dry matter, nutrient content, and potential dollar value of common types of manure.

Manure Type	Dry Matter	Total N	P_2O_5	K_2O	Value*
	%	-------------lbs/ton------------------			$
Feedlot Manure	62	24	21	25	18.5
Poultry Litter	77	63	61	50	47.2
		---------lbs./1000gal-----------			
Lagoon Effluent	0.5	4.2	1.0	5.0	2.56
Lagoon Sludge	7	15	16	11	11.5
Dairy Slurry	3	13	11	11	9.4

* Based on a per lb value of $0.30 for available N, $0.30 for P_2O_5, and $0.20 for K_2O

METHODS OF LAND APPLICATION

Manure can be applied to land by surface broadcasting using a manure spreader, by injection into irrigation system, or by tank wagon followed by plowing or disking, by broadcasting without incorporation, or by knifing under the soil surface. Research has shown that maximum nutrient benefit is realized when manure is incorporated into the soil immediately after application.

Immediate incorporation of solid manure minimizes N loss to the air and allows soil microorganisms to start decomposing the organic fraction of the manure. This increases the amount of available N to the crop. With liquid manure systems, the practice of injecting, chiseling, or knifing the manure beneath the soil surface reduces N losses by volatilization and potential runoff. Incorporation of either solid or liquid manure also reduces odor problems. Large N losses usually result from application by irrigation equipment. Actual losses depend on NH_4-N content, and increase as the irrigation water pH increases. Nitrogen loss by ammonia volatilization from surface applications is greater on dry, warm, windy days than on days that are humid and/or cold. That means loss generally is higher during the late spring and summer seasons than it is in the late fall and winter. It is especially important that poultry and veal calf manure be incorporated into the soil as soon as possible after application because of its high pH (alkalinity). To prevent local high concentrations of ammonium or inorganic salts, which can reduce germination and affect yields, manure should be applied uniformly.

Phosphorus and K, unlike N, are not subject to either volatilization or leaching losses. Incorporation of manure, however, will minimize P and K losses due to runoff, and increase their agronomic value.

PROCEDURES FOR SAMPLING AND ANALYZING MANURE

The actual nutrient value of manure from a particular operation will differ considerably due to the method of collection and storage. For accurate rate calculations, it is strongly recommended that the nutrient content of manure be determined by laboratory analysis annually or when manure handling procedure changes. The analysis report should include information on dry matter, total N, P and K. Nitrate-N, ammonium-N and water soluble P need to be determined sometimes.

How to Collect a Representative Sample

The key to an accurate manure analysis is to obtain a representative sample by mixing the manure and using proper sampling techniques. A considerable amount of nitrogen can be lost if a sample is not correctly taken, handled, and preserved.

For liquid manure storage facilities, samples may be collected by attaching a container, such as a jar or milk jug, to a long rod and using that to remove a sample of waste. If possible, agitate the contents of a manure pit to ensure a well-mixed sample. Liquid storage facilities have a tendency for the waste to stratify, with the solids settling to the bottom and the liquids remaining on top. Normally the N and K will be more concentrated in the top liquid, while the P will be concentrated in the bottom solids. Several sub-samples should be collected from the storage facility, placed in a bucket to make a composite sample, and mixed well by stirring. From this mixture, a quart size plastic container is filled half full. Filling the bottle half full will allow for gas expansion of the sample and prevent the bottle from exploding. The sample should be kept frozen or as cold as possible until you can take it to your county extension office or ship it directly to a laboratory. Liquid samples can also be collected during land application. These samples best represent the amount of nutrients applied to the land. Randomly place catch pans in the field to collect the liquid as it is land applied by an irrigation system or honey wagon. Immediately after the waste has been applied, collect the waste from catch pans and combine in a bucket to make one composite sample. Take the final sample from this mixture, and fill the container as described early. Sampling waste this way accounts for nutrient losses due to both storage and handling as well as losses due to application.

For solid manure, obtain samples from several parts of the manure source and place in a bucket to make a composite sample. Do not allow the material to dry, and take about 1 pound of final sample in a plastic bag, twist and tie tightly. For added safety, place in a second plastic bag. Preserve immediately by freezing.

Deliver the liquid or solid manure sample to the laboratory personally, or package thoroughly, in a strong, insulated container and ship the fastest way possible. Check with your county extension agent for more details on how to collect samples and where to obtain an analysis.

NUTRIENT AVAILABILITY OF MANURE TO CROPS

Not all nutrients present in manure are readily available to a crop in the year of application. To be used by plants, nutrients must be released from the organic matter in manure by microbial decomposition and into a chemical form that is soluble in water.

Most manure N is in ammonium (NH_4^+) and organic forms. Potentially, all of the ammonium-N (NH_4-N) can be utilized by the plants in the year of application. However, if manure is broadcast on the soil surface and not quickly incorporated, considerable NH_4-N will be lost to the air as ammonia (NH_3) gas increasing odor, as discussed earlier. The ammonium added will be subject to nitrification resulting in rapid formation of nitrate-N (NO_3-N). Nitrogen in the organic form must be converted (mineralized) into inorganic forms which are plant available (ammonium and nitrate) before it can be absorbed by roots. The amounts of organic N converted to plant-available forms during the first cropping year after application vary according to both livestock species and manure handling systems. In general, about 25% to 50% of the organic N may become available the year of application. Organic N released during the 2nd, 3rd and 4th cropping years after application is usually about 50%, 25% and 12.5%, respectively, of that mineralized in the initial season. Soil test data should be used to follow the potential accumulation of N after repeated manure applications.

If the soil organic matter levels are low, some N can be tied up (immobilized) in the soil and released in the subsequent years resulting in much less available the first year. In addition, manure contributes considerable organic matter to the soil and increases bacterial activity which can tie up inorganic N making it not immediately available to the growing plant. The average N available in the first year of application and in the consequent years is listed in Table 7.2.

Table 7.2. Estimated Ranges of Nitrogen Availability in Animal Manure

Manure Type	1st Year Availability	Future Availability
Feedlot manure	50% - 70%	10% - 20%
Poultry litter	50% - 70%	10% - 15%
Dairy manure	50% - 70%	10% - 20%
Swine lagoon effluent	30% - 50%	5% - 10%

The availability of P and K in manure is considered similar to that in commercial fertilizer since the majority of P and K in manure is in the inorganic form. For all manure types, 90% of P and K in the manure are considered available during the first year of application and 10% for future years. Another management approach is to rotate the fields that receive manure if excess P is applied so that P can be efficiently utilized in subsequent cropping seasons and P buildup in the soil is minimized.

DEVELOPING A FERTILIZER/MANURE APPLICATION PLAN

Some producers apply enough manure on the land to meet crop nutrient needs and then unnecessarily add commercial fertilizer. This practice not only wastes money and much of the manure's potential value as a plant nutrient source, but also can cause nutrient imbalance in the soil and increase nutrient leaching or runoff into water sources. Repeated applications of excess manure result in a wasteful buildup of P and K in soils. Salt buildup is also possible if manure salt concentration is higher than normal, application rate is excessive, and rainfall is low.

Livestock and poultry producers should develop a manure nutrient management plan that first maximizes the use of manure nutrients and then supplements with commercial fertilizers only if additional nutrients are needed for the crop. The major elements of such a plan should include:

- periodic analysis of the manure produced in the animal operation
- a routine soil testing program
- keeping accurate records of fields manured and the application rates used
- sufficient storage capacity for timely application
- field availability for manure application
- uniform applications and proper timing of manure application across the entire field
- calibration of manure spreaders so application rates can be determined
- applying manure to meet crop nutrient needs based on realistic yield potentials
- applying manure to a field every two or three years to more efficiently use all the nutrients in the manure.

SUGGESTIONS FOR PROPER LAND APPLICATIONS

The following are some suggestions to help ensure safe and effective application of animal manure to cropland:

- When applying manure and waste water to land, operators of animal feeding operations should utilize a buffer area (minimum horizontal distance of 150 feet or that required by state regulations) around water wells sufficient to prevent the possibility of waste transport to groundwater via the well or well casing;
- Unless immediately incorporated into the soil, surface apply manure at reasonable distances from streams, ponds, open ditches, residences and public buildings to reduce runoff, odor problems and to avoid neighbor complaints;
- To minimize farmstead odor problems, spread raw manure frequently, especially during the summer. Spread early in the day when the air is warming and rising rather is blowing toward populated areas or when the air is still;

- When the soil is frozen or saturated, apply manure only to relatively level land where runoff will not occur;
- Agitate liquid manure thoroughly in pits to ensure removal of settled solids. This is important for uniform application of the nutrients and for obtaining accurate, representative analysis samples;
- Consider irrigating with diluted manures (lagoon or runoff liquids) during dry weather to supply needed water as well as nutrient to growing crop;
- Do not spread liquid manure on water-saturated soils where runoff is likely to occur;
- Make safety your first priority when removing manure from tanks or pits. Because of oxygen deficiency or toxic gas accumulation, remove animals or increase ventilation in slatted floor areas over manure pits during agitation.

DETERMINING HOW MUCH MANURE CAN BE APPLIED

Land application rates should be based on the nutrient requirements of the crop being grown to ensure efficient use of manure nutrients and minimize the chances of leaching. Soil testing, manure analysis, irrigation water analysis, and proper estimation of yield goal are necessary to calculate proper agronomic application rates of manure and fertilizers. However, if manure analysis information is not available, the data in Table 7.1 and 7.2 may be used to calculate approximate application rates. Table 7.3 bellow illustrates the steps to come up with an agronomic rate of manure application. This is what one should do to maximize the benefits of manure and minimize the impact on the environment. However, more manure may be allowed to apply. More information on manure rules and regulations is available from Oklahoma Department of Agriculture, Food and Forestry and Oklahoma Natural Resource Conservation Services.

Oklahoma Cooperative Extension Services' Manure and Animal Waste Management wepsite is also a good source of information: http://www.animalwaste.okstate.edu/.

Table 7.3. Manure Application Rate Calculation Worksheet

Step 1	**Nutrient needs of crop (lb/acre)** Recommendations based on soil test values and a realistic yield goal.	N= _______ P_2O_5= _______ K_2O= _______
Step 2	**Total nutrient value of manure (lb/ton or lb/1000 gal)** Based on manure analysis of a representative sample collected close to the time of application.	N= _______ P_2O_5= _______ K_2O= _______
Step 3	**Determine available nutrients (lb/ton or lb/1000 gal)** Multiply the value from Step 2 by the nutrient availability, normally 50% for N and 90% for P & K.	N= _______ P_2O_5= _______ K_2O= _______
Step 4	**Calculate the rates of application needed for N, P, and K (tons/acre or 1000 gal/acre)** Divide values from Step 1 by values from Step 3.	N= _______ P_2O_5= _______ K_2O= _______
Step 5	**Select the rate of manure to be applied (tons/acre or 1000 gal/acre)** Choose the nutrient for which the manure rate is to be based. Select the highest of three if manure is used as a complete fertilizer; select the lowest for maximum nutrient use efficiency.	Rate= _______
Step 6	**Determine amount of available nutrients being Applied (lb/acre)** Multiply the rate (Step 5) by available nutrients (Step 3).	N= _______ P_2O_5= _______ K_2O= _______
Step 7	**Determine amount of supplemental nutrients Needed** Subtract the nutrients needed (Step 1) from nutrients being applied (Step 6). If the difference is negative, it is the amount of supplemental fertilizer needed.	N= _______ P_2O_5= _______ K_2O= _______
Step 8	**Determine total depth of application** Divide the rate (Step 5) by 27,000 to get irrigation depth needed to provide nutrients.	_____ acre-inch
Step 9	**Determine number of applications and amount of each application** Based on growth stages and crop nutrient needs at each state.	1^{st} =______acre-inch 2^{nd}=______acre-inch 3^{rd}=______acre-inch

ADVANCED CONSIDERATIONS

Phosphorus Management for Land Application of Organic Amendments

The soil scientists at Oklahoma State University have collaborated to present a brief scientific background of P behavior in soil and to present their views on management of P derived from land application of organic amendments (animal manure, biosolids, etc.). These concepts are summarized in a recommended P management plan for land application of organic amendments. The management plan is based on three criteria: soil test phosphorus (STP), water soluble soil P threshold, and impairment status of watershed with regard to P. The plan requires knowledge of (i) level of P that provides a crop response, (ii) levels of water soluble P that are considered excessive (above threshold), and (iii) amounts of runoff P that result in unacceptable risk to surface waters. The level of P that provides a crop response has been documented from decades of agronomic research at OSU. However, knowledge regarding (ii) levels of water soluble P that are considered excessive, and (iii) amounts of runoff P that result in unacceptable risk to surface waters is incomplete. Research is needed to provide information on these criteria from other disciplines or agencies. Without information on (ii) and (iii), the management plan proposed in the following for soils already containing STP>120 cannot be implemented. For this reason, applications of organic wastes must be limited to a strong knowledge base (i.e. crop production based on STP). Research is needed to provide a strong knowledge base on levels of soil test P that result in excessive levels of water soluble P and methods to determine unacceptable levels of P that may impact surface water quality.

Soil Test P and Crop Production

Initial and ongoing field research over the past 30-50 years has led to reliably linking soil test phosphorus (STP) levels to crop production. Although there are some differences in procedures, each of the 48 contiguous states in the US commonly use soil testing to identify when soils are deficient in P for crop production. Examples of this soil test calibration from Oklahoma State University are shown in Tables 4.3-4.6.

Recent research conducted at OSU has documented extreme variability in STP over short (3 feet) distances within fields and may be common. Consequently, when a composite sample has an STP value of 65, some portions of the field may still respond to P fertilization. Continue P fertilization until the composite sample tests 120 will assure the lowest testing parts of a variable field will have an STP of 65 and no longer show a yield increase to P additions. When the STP for a composite field sample is above 120, crops are not expected to benefit from continued P fertilization.

Conclusion 1. Phosphorus inputs will not be utilized to improve crop production when a field is identified by a composite soil sample to have an STP value of 120 or greater.

Soil Test P and Water Quality. Environmental concerns regarding the P level of surface waters have not commonly been the primary research objective of soil scientists. OSU soil scientists have traditionally recommended no application of P fertilizers after the STP reaches or exceeds 65 based on crop production (0-6" sample, Mehlich 3 extraction). Research establishing the effect of STP on water quality in Oklahoma is in progress. Recent identification of nutrient "impaired" watersheds in Oklahoma did not have input from OSU soil scientists.

The implied relationship of soil scientists to water quality problems has resulted from the knowledge that soil scientists have defined criteria for nutrient management to grow crops. Since eutrophication and hypoxia result from nutrient enrichment of surface water, mismanagement of nutrients in crop production systems has been blamed for these water problems. With regard to nitrogen management, there is now strong scientific evidence to support this blame.

Soil scientists have clearly shown that the form of phosphorus (dissolved P or water soluble P) responsible for eutrophication increases in the soil immediately after P fertilization and then gradually decreases. They have also shown that water soluble-P increases in proportion to increasing STP. From this, it is a logical deduction to conclude that risk of eutrophication increases with increasing STP, and that it is greater when STP is above 120 than when it is below 120.

Conclusion 2. P-fertilization increases the risk of water pollution. This risk is greater when STP is above 120 than when STP is below 120.

Water Soluble P. Phosphorus inputs that do not result in an increase in water soluble P should not increase risk to water quality. Phosphorus forms very insoluble compounds and has low water solubility in acidic (pH <5) and in calcareous (pH >7.5) soils. In addition, soils vary in their ability to retain P. Clay soils can adsorb more P than sandy soils. Soil texture greatly influences water soluble P and will affect the solubility of land-applied manure P. Approximately 75% of the P in feeds is present as phytic acid, a P-storage compound. Release of P from this compound, either in animals or soil, depends on the presence and activity of the enzyme phytase. Monogastric animals do not have the enzyme, hence much of the feed-P passes through them. Manure from these animals contains the P as phytic acid. The activity of phytase is pH dependent and may be low in calcareous soils. Thus, water soluble-P may remain at low concentrations in these soils when the continued P input is organic.

Conclusion 3. P inputs that no longer correct a soil-P deficiency for crop production may be environmentally safe if water soluble-P remains low (level consistent with STP of 120).

Best Management Practices (BMPs) and P in Water Runoff. When water soluble-P is higher than the concentration normally found in soils that adequately supply P to crops, water quality may not be adversely affected if the field is not a source of surface water runoff. Similarly, there is no risk to surface water quality from continued input of P if the field is not in an “impaired” watershed, or if there are no neighboring bodies of water. These conditions commonly exist in arid regions (e.g. Oklahoma panhandle).

When water soluble-P is abnormally high it may not pose a risk to neighboring bodies of water if soluble-P in runoff is low. This condition may be created by using buffer strips and/or treatment of soil/field with P fixing material, such as water treatment residuals to strip soluble-P from water as it leaves the field. Other conservation practices which reduce runoff and erosion can also reduce P loss from manured fields to surface waters.

Conclusion 4. Continued input of P to fields with high STP and water soluble-P are not a risk to water quality if there is no runoff, no neighboring bodies of water, quality of the water body is not limited by P, or the concentration of soluble-P is reduced to levels that do not result in unacceptable risk by buffer strips.

Management Strategies

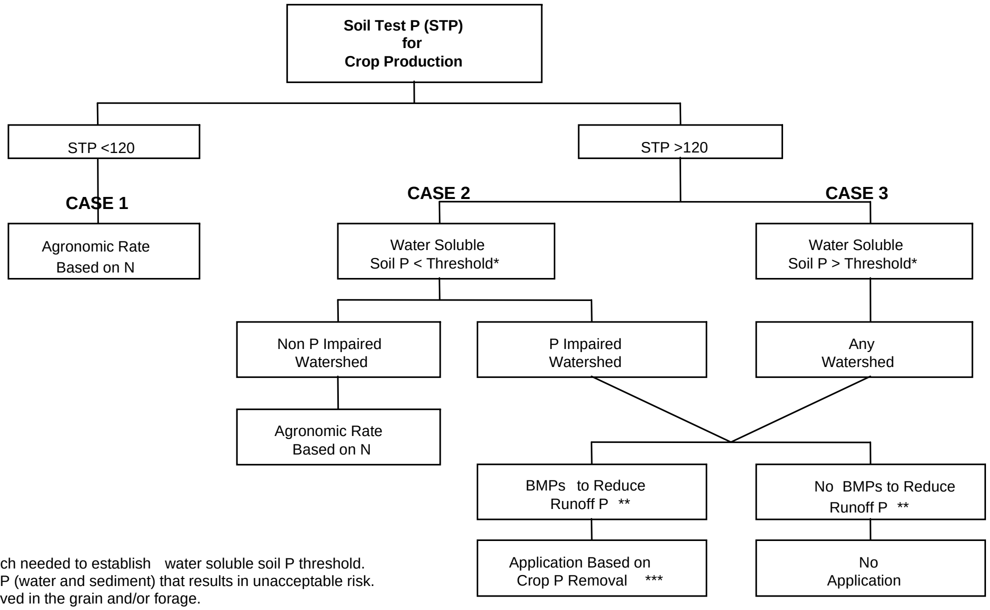
The current scientific foundation for P-management is the soil test used to identify P needs for crop production. When STP levels are above the critical level for crop production (120), the environmental risk of continued animal waste-P input could be rationally managed by use of a water soluble-P soil test and implementation of BMPs. Management decisions regarding land application of organic amendments are discussed below and illustrated in Figure 7.3.

Case 1: STP < 120 Fields receiving organic amendments should be soil tested annually. If the STP value is less than 120, animal waste and other organic amendments can be applied at a rate to meet the seasonal nitrogen needs of the next crop to be grown. The nitrogen input from animal waste is determined from a realistic crop yield goal and takes into consideration residual nitrate-nitrogen identified in the soil test. Recent soil test summaries indicate 82% of Oklahoma fields have an STP less than 120, and would qualify for this strategy.

Case 2: STP > 120 and Water Soluble Soil P < Threshold In this case, crops will not benefit from P inputs but may benefit from N inputs. The STP is above 120 but the water soluble-soil P is below the threshold level (to be determined from research studies) resulting in a low water quality risk, providing erosion is controlled. Application of organic amendments to meet crop N needs should not pose undue environmental risk relative to P. Agronomic N rates can be applied in a non-P impaired watershed.

However, organic waste applications should be limited in P-impaired watersheds. Additions based on agronomic N rate will increase STP and eventually create water soluble soil P levels above the threshold that may affect water quality in a P-impaired watershed. In P-impaired water, BMPs that control erosion and reduce P-runoff should be used if organic waste is to be land applied. Waste applications are limited to amounts based on crop P removal (P removed in grain and/or forage). Applications that support multiple years of cropping are possible (i.e. one-time application that supports 3 yr of crop P removal). No application of organic waste is recommended without incorporation of BMPs into the management plan.

Case 3: STP > 120 and Water Soluble Soil P > Threshold In this case, crops will not benefit from P input (STP > 120) and increased water soluble soil P has the potential to increase risk to surface water quality (surface water that receives excessive P from surface runoff). Runoff P has the potential to adversely impact P-impaired watershed. Therefore, BMPs that control erosion and reduce P-runoff should be used if organic waste is to be land applied. Waste applications are limited to amounts based on crop P removal (P removed in grain and/or forage). Applications that support multiple years of cropping are possible (i.e. one-time application that supports 3 yr of crop P removal). No application of organic waste is recommended without incorporation of BMPs into the management plan. The same recommendations apply to non-P impaired watersheds as a protective measure. These recommendations will limit P runoff and prevent non-P impaired watersheds from becoming P-impaired watersheds.



* Research needed to establish water soluble soil P threshold.

** Runoff P (water and sediment) that results in unacceptable risk.

*** P removed in the grain and/or forage.

Case 1: Beneficial crop response from N and P input and minimal water quality risk.

Case 2: No beneficial crop response from P input but crop response from N input. Low water quality risk where erosion is controlled because the soil has a low water soluble P. BMPs recommended to control soil erosion and runoff P in P Impaired Watershed.

Case 3: No beneficial crop response from P input. Potential water quality risk because increased water soluble P. BMPs recommended to control soil erosion and runoff P in watersheds.

Figure 7.3. Phosphorus management options for land application of organic amendments.

Chapter 8 Environmental Concerns Associated with Fertilizer Use

Use of fertilizer materials has generated numerous environmental concerns in recent years. Concerns can be categorized by their effect on water quality, air quality, and human and animal health. In each case, constituents of primary interest are nitrogen and phosphorus, although others need to be considered depending on the fertilizer source. As previously covered, there are many available fertilizer sources including commercial fertilizers, biosolids and animal waste. Environmental concerns become a potential hazard with the misuse of these materials. Misuse generally arises when fertilizer application rates exceed agronomic requirements. It is emphasized here that application of fertilizer materials is not environmentally unsound but excessive application of any of them can lead to potential hazards. In many states fertilizer use is now being regulated and it is expected that Oklahoma will follow this trend. Therefore, as an agriculture systems manager you should be aware of potential problems. By knowing the potential problems you can properly manage fertilizer inputs to maximize production yet minimize negative environmental impacts.

NITROGEN

Environmental concerns with N focus on water quality but also include air quality and human and animal health. Water quality issues include N concentrations in surface water and groundwater. Concerns for surface waters are related to N entering streams, ponds, and lakes where elevated levels will stimulate algae growth resulting in algae blooms. Upon the death of the algae, microbial activity increases resulting in a decrease in available oxygen for biological functions, a condition referred to as eutrophication. Eutrophication has a detrimental effect on most aquatic species. It occurs when there are adequate sources of nutrients, but the system is limited by the available oxygen, resulting in the death of many aquatic species including fish and invertebrates.

The most common pathway for land applied N to reach surface waters is by runoff waters. These waters will often contain soluble materials and soil sediments. Therefore, even N applied at agronomic rates and incorporated into the soil is susceptible to moving into surface waters by runoff when carried by soil particles. Nitrate-N is a soluble N form and ammonium-N can be attached to the soil particles as they are carried into the stream or impoundment. To minimize N problems associated with runoff from fields into surface waters several steps can be taken. One of the most effective is to maintain plant residue on the soil surface which will enhance water infiltration and reduce the amount of soil sediments moved from the field into surface water. Another effective practice is to leave a buffer strip of vegetation between the field and the surface water, which can act as a trap for many of the soil sediments. By catching sediments in the buffer strip the amount of N reaching the surface water is reduced.

Although eutrophication of surface waters is important, much of the regulation in other states focuses on the use of N in areas where a subsurface aquifer is within 10 feet of the soil surface. Nitrogen in the NO_3^- form is very susceptible to leaching through the soil profile as previously discussed, therefore, these sites possess a real possibility for elevated levels of NO_3^- to enter the aquifer when N application rates are in excess of agronomic rates. Concerns with nitrate reaching an aquifer are generally related to animal and human health rather than an imbalance in environmental nutrient requirements.

Methemoglobinemia (blue-baby syndrome) can result from the ingestion of nitrate in water or nitrate-rich food products. Ingested nitrate can then be reduced to nitrite in the upper gastro-intestinal tract, and once incorporated in the blood system can form methemoglobin. Methemoglobin, unlike hemoglobin, cannot function as an oxygen carrier ultimately resulting in anoxia or suffocation if high amounts are present. Infants younger than 3 months are highly susceptible to gastric bacterial nitrate reduction because they have very little gastric acid production and low activity of the enzyme that reduces methemoglobin back to hemoglobin.

N-nitrosamines are potent carcinogens in animals. These compounds can be synthesized from amines and nitrous acid under certain conditions. When nitrate is reduced to nitrite it can give rise to the formation of N-nitrosamine compounds that are an important class of chemical carcinogens for humans. However, nitrosamines occur in very few foods and at very low levels because of their chemical instability. It is important to note that the presence of nitrosamines in food products is generally not associated with nitrates from N fertilizers, but rather the use of nitrite as a curing agent in meats, poultry, and fish. Potassium nitrate has also been used as a food preservative. Other studies have shown an association between nitrate in drinking water and the incidence of gastric carcinoma in adults continuously exposed to high nitrate.

Agronomic solutions have been available for years to deal with fertilizer NO_3-N pollution of surface and subsurface water supplies. Nitrogen fertilizer recommendations based on removal and use efficiency have been shown to be both environmentally sound and economical. Recent research by the OSU soil fertility project has demonstrated limited potential for NO_3-N leaching when the recommended N fertilization rates are employed in continuous winter wheat. This work has also shown that N rates needed for maximum wheat grain yield can be exceeded by small amounts without increasing soil profile NO_3-N accumulation.

The use of N in agriculture has been identified as a contributor to water pollution. However, it also has been found that this contribution to ground water contamination occurs when N is managed improperly. Under continuous production of wheat, applied N at the recommended rate (using soil testing and realistic yield goals) will not result in increased

NO_3-N contamination of groundwater. Also, the sensor-based system developed at OSU (discussed in Chapter 10) will likely decrease the risk of NO_3-N contamination of groundwater, since this technology simulates soil testing, but on a much finer scale. By working at a sub-field scale, excessive N application can be reduced, thus reducing the risk of NO_3-N leaching to groundwater.

A final concern related to the use of N fertilizers in some regions is air quality. This is primarily related to the application of animal manures and biosolids and resulting odor associated with them. There could be a push to regulate land application of animal manures and biosolids based on the NH_3 associated with them. Some believe a potential exists for degradation of air quality and detrimental effects to human health. This could be extended to the application of ammonium and ammonia containing commercial fertilizers as well. To minimize concerns associated with air quality, it is recommended that ammonia-containing fertilizers be incorporated upon application. There are agronomic and financial reasons for doing this as well as those associated with air quality. By incorporating these fertilizer sources, the amount of N lost from the soil system is reduced, thus, saving on the quantity of fertilizer purchases or allowing more land area to be fertilized with animal manure or biosolids.

PHOSPHORUS

Environmental concerns with phosphorus focus on water quality, particularly surface water quality. Phosphorus in the soil is an immobile plant nutrient and is tightly adsorbed to soil particles significantly reducing leaching movement through the soil profile. Therefore, if phosphorus is to reach surface water, it must be transported by the sediment load in runoff waters. If phosphorus does reach a stream or other body of surface water, it can lead to the accelerated eutrophication of the recipient water body. As previously discussed, eutrophication is the condition where a body of water has an enriched nutrient load (phosphorus) but is limited by the available biological oxygen in the water. Algal species that proliferate in high phosphorus water include Anabaena, Ankstrodemus and Euglena. As these organisms die and are decomposed by other organisms, the available biological oxygen is significantly reduced causing adverse effects on other species of aquatic life. To reduce these adverse effects, proper application is needed.

Due to their immobility in the soil, nearly all commercial P fertilizers are incorporated after broadcast application or banded below the seed. To reach surface water, this source of P is transported in the sediment as well as in dissolved form in the runoff. Therefore, reducing runoff and erosion will reduce environmental concerns related to P. As with nitrogen, the most effective way to do this is to follow good soil conservation practices. These include increasing water infiltration, reducing runoff by maintaining surface residues and using buffer strips at the edge of the field. These good conservation practices allow you to maintain your fertilizers, reduce soil loss and increase water stored in the soil profile.

Land application of animal manures, particularly poultry litter (high in P), and some biosolids are done by broadcasting the material on the soil surface. In many cases, these fertilizer materials are applied to forage crops which eliminates their incorporation. When left on the surface in this manner, they may be subject to loss from the field in the runoff. To decrease the potential of P from these sources reaching surface waters, it may be necessary to apply using injection or knifing the material into the soil. Based application rate on crop P needs instead of N needs will slow down P build up in the soil. Again, another method to reduce P loss is to use a buffer strip at the edge of the field to reduce the amount of sediment and manure leaving the field.

OTHER CONTAMINANTS

With the decrease in suitable landfill sites for human waste and the increase in confined animal feeding operations, there has been a tremendous increase in the interest of land application of these materials. Land managers should view these materials as a valuable nutrient source and not a waste material. They contain many plant nutrients in addition to N and P, so operators who have them should use them to their maximum benefit. To date, no other constituents in these fertilizer sources have proven to be of major environmental concern when proper guidelines are followed. Each source has a different make-up due to ration formulation of materials in the municipal waste stream. Constituents which may need to be considered are copper (Cu) in animal waste and heavy metals in biosolids. Heavy metal concentrations of biosolids must be monitored with materials above threshold levels needing to be landfilled. More information about biosolids land application is available from Oklahoma Department of Environmental Quality.

Environmental concerns due to the application of fertilizers can be drastically reduced by proper management of these resources. Regardless of fertilizer form, if the quantity applied is greater than what is required for the crop then the potential exists for negative environmental impacts. To minimize negative environmental impacts, there are a few simple practices land managers can use: add only the amount of fertilizer needed to meet plant requirements, use buffer strips and do not apply fertilizers too close to bodies of water, and use good soil conservation practices which minimize soil erosion and maximize water infiltration. A combination of these good management practices will greatly reduce the potential for adverse environmental impacts.

Chapter 9 Laws and Acts Governing the Marketing of Fertilizer, Lime, and Soil Amendments in Oklahoma

The sale of fertilizer, agricultural lime, and soil amendments is governed within Oklahoma by specific laws and acts. This legislation has been enacted by State Government to provide recognizable product standards and to protect unsuspecting consumers from marketing fraud. Provisions of the legislation are carried out by the State Department of Agriculture, Food and Forestry. Copies of each document may be obtained by request from:

Oklahoma State Department of Agriculture, Food and Forestry
Plant Industry and Consumer Services Division
2800 North Lincoln Blvd.
Oklahoma City, OK 73105-4298
Tel. (405) 521-3864

The laws and acts most important to soil fertility and soil management are:

1. Oklahoma Fertilizer Act (including an amendment to exclude manipulated manures).
2. Oklahoma Soil Amendment Act of 1975.
3. Oklahoma Agricultural Liming Materials Act.

This chapter includes excerpts from the laws and acts that should be of most interest to users of fertilizer, lime, and soil amendments.

THE OKLAHOMA FERTILIZER ACT

The Oklahoma fertilizer act contains several sections, each addressing a particular issue pertaining to fertilizer use in Oklahoma. These sections and significant excerpts relating to soil fertility and fertilizer use follow.

Section 8-77.3. The first section, lists terms and their definitions, when used in the Act:

Fertilizer material - Any substance containing one or more recognized plant nutrients which are used for its plant nutrient content and is designed for use or claimed to have value in promoting plant growth except unmanipulated and manipulated animal and vegetable manures, marl, lime, limestone, and wood ashes, which are subject to the provisions of Section 2 of this act.

Mixed fertilizer - Any combination or mixture of fertilizer materials.

Bulk fertilizer - A fertilizer distributed in a non-packaged form.

Custom blend - A fertilizer formulated according to specifications furnished by a final consumer.

Custom blender - A person who mixes or commingles commercial fertilizer into a custom blend and who distributes such special blend. A custom blender shall not be required to register each grade of fertilizer formulated according to specifications which are furnished by a final consumer prior to mixing.

Brand - A term design or trademark used in connection with one or several grades of commercial fertilizer.

Label - The display of all written, printed, or graphic matter upon the immediate container, or a statement accompanying a fertilizer.

Unmanipulated manures - Substances composed primarily of excreta, plant remains, or mixtures of these substances which have not been processed in any manner.

Manipulated manures - Substances composed primarily of animal excreta, plant remains or mixtures of these substances which have been processed by natural or mechanical drying or composting and no other chemicals have been added.

Grade - The percentage of total nitrogen, available phosphate, and soluble potash stated in whole numbers. Specialty fertilizers may be guaranteed in fractional units of less than one percent of total nitrogen, available phosphate, and soluble potash. Fertilizer materials, bone meal, manures, and similar materials may be guaranteed in fractional units.

Specialty fertilizer - A fertilizer distributed for non-farm use.

Distributor - Any person who distributes fertilizer.

Broker - A person who negotiates sales and purchases between a manufacturer, distributor, final consumer, or retailer of commercial fertilizer.

Fertilizer dealer - Any person operating a business that is engaged in the distribution or sale of a commercial fertilizer. The term fertilizer dealer shall not include an ultimate consumer who is engaged in the physical act of application of a commercial fertilizer or a retail store selling only bagged registered commercial fertilizer.

Section 8-77.5. Registrations

A. Annual fee of $50.00.

B. Any person operating a business engaged in the distribution or sale of a commercial fertilizer shall obtain a license for each business location. An application for license shall include name and address of licensee, and name and address of each distribution point.

C. Additional plant food elements may also be included in the guarantee if approved by the Board.

D. Registrations shall be permanent unless cancelled by the registrant or by the Board.

E. A custom blender shall not be required to register each grade of fertilizer formulated according to specifications which are furnished by a final consumer prior to mixing, but shall be required to be licensed and shall be the guarantor to that custom blend.

F. Each brand and grade of commercial fertilizer shall be registered with the Board before being offered for sale or distributed in Oklahoma. The following information is required for registration.

1. The net weight for packaged fertilizer.
2. Brand name and grade.
3. The name and address of the registrant.
4. The guaranteed analysis showing the minimum percentage of plant food claimed in the following order and form:

Total Nitrogen…(N)……………...___________percent
Available Phosphate…(P_2O_5) ….___________percent
Soluble Potash…(K_2O)………….___________percent

Section 8-77.6. Labels

Containers shall have placed on or affixed to the container in written or printed form the information required by paragraphs 1, 2, 3, and 4 of subsection A of Section 8-77.5 of this title, either:

1. on tags affixed to the end of the package between the ears or on the sewed end or both between the ears and on the sewed end; or
2. directly on the package in such manner as determined by the Board.

If distributed in bulk, a written or printed statement of the weight, as well as the information required by paragraphs 2, 3, and 4 of subsection A of Section 8-77.5 of this title, shall accompany delivery and be supplied to the purchaser.

Section 8-77.7. Inspection fee and tonnage report

A. For the purpose of helping to defray the expenses of inspection and otherwise administering and carrying out the provisions of the Act, an inspection fee shall be paid to the Board on all commercial fertilizer sold or distributed for use within this state. All such fees collected shall be deposited in the State Department of Agriculture Revolving Fund.

B. Each registrant distributing commercial fertilizer in this state shall file with the Board not later than the last day of January, April, July, and October of each year, a quarterly statement under oath, setting forth the number of net tons of commercial fertilizer distributed in this state during the preceding three (3) calendar months. An inspection fee of sixty-five cents ($0.65) per ton shall accompany such statement of which thirty cents ($0.30) per ton shall be forwarded directly to a special Soil Fertility Research Account in the Department of Plant and Soil Sciences of the Division of Agriculture at Oklahoma State University for the sole purpose of conducting soil fertility research involving efficient fertilizer use for agronomic crops and forages and ground water protection from plant food nutrients. The Department of Plant and Soil Sciences of the Division of Agriculture at Oklahoma State University shall present an annual report to the Agriculture Committees of the Legislature on the use of the special

Soil Fertility Research Account fund. If no fertilizer was sold or distributed in this state for the quarter, the registrant shall submit a statement for the quarter as required by this subsection reflecting such information and shall remit a minimum fee of Five Dollars ($5.00) with the statement.

Section 8-77.9. Sampling and analysis

This section allows for sampling and analyzing fertilizers to determine if they are in compliance with the registration and guaranteed analysis.

Section 8-77.10. Plant food deficiency

A. If an analysis shall show that a commercial fertilizer falls short of the guaranteed analysis beyond a reasonable tolerance established under rules by the Board, the Board may require the payment of a refund to the consumer in the amount twice the current value of the plant food deficiency. All penalties assessed under this section shall be paid to the consumer of the lot of commercial fertilizer represented by the sample analyzed within thirty (30) days after the date of notice from the Board to the guarantor, receipts taken therefor and promptly forwarded to the Board. If such consumer cannot be found, the amount of the penalty shall be forwarded to the Board and be deposited in the State Department of Agriculture Revolving Fund.

Paragraph B deals with alteration of a fertilizer grade as a result of mixing fertilizers such that the original guarantee is changed. Paragraph C identifies how nutrient value will be determined.

D. If any commercial fertilizer in the possession of a dealer or consumer is found by the Board, or any authorized agent thereof, to be short in weight, the guarantor of such commercial fertilizer shall within thirty (30) days after notice from the Board pay to the consumer a penalty equal to twice the value of the actual shortage. Underweight commercial fertilizer being offered for sale to a consumer shall be deemed in violation of the law and subject to removal from sale.

Section 8-77.11. Commercial value

The Board determines the values per unit of N, P, and K. This value is used in assessing penalty payments.

Section 8-77.12. Misbranding

Defines improper labeling.

Section 8-77.13. Adulteration

No person shall distribute an adulterated fertilizer product. A fertilizer shall be adulterated if:

1. It contains any deleterious or harmful substance in sufficient amount to render it injurious to beneficial plant life, animals, humans, aquatic life, soil, or water when applied in accordance with directions for use on the label;

2. If adequate warning statements or directions for use which may be necessary to protect plant life, animals, humans, aquatic life, soil, or water are not shown upon the label;
3. Its composition falls below or differs from that which it is purported to possess by its labeling; or
4. It contains unwanted crop seed or weed seed.

Section 8-77.14. Publications

This section provides for the publication of test results for the analysis of fertilizers as compared to their guaranteed analysis and for the publication of the sale and distribution of fertilizer in the state.

Section 8-77.15. Storage, use, and application

This section prohibits fertilizer discharges.

Section 8-77.16. Seizure and condemnation

This section provides the Board authority to take appropriate action in the event fertilizer sales are in violation of this act.

Section 8-77.17. Violations

This section allows for discretionary enforcement action for minor violations by utilizing notice of violations and warnings.

Section 8-77.18. Exchanges between manufacturers

Allows free exchange of materials among members of the industry.

A new section of the OKLAHOMA FERTILIZER LAW was passed in 1991 to address manipulated manures. Pertinent aspects of the law follow.

Section 2. New law

A. Any person operating a business that is engaged in the distribution, use, or sale of manipulated manures shall not be subject to the provisions of Sections 8-77.5 and 8-77.7 of Title 2 of the Oklahoma Statutes for the sale, use or distribution of such manipulated manures if:

1. the manipulated manures offered for sale, sold, or distributed in this state in bulk do not reflect by label or otherwise any warranties or guarantees of the contents of such manures other than the animal sources of the manures; and
2. the person engaged in the selling, use or sale of manipulated manures does not in any manner make or offer any warranties or guarantees of the manipulated manures other than the animal sources of the manures. The provisions of this paragraph shall not prohibit a person engaged in the selling, use, or sale of manipulated manures from providing the consumer information regarding analysis of manipulated manures.

OKLAHOMA SOIL AMENDMENT ACT OF 1975

This legislation has many of the same provisions as the Oklahoma Fertilizer Law and the Oklahoma Liming Materials Act. Additional, relevant provisions include the following.

Definitions:

Soil Amendment - Includes any substance which is intended to improve the physical, chemical or other characteristics of the soil or improve crop production, except the following: commercial fertilizers, agricultural liming materials, agricultural gypsum, unmanipulated animal manures, unmanipulated vegetable manures and pesticides; provided that commercial fertilizer shall be included if it is represented to contain, as an active ingredient, a substance other than a recognized plant food element or is represented as promoting plant growth by other than supplying a recognized plant food element.

Labeling - All written, printed or graphic matter upon or accompanying any soil amendment, and all advertisements, brochures, posters, television or radio announcements used in promoting the sale of such soil amendments.

Active Ingredient - The ingredient or ingredients which affect the physical, chemical or other characteristics of the soil and thereby improve soil conditions.

Misbranded - Means and shall apply if:

a. any soil amendment bears a label that is false or misleading in any particular,
b. any soil amendment is distributed under the name of another soil amendment,
c. any material is represented as a soil amendment or is represented as containing a soil amendment, unless such soil amendment conforms to the definition of identity, if any, prescribed by regulation,
d. the percentage of active ingredient in any soil amendment is not shown in the approved ingredient form, or
e. the labeling on any soil amendment is false or misleading in any particular.

Subsequent sections of the act provide for: labeling requirements; proof of claims (this may include experimental data and advice from the OSU Agricultural Experiment Station); Board approval for listing or guaranteeing amending ingredient(s) (may rely on outside sources such as the OSU Agricultural Experiment Station for assistance in evaluations); soil amendments must be registered with the Board before they can be distributed in the state. SECTION 1708 states activities that specifically violate the Act, and in so doing summarizes the intent of the Act, as follows:

It shall be a violation of this act for any person:

1. To distribute a soil amendment that is not registered with the Board;
2. To distribute a soil amendment that is not labeled;

3. To distribute a soil amendment that is misbranded;
4. To distribute a soil amendment that is adulterated;
5. To fail to comply with a stop sale, use or removal order; or
6. To fail to pay the inspection fee.

OKLAHOMA AGRICULTURAL LIMING MATERIALS ACT

In addition to the provisions identified by the Oklahoma Fertilizer Law and the Oklahoma Soil Amendment Act, the Oklahoma Agricultural Liming Materials Act provides for the following specifics relevant to liming materials.

Definitions:

Agricultural Liming Material - A product whose calcium and magnesium compounds are capable of neutralizing soil acidity.

Burnt Lime - a material made from limestone, which consists essentially of calcium oxide or a combination of calcium oxide with magnesium oxide.

Calcium Carbonate Equivalent (CCE) - the acid neutralizing capacity of an agricultural liming material expressed as weight percentage of calcium carbonate.

Effective Calcium Carbonate Equivalent (ECCE) - The percent of calcium carbonate equivalent (CCE) multiplied by the "fineness factor".

Fineness - The percentage by weight of the material which will pass U.S. standard sieves of specified sizes.

Fineness Factor - The degree of fineness of the liming material used and shall be determined as prescribed under rules.

Hydrated Lime - a material made from burnt lime which consists essentially of calcium hydroxide or a combination of calcium hydroxide with magnesium oxide and/or magnesium hydroxide.

Industrial By-Products - Any industrial waste or by-product containing calcium or calcium and magnesium in a form that will neutralize soil acidity.

Limestone - A material consisting essentially of calcium carbonate or a combination of calcium carbonate with magnesium carbonate capable of neutralizing soil acidity.

Marl - A granular or loosely consolidated earthy material composed largely of sea shell fragments and calcium carbonate.

In addition to normal labeling requirements, agricultural liming materials must be identified to show; the net weight of the liming material; minimum percentage of Effective Calcium Carbonate Equivalent (ECCE) guaranteed; the maximum percentage of moisture if it exceeds 5% at the point of sale.

Chapter 10 Soil Fertility Research 2000

Few disciplines can compete with soil fertility and plant breeding concerning their impact on increased crop production in the world. However, both continue to be challenged considering our current global population of 6.3 billion, and that is expected to double by 2050. Future research efforts must result in technologies that increase yields per unit area. Although many different research topics are underfoot at OSU, precision agricultural management techniques which sense and treat each 10 square feet independently, will likely result in the increased grain yields needed to support our ever growing world population.

HISTORICAL

The 14 long-term continuous wheat, sorghum, and cotton fertility experiments at Oklahoma State University have been instrumental in identifying optimum rates of applied nitrogen, phosphorus, and potassium. In each of the 14 long-term experiments, more than 20 years of continuous crop production have been evaluated. Both in terms of environmental safety and economic potential, these long-term experiments represent a "natural library" of information in terms of experimental monitoring of inorganic/organic nutrients in the soil profile. Very few other states have the breadth of long-term experiments where the same treatments have been applied to the same plots over time.

MAGRUDER PLOTS, 1892-PRESENT

The Magruder Plots were started in 1892 and have had continuous wheat grown under variable fertility for 114 years. Although several changes have taken place since the trial was first initiated, the Magruder plots remain the oldest continuous soil fertility wheat experiment west of the Mississippi River. These plots along with the other long-term experiments have demonstrated a marked decrease in soil organic matter over time in a continuous cultivated wheat production system (Figure 10.1). Similarly, as discussed in Chapter 5, total N in these soils (from the organic matter pool) has mirrored the soil organic matter decline with time. This work has clearly demonstrated that continuous cultivation practices include an invisible price tag (soil organic matter decline). Soil organic matter levels of 1% (initially started at 4%), soil tilth, productivity, and overall fertility of these soils (pH, availability of macro and micronutrients) have all become adversely affected with time. Because rebuilding soil organic matter levels is difficult, future research will target management practices that are capable of stabilizing present organic matter levels.

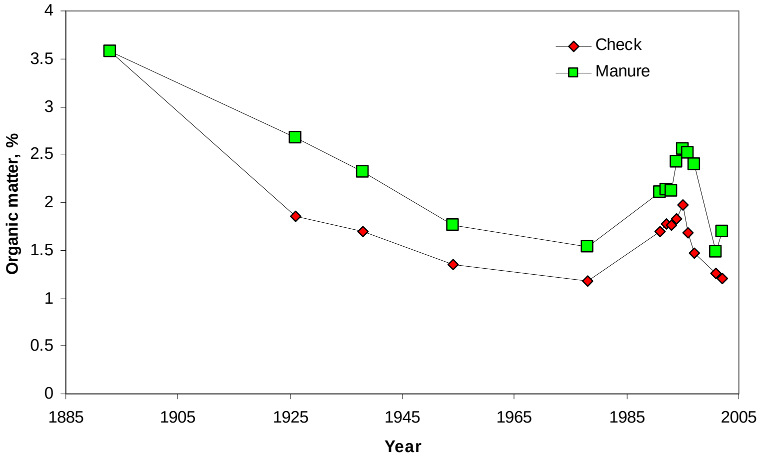


Figure 10.1. Changes in soil organic matter from the check (unfertilized) and manure treatments, 1892-2002, Magruder Plots, Stillwater, OK.

NITRATE-NITROGEN CONTAMINATION

Public interest in the environment and concern for nitrate-nitrogen contamination of groundwater from surface applied fertilizers prompted close examination of several of the 14 long-term experiments for build-up of nitrogen in the soil profile. Results from soil cores, taken to a depth of 10 feet from Experiment #502 initiated in 1970, clearly showed that no subsurface contamination of ammonium-N and nitrate-N was found when N was applied at the recommended rates (less than or equal to 80 lb/acre for a yield goal of 40 bu/acre, or 2 pounds of N per bushel). The other long-term experiments provided results similar to that illustrated in Figure 10.2.

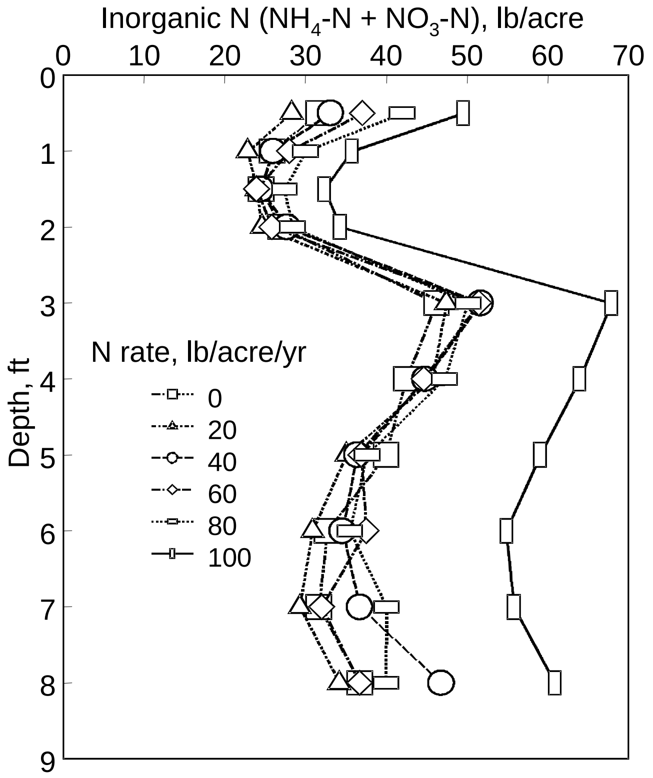


Figure 10.2. Soil ammonium-N and nitrate-N in pounds/acre/profile increment as a function of nitrogen applied, following twenty years of annual applications in continuous winter wheat, Lahoma, OK.

HIGHLIGHTS FROM SOIL FERTILITY RESEARCH

Low rates of foliar applied N (pre and post flowering) can increase grain protein. Applying rates as low as 10 lbs N /ac using UAN increased grain protein levels in 5 of 6 site years. Both pre and post flowering N applications (10-30 lbs N/ac) increased grain protein, but seldom increased grain yield. .

High NUE's recorded for forage production systems. When wheat or any other forage is produced for "forage" only, NUE's are higher because the plants are not allowed to approach maturity, when plants can lose NH3 through the leaves. This is a common process whereby plants must remobilize organic N into inorganic forms in order to transfer them to the grain for amino acid and protein synthesis. While forage production systems are more efficient, we still need the essential amino acids present in grains for human and animal consumption.

Grain yield potential can be predicted mid-season. Grain yield "potential" can indeed be predicted using NDVI sensor readings collected from December to March in winter wheat and before V12 in corn. This is incredibly important because we can predict the "N Removal" and subsequent fertilizer N demand using this approach.

Responsiveness to Fertilizer N Changes from year to year. Using the response index (NDVI of the N Rich strip divided by NDVI in the farmer practice) we can determine just how responsive the wheat or corn crop will be to fertilizer N from mid-season fertilizer N applications.

How late can N be applied without decreasing yields? In wheat, early season N stress can be alleviated via applied N before Feekes 5 (post dormancy), while corn can wait until the 10 leaf stage (V10). Of course, some N must be applied preplant, but you can "catch up" if you wait to apply N later in the season when NUE's are also much better.

Corn yields vary by plant. Over trials in the USA, Argentina, and Mexico, by-plant corn grain yields were found to change on average by more than 47 bu/ac. In other words, each plant and its neighbor differ in yield by more than 47 bu/ac and this was found in high yielding fields (> 200 bu/ac) and low yielding fields (< 100 bu/ac). It should come as no surprise as to why precision application methodologies are being developed by plant.

NUE increased by < 15%. Can nitrogen use efficiencies (NUE) be increased via precise N application where and when it is needed? Absolutely. Wheat and corn trials where N was applied based on yield potential and N responsiveness increased by more than 15%, while also increasing the bottom line, farmer profit.

Use of nitrogen fertilizers in Oklahoma crop production have little impact on nitrate leaching. Nitrate leaching has been found to be of limited importance in continuous winter wheat, sorghum, and cotton production systems when farmers apply the recommended rate. No nitrate accumulation was found in subsoil samples from six long-term experiments until the fertilizer requirement for maximum yield had been exceeded (annually) by 20 lb N/acre.

Buffering concept explains why nitrate leaching is not expected in winter wheat. Soil-plant inorganic nitrogen buffering was proposed by OSU researchers to explain why nitrate leaching from applied fertilizer in winter wheat was not expected under conventional practices. This concept documents the biological pathways which lead to fertilizer N losses and has received national recognition in two of the American Society of Agronomy peer reviewed Journals.

Low rates of applied nitrogen in alfalfa increases yields. Low rates of N fertilizer (20 lb N/acre) increased alfalfa yields when N was applied immediately following each cutting, late in the season. Applying N immediately following the first and second harvests (late spring and early summer) did not increase yields. At a cost of 23 cents/lb of N (Urea), applying 20 lb N/acre was economical when the N fertilizer was applied within 5-10 days following the fourth and fifth harvest.

Well water study documents limited changes in nitrate-N over the past forty years. Comprehensive sampling of 50 water wells in Grant, Garfield, and Kingfisher counties indicate that few significant increases in nitrate-N have taken place over the past forty years. Comparisons made between 1950 and 1993 well water analysis also showed no relationship between depth to the aquifer and nitrate-N.

Band applied P fertilizer increases wheat yields in acid soils. Placing phosphorus fertilizer with the wheat seed at planting was found to be an effective alternative to liming in strongly acid soils and offers a short-term economical option for farmers.

Foliar application of P can increase wheat and corn yields. When soil test P deficiencies were not severe, foliar applied P at rates ranging from 2 to 8 lbs P/ac increased wheat and corn grain yields. This approach could assist in maximizing yields especially since P use efficiencies are much greater when foliar applied.

Stability analysis allows researchers to assess the effects of rainfall and temperature on fertilizer practices. A new statistical tool (stability analysis) was used to determine the effects of environment (rainfall and temperature in a given season) on nutrient response in long-term experiments. Using this tool, recommendations could conceivably be altered for specific geographic locations.

Residue inversion improves moisture conservation. Wheat straw placed in a continual layer two inches beneath the surface of the soil (residue inversion) was effective in reducing evaporation losses in an experimental greenhouse project. Although mechanization of this practice is still prohibitive, it could prove advantageous in arid environments.

Bermudagrass yield and forage quality improved at high rates of applied N fertilizer. Two experiments conducted with the Noble Foundation showed that bermudagrass forage yield and protein were maximized when N was applied at a rate of 600 lb N/acre in the spring (total of 8 tons of dry matter produced from 4 harvests).

Plant N loss as ammonia gas documented in winter wheat. Gaseous loss of N from wheat plant tissue takes place throughout the growing season. Losses are greater from flowering to maturity when plants remobilize N from growing tissue to the grain. Plant N losses in excess of 40 lb N/acre/yr help explain why N recovery levels seldom exceed 70%. Unaccounted-for-N may be incorrectly assumed to be lost to leaching.

Method to interseed legumes in corn is investigated. Canopy reduction (removing the tops of corn at physiological maturity) has been successfully used to interseed various legumes. Late-fall and early-spring legume growth can result in increased amounts of biologically fixed N (up to 70 lbs N /ac fixed) while also contributing to increased productivity in continuous corn production systems.

Timed foliar fertilizer evaluated for cheat control in wheat. Cheat (Bromus spp.) infested wheat fields continue to be a major production problem in Oklahoma. Because of this, alternative methods of control are being evaluated. One method includes the use of foliar applied fertilizer (UAN) applied during cheat flowering (usually 1 to 2 weeks after the wheat has flowered). This foliar N application assists in dessicating both the stigma and pollen within the developing seed. Results from this work have shown that viable cheat seed can be reduced by as much as 80% using foliar applications of N immediately following wheat flowering.

Combined application of P fertilizer and gypsum improves availability. Conventional phosphorus fertilizer is immobilized when applied to acid soils. This is because it is fixed by either iron and/or aluminum (at low pH) and rendered unavailable for plant use. Recent research has found that applying triple superphosphate with gypsum can increase long-term P availability by intentionally precipitating the P fertilizer as calcium phosphate in acid soils.

Applied N fertilizer in native range systems improves yields. Native bluestem pastures are seldom fertilized to increase production. Work at Stillwater and Bessie, OK has found that bluestem forage production and forage protein increased linearly up to 200 lb N/acre.

Evaluation of high P rates applied at stand establishment for alfalfa. Current work suggests that in high yielding environments (e.g. irrigated), alfalfa may respond to P fertilizer inputs above those suggested by calibrated soil tests. Further, high preplant or biennial P fertilizer rates, either broadcast and incorporated or injected in a band, may provide a P fertility foundation with the potential for sustaining alfalfa yields for several years.

RESEARCH IN PROGRESS

Long-term experiments continue to document the benefits of fertilization. Long-term N, P, and K fertilization in winter wheat, cotton, and sorghum continues to be evaluated. Results from this work have identified increased gaseous plant N loss at higher rates of applied N. This has been further evidenced in a P deficient field experiment where nitrogen recovery decreased with increasing P applied (N and K rates constant). These trials also serve as the testing ground for much of our precision agriculture research using optical sensors.

PRECISION AGRICULTURE

Should we manage every acre independently? Every 100 square feet? Every 10 square feet? Conclusive work at OSU has shown that significant differences in surface soil test analyses are found when samples are less than 10 feet apart for both mobile and immobile nutrients. In theory, environmental stewardship should employ management practices that conform to the resolution where detectable differences in soil test parameters are observed in the field. Because we have detected differences in yield and soil test analyses from areas less than 10 feet apart, management strategies (precision agriculture) to sense and treat at this scale are being developed. Precision agriculture technologies that operate at larger resolutions (> 10 square feet) will not optimize variable inputs.

Can phosphorus and sulfur deficiencies be detected using sensor measurements from growing wheat? Current work at OSU has not found promising results relative to the identification of P or S deficiencies using optical sensors. However, we continue to research this topic.

Can combined management practices result in increased nitrogen use efficiencies (NUE)? At many locations from 1999 to 2005, the soil fertility research program has found that mid-season applications of N based on predicted yield and the response index can increase NUE and farmer profit. Combined, our goal is to obtain a set of management practices that will elevate NUE's in wheat and corn to 70%.

Chapter 11 The Promise of Precision Agriculture

INTRODUCTION

Precision agriculture has become an integral part of modern day farming that impacts growers, fertilizer dealers, equipment manufacturers, and environmental groups. Substantial work in precision agriculture has used yield maps as keys to identifying variability in crop production systems. Present day yield maps that use global positioning systems (GPS) have been generated at a resolution of approximately 30x30 ft. This means that an independent management practice could theoretically be imposed on a 900 square foot area. Some differentially corrected GPS systems work at a 3x3 ft resolution or 9 square feet.

Unlike yield maps which only document the 'effect' (yield), sensor-based management practices must rely on cause and effect relationships in order to function. For Oklahoma wheat farmers, sensor-based N application is now commercially available (www.ntechindustries.com). Sensor-based systems are capable of detecting nutrient needs on-the-go and can simultaneously apply prescribed fertilizer rates based on those needs. These systems differ from GPS driven yield maps since they operate at ground level and can detect differences in areas smaller than 1x1 ft. Work at OSU has documented significant differences in soil test parameters when sampled on a 1x1 ft grid, therefore, this resolution or treatable area is considered critical in order to 'treat the variability'. The variable rate technology team at OSU has also focused on the relationship between spectral reflectance at specific wavelengths with wheat forage yield and forage N uptake. This allows in-season wheat N deficiencies to be detected using sensors.

Similar to taking soil samples and generating a fertilizer recommendation based on that data, sensor-based systems collect similar data, however, they do so on a much finer scale. The sensor-based N fertilizer applicator developed at OSU collects the equivalent of 4300 samples per acre and applies a prescribed rate to 4300 independent areas within each acre (every 10 square feet).

RADIANT ENERGY

When white light from the sun strikes the surface of soil or plants, it is reflected in wavelengths that have a characteristic frequency and energy (Figure 11.1). The visible portion of light can be separated into red, orange, yellow, green, blue, and violet. Wavelengths and relative energy levels of gamma rays, x-rays, ultraviolet, infrared, microwave, and radio waves are also reported in Figure 11.1. If, for example, red light was absorbed by a certain substance, we would actually be seeing green (visible color absorbed compared to the visible color transmitted, Figure 11.1).

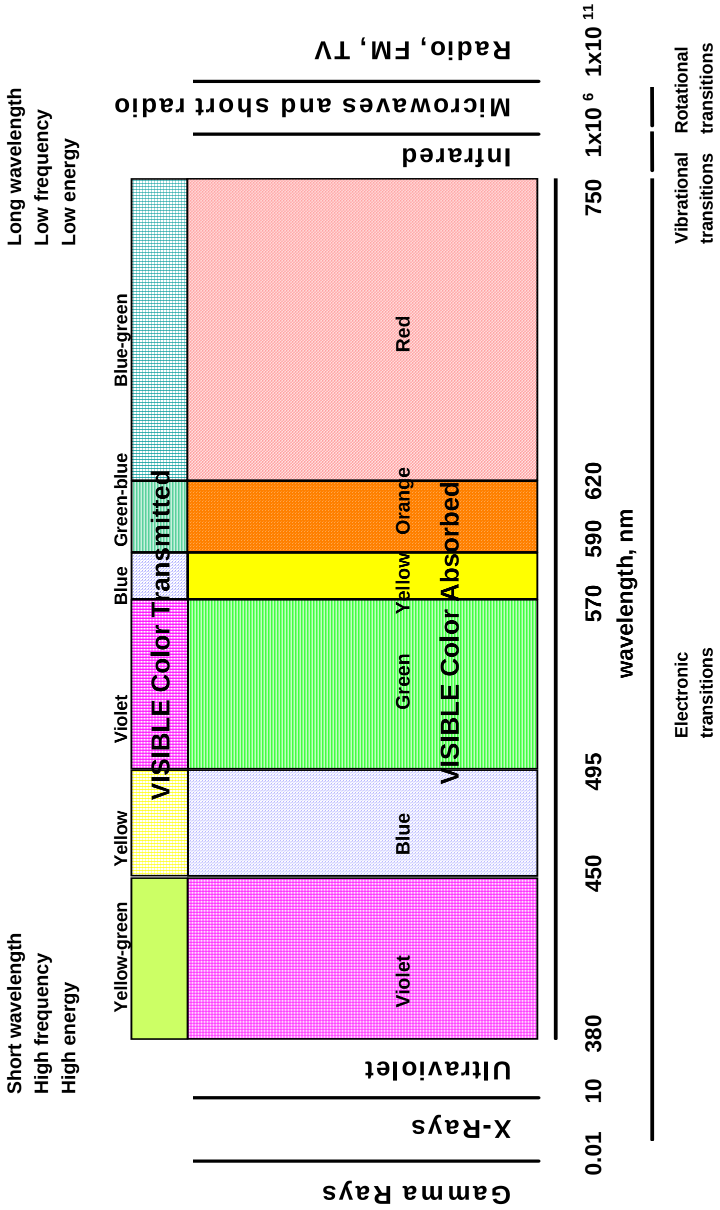


Figure 11.1. Characteristics of the visible and non-visible portions of the spectrum, and resultant colors transmitted when the light of another color is absorbed.

If blue light were absorbed we would see yellow. Keeping this in mind, the yellow-green color that we associate with nitrogen deficiencies should be characterized by having more violet light absorbed by the plant material (Figure 11.1). Or alternatively, the intensity of green in plants should be characterized by the amount of red light absorbed. Phosphorus deficiencies in plants should theoretically result in increased absorbance of green light since increased purple coloring of leaf margins is expected. What is actually being measured at OSU is spectral reflectance, or the radiated energy from plant and soil surfaces, corrected for incoming white light.

Spectral reflectance measurements for red and near infrared (NIR) wavelengths have been measured in wheat from December to February using photodiode based sensors. This work has shown that the normalized difference vegetative index (NDVI) is highly correlated with wheat forage N uptake at several locations, using a wide range of varieties. This is important since many researchers have shown that wheat forage total N uptake during the winter months can be a reliable predictor of topdress N needs. Because N uptake can be predicted indirectly using spectral radiance measurements, sensors can reliably provide simulated 'on-the-go' chemical analyses. Using NDVI, fertilizer N has been topdressed from January to February using ‘prescribed amounts’ based on the spectral reflectance measurements. Grain yields have increased as a result of applying topdress N and no differences have been found between variable and fixed N topdress rates. Also, varying N rates based on NDVI resulted in improved N use efficiency when compared to the fixed topdress N rates. In addition to improving site-specific N use efficiency, this technology will likely decrease the risk that over fertilization poses to the environment.

HISTORY OF USING SPECTRAL DATA

The use of spectral data for indirect chemical analysis is not altogether new. In the past, near infrared (NIR) diffuse reflectance spectrophotometry was used to measure protein, moisture, fat, and oil in agricultural products. As early as 1972, leaf reflectance at 550 (green) and 675 nm (red) wavelengths were used to estimate the N status of sweet peppers. The NIR spectral region has also been used for predicting organic C and total N in soils. Each constituent of an organic compound has unique absorption properties in the NIR wavelengths due to stretching and bending vibrations of molecular bonds between elements. One band (780-810nm) is particularly sensitive to the presence of amino acids ($R\text{-}NH_2$) which are the building blocks of proteins. The presence and/or absence of these amino acids largely determines the N content of the plant.

SENSOR BASED OR MAP BASED TECHNOLOGY?

Sensor based systems collect data (e.g., spectral reflectance) on-the-go from the plant canopy or soil. Without having a known reference or fixed position, the sensor data is then used to apply fertilizer or other agricultural chemicals (to the area which was read) at prescribed rates. Present map based systems require the use of global positioning systems or GPS. These systems were first developed for military purposes in order to better locate a specific target or position. Although this satellite based system is still used by the military, it is now available for a wide range of uses. Conventional GPS systems used today have a resolution of ±10 ft. What this means is that one 100 square ft area (10'x10') could be confused for another neighboring 100 square ft area when relying on the information delivered from GPS units.

Sensor based variable rate systems avoid traditional costs (such as soil sampling, chemical analysis, data management, and recommendations) and can instantaneously adjust the application rate based on sensor measurements of fertility as the applicator travels across the field. At present, the OSU sensor-based N applicator treats each 3x3 ft area independently. In other words, present sensor based systems operate at a resolution 10 times finer than what is presently available with GPS.

TOPDRESS FERTILIZER RESPONSE

Whole-plant total N (forage collected between December and February) has been used to predict N fertilizer requirements in winter wheat. Work in Oklahoma has found significant increases in grain yield from topdress N applied during this time period. Numerous researchers have found increased fertilizer N use efficiency in winter wheat and corn when N was applied topdressed at lower rates. Variable rate technology capitalizes on this work by reducing the total field N rate, while also having the potential to optimize N use efficiency at a much finer resolution (defined area for which N rates can be adjusted on-the-go). Current OSU work indicates that this resolution is somewhere near 4 square ft.

IMPACT

Almost 1,000,000 tons of fertilizer are annually sold in Oklahoma. Of this, over one-half is used to fertilize the 7,000,000 acres of winter wheat. Nitrogen fertilizers comprise almost 73% of the total fertilizer sales in Oklahoma. The annual expenditure on N fertilizers for winter wheat production in Oklahoma exceeds $50,000,000 every year. These figures are important when considering the potential impact that sensor-based precision agriculture is expected to have.

Initial results from sensor-based-variable-rate experiments at OSU suggest that fertilizer N use efficiency can increase from 50 to 70% using this technology. This is largely because the sensors are capable of detecting large differences within extremely small areas (3 x 3 ft) in an entire field (Figure 11.2). Note that the total area shown in Figure 11.2 is little more than one half of an acre. Instead of applying a fixed rate of 90 pounds of N per acre to a 160 acre field, this technology allows us to apply the prescribed amount to 774400 individual 3 x 3 ft areas within the 160 acre field at N rates that range from 0-90 pounds.

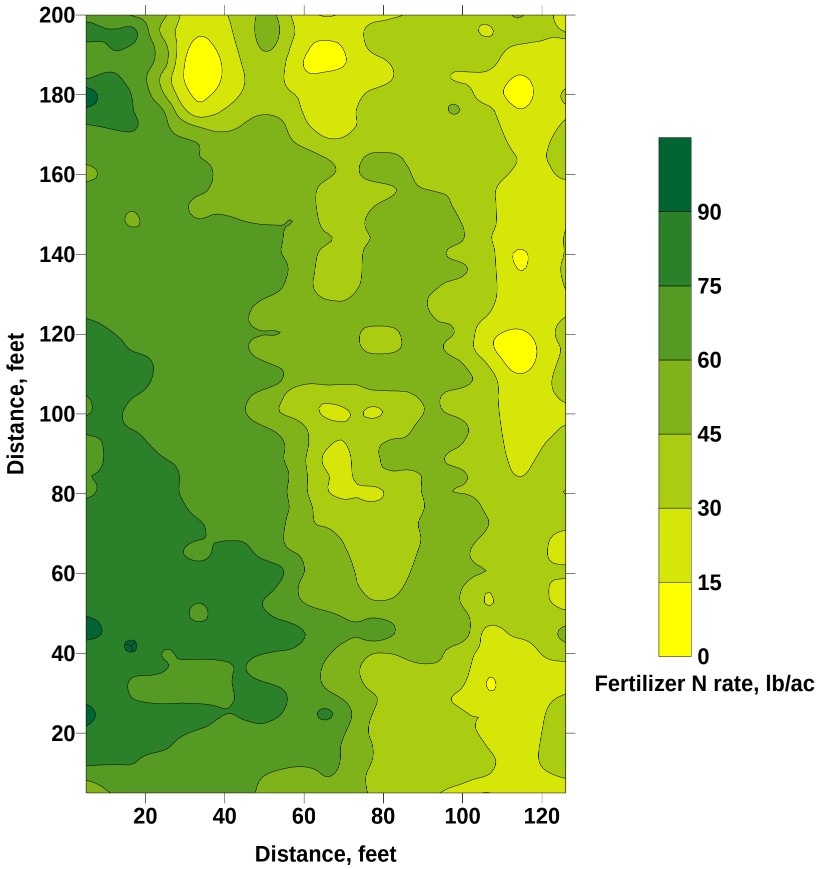


Figure 11.2. Contour map of recommended fertilizer N (lb/ac) based on spectral radiance readings collected from winter wheat in January.

When fertilizers are applied in excess of that needed for maximum yields, the potential for surface and subsurface nitrate contamination of water supplies increases. If the resolution where real differences exist in the field is very fine, as this work has shown, the need for precision agriculture should increase since this defined resolution will be more environmentally sensitive. It is expected that fertilization practices will rapidly become tailored to the environment when using sensor-based technology.

Chapter 12 The New Nitrogen Recommendation Strategy

Improved N recommendation strategies are more important today then ever. Nitrogen fertilizer will likely approach $0.50 per pound of actual N within the next few years, largely due to rising oil and natural gas prices. In this light, methods that increase nitrogen use efficiencies, and farmer profitability are no longer simply commendable, but required. The N Rich Strip program discussed in the next few pages along with the Sensor Based Nitrogen Rate Calculator can provide farmers with immediate improvement in NUE, and profit. Questions, regarding this program can be directed to the authors of the Soil Fertility Handbook, either via email (wrr@mail.pss.okstate.edu or haz@mail.pss.okstate.edu) or by phone, and we encourage producers to do so (405 744-6418 and FAX 405 744-9575).

THE FUTURE: N RICH STRIPS ARE HERE TO STAY

Nitrogen-Rich Strips replace the use of yield goals for making mid-season fertilizer-N recommendations.

Maximum wheat yields vary greatly from year-to-year, and the amount of N that the environment delivers (essentially for free) changes even more. What is this “free environmental N?” After crops are planted, there is a lot of N that can be used by the plant that does not come from fertilizer. In general this free N comes from two sources, N mineralized from soil organic matter and that deposited in the rainfall. If conditions from planting to mid-season are warm and wet, the N mineralization (N in organic matter that becomes available) can lead to over 40 lbs N/ac made available to the crop. Up to an additional 20 lbs of N in the rainfall can lead to a total of over 60 lbs N/ac without ever applying any fertilizer. Alternatively, if conditions from planting to mid-season fertilizer N application are cool and dry, less than 20 lbs of N/ac will be delivered to your wheat crop from the environment (organic N and rainfall).

Nitrogen Rich Strips can tell you how much N the environment delivers, and when using our web-based Sensor Based Nitrogen Rate Calculator, we can tell you exactly how much additional mid-season fertilizer N should be applied to achieve maximum yields.

http://www.soiltesting.okstate.edu/SBNRC/SBNRC.php

How is this done? Using the GreenSeeker Hand-Held Sensors, actual wheat grain yields can be estimated using the NDVI readings (value output from the sensors) from the Nitrogen Rich Strip compared to the

Farmer Practice, and knowing the date when the wheat was planted. Essentially, the NDVI value from the hand-held sensor outputs "total biomass." For readings collected between January and March (regardless of when the wheat was planted), we can estimate "biomass produced per day." This value is used to predict the wheat grain yield obtainable. With these #'s we can accurately predict both the yield and the need for additional N.

In some years, there will be minimal amounts of N needed, while in others there will be significant quantities required for maximum yield. Why should we apply the same rate each year when the yields are different? Why should we apply the same rate each year when the environment delivers (for free) totally different amounts and that impact the rate required from mid-season N applications.

In the picture above, Jason Lawles inspects the Nitrogen Rich Strip (left) compared to the normal farmer practice (right). In this case, the NDVI reading on the left was 0.75, and the NDVI reading on the right was 0.61. The response index of 1.23 (0.75/0.61 = 1.23) indicates that we could achieve a 23% increase in yield if added N fertilizer is applied. The topdress N rate is determined by computing N uptake in the N Rich Strip minus N uptake in the farmer practice, divided by an efficiency factor. All of this is done automatically on the SBNRC web site (listed above) and that reports both the projected wheat grain yields (based on these readings and when the crop was planted) and the optimum topdress fertilizer N rate.

Even if you do not have access to a GreenSeeker Hand-Held sensor, you need to apply your Nitrogen Rich Strip preplant (or soon thereafter) in each and every field, and to use the difference between the Nitrogen Rich Strip and your conventional practice to determine how much N the environment delivered and whether or not you should apply fertilizer N. If you cannot see the difference between the Nitrogen Rich Strip and your conventional practice (visual interpretation from January to March), you are unlikely to obtain any benefit from mid-season fertilizer N.

What we do know is that the amount of N required from one year to the next changes drastically. Our long-term experiments clearly show that in some years, less than 20 lbs of fertilizer N/ac can be required for maximum yields, while in others 120 lbs of N/ac is needed. Furthermore, if excess N is applied one year, it has limited impact on the demands for N the subsequent year. In other words, we need to re-determine the mid-season fertilizer N rate each and every year.

In general, how much N should I apply preplant for my Nitrogen Rich Strip?

Grain Yield	N Rich Strip
20	50
30	75
40	100
50	125
60	150
70	175

If you are also soil testing, the amount of N in the soil test (NO_3-N) should be subtracted from these recommended amounts. **If you have a forage + grain production system, these preplant N rates for your N Rich Strip should be increased by 20 to 30%**. There is no fixed recommendation, but rather you should use common principals to arrive at a rate where N will not be limiting throughout the season. Farmers are not going to take the risk of applying the rate for a “N Rich Strip” to their entire field, simply because on average it will not pay. What the N Rich Strip does is it serves as a guide to how much “topdress” N should be applied to maximize yields, taking into account how much the environment delivered for free.

<u>What if I didn’t get the N Rich Strip out Preplant?</u>

Putting out your N Rich Strip as late as the end of December is probably OK, but the best mid-season fertilizer N rates are going to be determined from N Rich Strips that were put out at planting or soon thereafter.

<u>Where should I put the N Rich Strip?</u>

In general, we recommend placing the N Rich Strip in the middle of the field, applied over the entire length. Also, the starting point should be somewhere close to a drive-by road, thus allowing visual inspection on a daily basis.

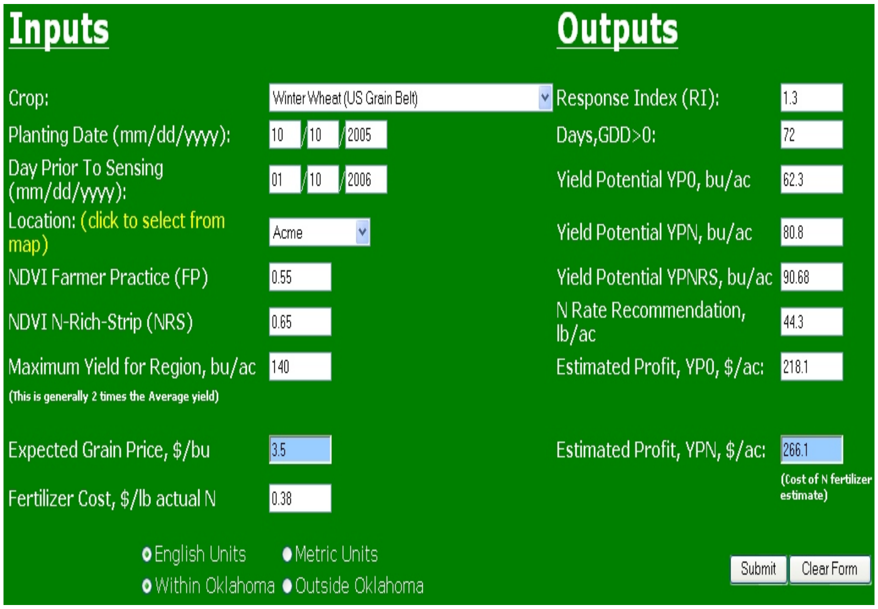
Where do I go with Questions?

You can consult our Nitrogen Use Efficiency Web site (www.nue.okstate.edu) or you can give us a call at OSU.

What can I expect from Using this Technology?

This method will allow you to determine the ideal topdress N rate. Over the years we have seen that this is worth over $10.00 per acre. All you have to do is put out your N Rich Strip and use it as a guide for mid-season N fertilization. When fertilizers are applied in excess of that needed for maximum yields, the potential for surface and subsurface nitrate contamination of water supplies increases.

Do you have an example of the Sensor Based N Rate Calculator and what I should do?



Inputs

Crop: Winter Wheat (US Grain Belt)
Planting Date (mm/dd/yyyy): 10 / 10 / 2005
Day Prior To Sensing (mm/dd/yyyy): 01 / 10 / 2006
Location: (click to select from map) Acme
NDVI Farmer Practice (FP) 0.55
NDVI N-Rich-Strip (NRS) 0.65
Maximum Yield for Region, bu/ac 140
(This is generally 2 times the Average yield)
Expected Grain Price, $/bu 3.5
Fertilizer Cost, $/lb actual N 0.38

● English Units ○ Metric Units
● Within Oklahoma ○ Outside Oklahoma

Outputs

Response Index (RI): 1.3
Days,GDD>0: 72
Yield Potential YP0, bu/ac 62.3
Yield Potential YPN, bu/ac 80.8
Yield Potential YPNRS, bu/ac 90.68
N Rate Recommendation, lb/ac 44.3
Estimated Profit, YP0, $/ac: 218.1
Estimated Profit, YPN, $/ac: 266.1
(Cost of N fertilizer estimate)

First, using the winter wheat option on the Sensor Based N Rate Calculator (http://www.soiltesting.okstate.edu/SBNRC/SBNRC.php), using the "Within Oklahoma" option, you have to do the following:

1. Enter your planting date.
2. Enter the day prior to sensing (again, the day prior to sensing is necessary because this calculator relies on weather data from the Oklahoma MESONET that does not include the current day.
3. Enter your location, or click from the Oklahoma map to identify the MESONET station closest to your farm.
4. Collect GreenSeeker NDVI readings (200 or more feet) from the Farmer practice (this would be from an area in the field adjacent to where you placed the N Rich Strip, and that was representative of the rest of your field).
5. Collect GreenSeeker NDVI readings (200 or more feet) from the N Rich Strip, adjacent to the area where you collected NDVI for your "Farmer Practice."
6. For both #4 and #5, these values need to be collected within each and every field. Even if two adjacent fields differed in planting dates by only 2 days (or sensing dates), the N recommendation is likely to be different.
7. The Maximum Yield for the Region is generally 2 times greater than the average for a field, but can be as great as 3 times the average. The need for this input is to avoid fertilizing for unrealistic yields.
8. The expected price you hope to obtain for your wheat grain (when you sell or harvest it) should be entered, along with the price of fertilizer you are having to pay per pound of N at the time of N fertilization. These two values are used to estimate gross profits (on the right hand side) using the estimated yield levels with and without N fertilization (at the rate recommended) accounting for how much N was applied at the entered price values.
9. OUTPUTS: The Response index is essentially the NDVI of the N Rich Strip divided by the NDVI of the farmer practice. If this is 1.3, it says that you can achieve a 30% increase in yield if you fertilize, but by itself does not provide you with the N rate that should be applied.
10. If you entered with "Within Oklahoma" option, it takes the date of planting and the sensing date (1 day prior) and looks up from the Oklahoma MESONET the # of days from planting to sensing where GDD >0. GDD or growing degree days is computed as daily (Tmin + Tmax)/2 – 40F. This essentially determines the # of days where average temperatures were > 40F, or where growth was possible. This is important in winter wheat, because many days in the winter wheat cycle have low temperatures and growth does not take place. NDVI is essentially an estimate of biomass, thus biomass accumulated per # of days where growth was possible is "growth per growing day" or "growth rate." This value is an excellent estimate of mid-season "yield potential."
11. YP0 (yield potential without applying additional N) and YPN (projected yield to be obtained if the farmer applies the recommended

fertilizer N rate listed) are **estimates** of wheat grain yield (or other crops, depending on the algorithm used) based on the data provided by farmers from each field on the INPUT side of the Sensor Based N Rate Calculator. If growth continues in the same fashion as that encountered from planting to sensing, we have ample data to confirm that these estimates of yield potential are very accurate.

12. Using the estimate of yield potential, the yield obtainable if N is applied is determined by multiplying YP0 times an adjusted RI (usually a bit higher than the estimated RI, based on collected data). The N rate recommended is simply the difference in grain N uptake for YPN and YP0 divided by an efficiency factor of 0.60. The reason for using 0.60 is simply because topdress N applications will seldom encounter an N use efficiency greater than 0.60.

13. Again, the estimated gross profits listed employ the grain and fertilizer prices and the estimates of yields obtainable with and without N fertilizer. This decision making tool often provides farmers with a “yes or no” answer of whether or not it will pay to apply fertilizer N (for that season), and if so, how much.

14. Use this methodology and you can add $10.00 per acre to your profit margin! It is that simple.

Figure 11.3. Various terms used in sensor based technology.

NDVI: normalized difference vegetative index, = (NIR-red)(NIR+red).

Yield potential: estimated optimum yield that a farmer can obtain based on growing conditions from planting to the time of sensing. This is yield potential, not “yield” and essentially replaces “yield goals.” NDVI estimates biomass, and we divide NDVI by the # of days from planting to sensing which is an estimate of “biomass produced per day.” This is growth rate and that is correlated with final yield potential.

Response Index: This is estimated using NDVI from the N Rich strip divided by NDVI from the farmer practice. NDVI is measured using the GreenSeeker sensor. This is an estimate of the responsiveness to applied N that a farmer is likely to encounter and that varies from year to year in the same field. Why? Because the environment delivers a lot of N for free some years (warm, wet winters where a lot of N is mineralized from soil organic matter, and N deposition in rainfall). Why apply N if it isn’t needed and the environment delivered a lot for free? Stop asking why, get your N Rich Strip out and save yourself > $10/acre/year.

Radiance: the rate of flow of light energy reflected from a surface.
Wavelength: distance of one complete cycle
Frequency: the number of cycles passing a fixed point per unit time

$l = c/v$
l is the wavelength in cm
v is the frequency in sec^{-1} or hertz (Hz)
c is the velocity of light ($3x10^{10}$ cm/sec)

Electromagnetic radiation possesses a certain amount of energy. The energy of a unit of radiation, called the photon is related to the frequency by
$E = hv = hc/l$
E is the energy of the photon in ergs
h is Planck's constant 6.62×10^{-27} erg-sec

The shorter the wavelength or the greater the frequency, the greater the energy. Energy of a single photon (E) is proportional to its frequency (v) or inversely proportional to its wavelength.