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Fertilizers AND THEIR USE

TEXAS AGRICULTURAL EXTENSION SERVICE
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Cover Photo

Research is important in determining conditions under which fertilizer is needed. The cover photo shows plots of cotton on which moisture - fertility relationships are being studied by the Texas Agricultural Experiment Station.

Fertilizers and Their Use

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PLANTS ARE MUCH like human beings. They need air to breathe, water to drink and nutrients to help them grow and reproduce. If any one of these is not available, the plants wither and die.

When air and water are in balance, plant nutrients—or fertilizer—can be used effectively by plants.

First Uses of Fertilizers

For more than 4,000 years, farmers have used fertilizers to increase crop yields. The Chinese, Greeks and Romans used animal manures, marl, chalk and wood ashes. They had no knowledge of the chemistry of soils and fertilizers to guide them, but they knew that animal residues and manures increased plant growth. Not until early in the Nineteenth Century did man know why organic matter and animal manures increased yields.

At that time they learned that the chemical elements in organic residues, and not the organic matter itself, increased plant growth. Organic residues always have been good sources of plant nutrients. Since they were once living material, they contain a fairly good balance of the elements essential for plant growth. Organic residues constituted the first fertilizers in agriculture.

When white men came to America, Indians were placing a fish under each hill of corn at planting time. They had learned that often this practice meant the difference between a crop and no crop. They also knew that certain sizes of fish should be used and that placing them in the hill at planting time was better than putting the fish on the top of or in the ground after the corn had begun to grow. Today, we know that the fish contained considerable nitrogen and phosphorus, but that time had to be allowed for decomposition to make these nutrients available to plants.

The first commercial fertilizers were used about 1830, when Chilean nitrate was imported. Guano also was brought in from Peru. These two materials helped the farmer to learn the general values of fertilizers and to stimulate further development of the fertilizer industry. In 1868, the productior of superphosphate from chemicals began in Baltimore. For many years thereafter, the fertilizer industry remained largely a salvage outlet for waste products from meat-packing plants, fish canneries and oil-seed industries.

Invention of new processes made it possible for fertilizer to grow into a large chemical industry.

Fig. 1. America's first use of fertilizers. Squanto, the first demonstrator, places a fish in the hill for corn.

Two of these processes were the recovery of ammonia from byproduct coke ovens and the chemical fixation of nitrogen from the air.

Fertilizer Use Today

Today, fertilizer is used in increasing quantities. Fertilizer consumption in Texas increased from 13,500 tons in 1906 to over 666,000 tons in 1957-58. Table 1 shows the increase in fertilizer consumption in Texas over the past years.

Table 1. Fertilizer Consumption in Texas

Fiscal year	Tons
1905-06	13,500
1910-18 (8-yr. av.)	48,861
1918-28 (10-yr. av.)	78,848
1928-38 (10-yr. av.)	78,608
1939-48 (10-yr. av.)	220,096
1948-53 (5-yr. av.)	563,493
1953-54	543,518
1954-55	603,828
1955-56	566,339
1956-57	626,545
1957-58	666,130

Plant Nutrients

Sixteen elements presently are considered essential for plant growth. Two others are considered by some to be essential. If any of the 16 essential elements are deficient, plants will not grow properly. The essential elements are listed in Table 2.

Table 2. Essential Plant Nutrients

Elements from air and water	Elements from the soil			
	Primary elements	Secondary elements and amendments	Trace elements	
Carbon Hydrogen Oxygen	Nitrogen Phosphorus Potassium	Calcium Magnesium Sulfur	Iron Manganese Copper Molybdenum Chlorine?	Boron Zinc Cobalt Sodium?
Constitute approximately 95% of plant weight	Constitute approximately 5% of plant weight			

Three of these elements—carbon, hydrogen and oxygen—come from the air and water. They make up approximately 95 percent of the plant's weight. Carbon comes mainly from the air. Hydrogen is obtained from water. Oxygen comes from both, but mainly from the air.

The other 13 elements come from the soil, with the exception that legumes obtain a portion of their nitrogen from the air. These elements constitute the other 5 percent of the plant's weight.

The 13 elements obtained from the soil are used in varying amounts. Some are used in fairly large quantities, and others are used in extremely small quantities. Because of this, they may be grouped into three classes—primary, secondary and trace elements.

Primary Elements

Nitrogen, phosphorus and potassium are considered to be primary elements since they are used in relatively large quantities by plants. Texas soils often are deficient in nitrogen and phosphorus and in some areas are deficient in potassium.

Fig. 2. All plant nutrients must be supplied in adequate quantities for good growth.

Soil

Nitrogen in the soil comes primarily from one source—the decomposition of organic material. In the process of decomposition, nitrogen exists in many forms. During the final two steps of decomposition, nitrogen is in the ammonium (NH_4^+) form and finally in the nitrate (NO_3^-) form. It is these two forms in which plants absorb nitrogen. Most plants will take up nitrogen in the nitrate form. Some plants in the early stages of development utilize the ammonium form. Some crops, such as rice, continue to take up nitrogen in the ammonium form throughout their growing period.

Soil phosphorus comes from the weathering and breakdown of phosphorus-bearing minerals. It exists in the soil in many forms with its most available form generally believed to be monocalcium phosphate. The form in which phosphorus exists depends to a large extent on the acidity or alkalinity of the soil. The amount of phosphorus existing in the soil in an "available" form for plant use is normally small. However, as soon as it is absorbed by the plant, more becomes available. The speed with which it becomes available determines whether phosphorus should be applied.

Soil potassium comes from the weathering of potassium-bearing minerals. It usually is present in the soil in fairly large quantities with many soils containing as much as 80,000 pounds per acre foot of soil. Potassium exists in the soil in "available" and "unavailable" forms. The available form is often called "exchangeable" potassium. When some of the available is used by the plant, more potassium becomes available. Like phosphorus, the need for applying potassium depends on the speed with which it becomes available and the level of available potassium present.

Function of Primary Elements and Effects

All of the elements necessary in plant growth combine and work together in performing various functions in the plants. Each element has a specific function and its effects can be noted.

Nitrogen is essential in protein formations. It is present in a substance called "protoplasm"—the viscous, watery substance in plant cells—called the living material in the plant. Nitrogen is also present in chlorophyll—the substance that gives the plant its green color.

An adequate supply of nitrogen will have the following effects on plant growth if kept in balance with other elements:

1. Increase yield
2. Encourage vegetative growth
3. Encourage root growth
4. Give the plant a dark-green color
5. Produce succulence in vegetative growth of plants
6. Increase protein content of forages and grain
7. Hasten maturity

If applied in excessive quantity or if balance is not maintained, nitrogen may:

1. Increase lodging of grain crops
2. Cause plant to stay vegetative and reduce fruiting, thus delaying maturity
3. Increase susceptibility to disease

(Note: Most Texas soils are more likely to be deficient in nitrogen than oversupplied.)

Phosphorus is concerned mainly with energy relationships within the plant. Phosphorus forms a compound in the plant which is used as a means of storing energy which comes from the sun. The energy is later released and utilized in plant growth or reproduction. Phosphorus also is necessary in a process known as "mitosis"—a process which takes place in reproduction.

Following are the effects of phosphorus on plant growth:

1. Encourage both vegetative and root growth
2. Hasten maturity
3. Encourage flowering, fruiting and seed production
4. Improve quality
5. Is necessary for formation of carbohydrates, proteins, fats and oils
6. Increases disease resistance

Potassium is the "elusive" element in the plant. It seldom combines into a specific compound within the plant. It is difficult to define the function of potassium in the plant. It is believed to be involved in energy transfer in plants and is definitely associated with plant respiration. Potassium is believed to be involved in photosynthesis—the process by which the plant receives energy from the sun and utilizes it in the formation of carbohydrates.

Potassium has the following effects on plant growth:

1. Encourage both vegetative and root growth
2. Improve plant vigor
3. Increase disease resistance
4. Aid in chlorophyll formation
5. Increase stalk strength in corn and sorghum

Secondary Elements

Calcium, magnesium and sulfur are classed as the secondary elements. They normally are well supplied in most areas of the State for most crops with the exception of some soils in East Texas and perhaps the Coast Prairie. Localized deficiencies occur in small areas in other parts of the State.

Function of Secondary Elements and Effects

Calcium is part of a compound found in cell walls of plants. Adequate calcium in the plant improves plant vigor and increases its resistance to certain diseases. Calcium will neutralize certain toxic organic acids in plants. Calcium also is necessary for the growth of new plant parts.

Magnesium has two primary functions in plants. It is an essential part of chlorophyll. It also aids in the formation of phosphorus compounds as well as other complexes in plants. To perform this function, it acts as a "catalyst" or "activator" for plant processes.

The function of sulfur in the plant is not too well known. It is present in certain plant proteins and affects cell formation and division and increases plant growth.

Soil Amendments

Besides being essential plant nutrients, the secondary elements are also soil amendments. The primary purpose of soil amendments is to make the soil more favorable for plant growth by improving the physical, chemical or biological conditions of the soil.

Calcium has several benefits when applied to acid soils. As a result of correcting soil acidity, conditions are more favorable for the activity of micro-organisms. Certain nutrients, particularly phosphorus, become more available. Calcium usually is applied in the form of agricultural limestone (calcium carbonate) on acid soils. Magnesium will give somewhat the same effect as calcium. Often it is applied as dolomitic limestone.

Calcium often will benefit alkaline soils—when the alkalinity is mainly due to the presence of sodium. Calcium, when applied as gypsum (calcium sulfate), will improve the physical condition of black alkali or sodium soils. In these soils, calcium replaces sodium on soil particles and the soil forms into larger soil aggregates.

Fig. 3. Limestone use is essential for best growth of most crops on acid soils.

Sulfur is applied as a soil amendment on soils that are too alkaline. It usually is applied as elemental sulfur, but also can be applied as sulfuric acid. Sulfur oxidizes (combines with air) in the soil to form sulfuric acid. This in turn reduces the alkalinity and increases the acidity. In soils which contain excess free calcium carbonate, sulfur would be needed in such large amounts that it would be too costly to use on a field scale.

Trace Elements

Trace elements are those that are needed in small quantities. The trace elements essential for growth are manganese, iron, copper, zinc, boron, cobalt and molybdenum. Sodium and chlorine sometimes are considered essential.

Trace elements, also known as minor elements or micronutrients, are just as essential to plant growth as the primary or secondary elements.

Their function, as a group, in plant growth is to act in such a way that they control and influence those plant processes involved in plant growth. They are called activators or catalysts. Some are parts of plant compounds, such as iron in chlorophyll. Some also are parts of plant enzymes. The general effect of trace elements is to improve plant vigor and growth.

Trace elements are fairly well supplied in most Texas soils except for zinc deficiency on some soils where pecans are grown. In some alkaline soils, iron is not in an available form, and some plants, such as grain sorghum, lawn grasses and ornamentals, will show iron deficiency symptoms.

Source of Nutrients

The main source of plant nutrients is the soil itself. When the level of a nutrient in the soil is low, additional amounts need to be applied. These can be supplied by adding commercial fertilizer or organic materials such as barnyard manure and plant residues.

Commercial Fertilizer

Materials Supplying Nitrogen

Nitrogen can be supplied by a number of fertilizer materials as either solids, liquids or gases.

Ammonium nitrate is a solid nitrogen fertilizer containing 33.5 percent nitrogen (N). Half of this N is in the ammonium form and half in the nitrate form. It is completely soluble in water and takes up moisture when exposed to the air.

Ammonium sulfate is a solid nitrogen fertilizer which contains 21 percent N. All nitrogen is in the ammonium form and is water soluble. Because of the sulfur in this fertilizer, it tends to increase soil acidity.

Urea is a solid organic nitrogen compound which, when added to the soil, hydrolyzes to the ammonium form and eventually is converted to the nitrate form. This commercial material contains about 45 percent N. Urea also is sold in combination with formaldehyde as urea formaldehyde and contains 38 percent N.

Sodium nitrate, calcium nitrate and *calcium cyanamid* are three other solid sources of nitrogen fertilizer. They contain 16, 17 and 21 percent N respectively. All three leave a residual alkalinity in the soil, which may be slightly beneficial when used on acid soils, but of no extra value on alkaline soils. Continued use of high rates of sodium nitrate on medium-to-fine textured soils would be undesirable due to the buildup of sodium. Calcium cyanamid should be applied at least two weeks before planting and should not come in contact with the seed or growing plants because it has a temporary herbicidal effect.

Anhydrous ammonia, a gaseous form of nitrogen, contains 82 percent N in the ammonia form. It is a liquid when kept under pressure. When applied to the soil, it is released from pressure, and is injected into the soil as a gas. Since special equipment is necessary for application, much of it is custom applied.

Liquid sources of nitrogen include several nitrogen solutions ranging from 21 to 41 percent N. These solutions vary from all ammonium to half ammonium-half nitrate solutions. Some of the solutions have to be kept under pressure and injected into the soil. Most of them can be applied with a properly equipped sprayer.

Price is the main consideration in determining which nitrogen source to use. Under most conditions, all sources of nitrogen will give equal results if used on an equivalent nitrogen basis. To determine which nitrogen fertilizer to use, consider the price per pound of N and the cost of application and use the most economical nitrogen source. (To determine the price per pound of N, multiply the percent N by 2000. Then divide the price per ton by this figure.)

The residual acidity of nitrogen fertilizers often is considered in deciding which to buy. Ammonium sulfate leaves an acid residual about three times that of ammonium nitrate, urea, anhydrous ammonia and most nitrogen solutions. If fertilizer and handling costs are about the same on all nitrogen fertilizers, ammonium sulfate may be more desirable on *alkaline soils* than other sources, but less desirable on *acid soils.* The residual acidity from nitrogen fertilizer is not a serious problem on acid soils since half a ton of limestone every 8 to 10 years will correct the acidity from the usual rates of application.

Materials Supplying Phosphorus

Straight fertilizer materials supplying phosphorus are rock phosphates and superphosphates.

Rock phosphate is the naturally occurring mineral form of phosphorus. It is found in large deposits in Idaho, Montana, Utah, Wyoming, Tennessee and Florida. The phosphorus content of rock phosphate is variable but it is usually guaranteed to contain 33 percent *total* P_2O_5 which is relatively insoluble and a small portion of which will become available each year, depending on soil conditions and the crops grown.

Colloidal phosphate is another type of phosphorus on the market and is sold under various trade names. This material is a product from the washings of the rock phosphate at the mines. It usually contains 20 to 22 percent *total* P_2O_5 which also is relatively insoluble with a small portion becoming available each year.

Rock phosphate and colloidal phosphates have their greatest value in acid soils where leguminous-type crops are grown. It is seldom of any value when applied to alkaline soils.

The other type of phosphorus fertilizers is the superphosphates.

Superphosphate is made by treating rock phosphate with sulfuric acid, resulting in a material which contains 18 to 22 percent *available* P_2O_5. It usually is marketed as 0-20-0. When rock phosphate is treated with phosphoric acid, *triple superphosphate* results ranging from 40 to 48 percent *available* P_2O_5. It is usually sold as 0-45-0. Both of these superphosphates are recommended on Texas soils where phosphorus is needed.

Calcium metaphosphate is another type of phosphorus fertilizer containing available phosphorus. It is a high-analysis fertilizer containing 60 to 63 percent *available* P_2O_5 and usually is sold as 0-62-0. Its effectiveness is about the same as the superphosphates, and may be used where phosphorus is needed. Calcium metaphosphate may be less

Fig. 4. Close-up of equipment for applying anhydrous ammonia. Nitrogen is released from under pressure in the tank, moves through the rubber hoses and is injected into the soil behind the knives.

effective than other available phosphates on short-season crops.

Liquid phosphoric acid is another fertilizer carrying available phosphorus. It usually is sold as 0-54-0. Because of its corrosive action, it normally is custom applied. Its effectiveness is about the same as superphosphate if used in equivalent quantities of P_2O_5 per acre.

The source of phosphorus to use—rock phosphate, superphosphate, calcium metaphosphate or liquid phosphoric acid—depends on conditions. The rock phosphates should be restricted to the acid soils of the East Texas Timberlands and Coast Prairie. The other three sources—those containing "available" phosphorus—can be used anywhere in the State if phosphorus is needed.

Rock phosphate is a suitable source of phosphorus for continuous legume pastures on acid-to-neutral soils.

Look primarily at the cost per pound of P_2O_5 and the cost of application to determine which source of the "available" phosphates to use. Phosphorus from any of the sources should be of equal value if applied in equivalent amounts of P_2O_5. Both solid and liquid forms of phosphorus should be of equal value.

Materials Supplying Both Nitrogen and Phosphorus

Some fertilizer materials contain both nitrogen and phosphorus. Special reactions may be set up to combine these nutrients chemically to form a special compound. An example of this is the ammoniation of phosphoric acid to form an ammonium phosphate, such as 11-48-0 or 21-53-0.

Materials Supplying Potassium

Fertilizer materials supplying potassium are *potassium chloride* (muriate of potash) and *potassium sulfate*. Potassium chloride is sold as 0-0-60 which is 60 percent available potash (K_2O). Potassium sulfate is sold as 0-0-50 and contains 50 percent available K_2O. Either source is satisfactory. The 0-0-60 is easier to find on the market. Potassium-magnesium sulfate, another source of potassium, contains 21 percent K_2O and 18 percent magnesium.

Mixed Fertilizers

Mixed fertilizers are another source of nitrogen, phosphorus and potassium. They contain at least two, and sometimes all three, of the major plant nutrients.

Mixed fertilizers may be used when the soil is deficient in more than one nutrient and when the amount needed is small. The application cost of mixed fertilizer usually is cheaper since only one application is needed. The various plant nutrients are well mixed.

Mixed fertilizers are made by combining proper amounts of the different carriers of the nutrients to obtain the desired composition. For example, ammonium sulfate, superphosphate and muriate of potash may be mixed to prepare the desired grade.

Mixed fertilizers often are referred to in terms of grades and ratios. The grade of a fertilizer is the actual percentage composition of the three primary nutrients. For example, a 10-20-10 grade means 10 percent N, 20 percent P_2O_5 and 10 percent K_2O. A fertilizer ratio is the ratio of N to P_2O_5 to K_2O. The ratio of a 3-12-12 fertilizer is 1:4:4. Other grades with the same ratio would be 4-16-16, 5-20-20 and 6-24-24. All of these grades with the same ratio would have equal value if used in equivalent quantities of plant nutrients. For example, 100 pounds of 6-24-24 will generally do as much good as 200 pounds of 3-12-12, with a few exceptions.

Fig. 5. Phosphorus fertilizer increases yield of Hubam sweetclover. Fertilized plot is 2 feet high; unfertilized, 1 foot.

The higher the analysis of a fertilizer in the same ratio, the lower the cost per unit of plant nutrients should be. For example, it is cheaper to handle, sack and transport 100 pounds of 12-24-12 than 200 pounds of 6-12-6, and the major plant nutrients obtained would be of equal value. High analysis fertilizers should be used where available.

The material in a fertilizer other than the plant nutrients is called "filler." It usually is added to give the fertilizer a better storing quality and help the fertilizer flow more freely. Higher analysis fertilizers contain less of this type of material.

Fertilizers, both straight and mixed goods, by law must contain the amount of fertilizer listed on the fertilizer sack. A manufacturer, for instance, guarantees that a 10-20-0 grade contains 10 pounds of N, 20 pounds P_2O_5 and not any K_2O per 100 pounds of fertilizer.

Liquid mixed fertilizers are relatively new. They are made from various water-soluble carriers of the major nutrients. Liquid fertilizers may have the same ratio and grade as dry fertilizers. Liquid and dry fertilizers usually are considered of equal value, if each supplies the same quantities of plant nutrients. Price of the fertilizer and cost of application should be the main consideration in deciding which to use.

Materials Furnishing Secondary Elements and Used as Soil Amendments

Limestone (calcium carbonate) is the primary source of calcium as a nutrient. Gypsum (calcium sulfate) is another source of calcium as a nutrient, even though it is used primarily as a soil amendment. Other sources of calcium are ground oystershell, ground marl, builders' lime and burnt lime.

Magnesium as a nutrient is supplied primarily from dolomitic limestone, which is approximately 45 percent magnesium carbonate and approximately 55 percent calcium carbonate. Dolomitic limestone is found in small areas of the State and is handled and applied similar to calcitic limestone (all calcium carbonate). Another source of magnesium is Epsom salts, which is magnesium sulfate, and is satisfactory if the price is not prohibitive.

Sulfur as an element can be applied as elemental sulfur, sulfuric acid, calcium sulfate (gypsum) and in many low-analysis fertilizers such as 0-20-0. The source of sulfur to use depends on the distance it has to be transported. In some areas, it might be more economical to apply it as part of a fertilizer, such as in ammonium sulfate or superphosphate.

As soil amendments, both calcitic and dolomitic limestone are used to correct soil acidity, which means that the soil is more favorable for microorganism activity. Certain nutrients, particularly phosphorus, usually become more available.

Gypsum is used in the reclamation of sodic soils containing a relatively high percentage of sodium. When soils become saturated with sodium, they tend to become dispersed and run together. An application of gypsum will cause the sodium to react with the sulfate and leave calcium in the soil. Calcium causes granulation, thereby resulting in a better physical condition.

Materials Furnishing Trace Elements

Trace elements can be supplied individually as a specific compound or they can be applied as a mixture of the salts or chelated form of the various trace elements. Where a specific minor element deficiency is apparent, this deficiency usually is corrected by the direct use of a compound containing that specific minor element.

Iron, the trace element most likely to be deficient in many Texas soils, can be supplied from several sources—iron chelates or iron sulfate (copperas). Iron chelates (salts of organic acids) usually have a longer lasting effect than iron sulfate, but they are more expensive. Both sources can be applied directly to the soil or sprayed on the plants, but iron sulfate will be more effective as a spray. Iron deficiencies often are due to the unavailability of iron rather than the lack of iron in the soil. In many alkaline soils, most of the iron is present in a form which cannot be used by plants. Any practice of making the soil more acid such as manuring and using sulfur often corrects the deficiency by making the iron more available.

Copper can be supplied as copper sulfate (bluestone) or as a chelate. Too much copper in a soil is toxic to plant growth. Usually not more than 8 to 10 pounds of actual copper should be applied to the acre.

Zinc can be applied as zinc sulfate or as a chelate. It can be applied as a foliar spray or a direct soil application.

Manganese can be supplied as manganese sulfate or as a chelate, as a spray or soil application.

Boron is supplied by the use of borax. An excess of boron is toxic to plants. Rates above 25 pounds per acre should not be used.

Barnyard Manure and Crop Residue

Barnyard manure and crop residues are good sources of plant nutrients for increasing crop production and maintaining soil fertilty. The plant nutrient content of manure varies depending on the type of livestock, type of litter or bedding and method of handling.

Fig. 6. A complete fertilizer was applied at left. At right, no fertilizer was applied.

Poultry manure usually contains more plant nutrients than other manures. It contains approximately 20 pounds N, 16 pounds P_2O_5 and 8 pounds K_2O in each ton. Cattle manure will contain approximately 10 pounds N, 5 pounds P_2O_5 and 10 pounds K_2O in each ton. Other types of animal manures contain approximately the same quantities of plant nutrients.

The value and quality of manure depends on the type and amount of litter or bedding used. Chopped cornstalks or small grain straw contain more plant nutrients than a material such as sawdust. Some litter or bedding in manure is advantageous because it absorbs the liquid portion. However, too much bedding or litter lowers the quality of the manure by tying up nitrogen needed to decompose the manure.

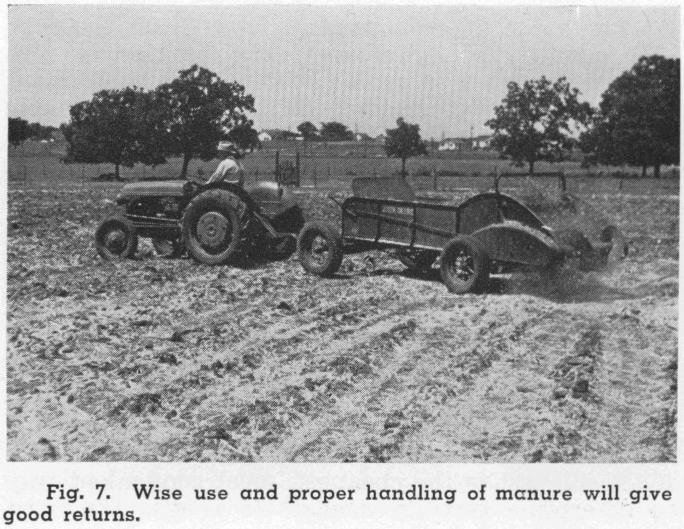


Fig. 7. Wise use and proper handling of manure will give good returns.

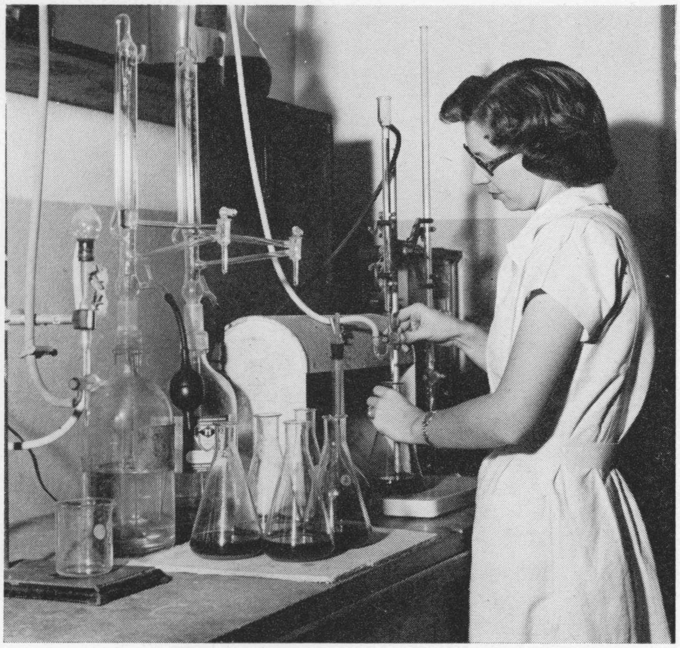


Fig. 8. Chemical soil tests to determine fertilizer needs result in greater profit.

Manure should be spread as soon as it accumulates since losses of plant nutrients can occur if the manure is not stored properly. In the case of grass or sod crops, this would be practical and advisable. However, in the case of row crops, it would be advisable generally to store the manure and spread it shortly before the land is prepared for the next crop. This practice decreases the loss of nutrients due to leaching and erosion. For storing manure prior to spreading, let it accumulate in the shed with plenty of litter or bedding, or store it for protection from rainfall and losses due to leaching.

The value of manure depends on many factors. If it is handled and applied properly, one ton of manure will give yield increases worth $3 to $7 per acre, if the plant nutrients are needed.

The value of crop residue depends on the type and quantity. Leguminous crop residue is considered the most valuable; however, nonleguminous crop residue with added nitrogen is a valuable source of plant nutrients.

How to Determine Fertilizer Needs

Several methods can be used to determine the fertilizer needs of soil for a given crop. They are soil tests, plant tissue tests, field trials and deficiency symptoms. The ideal way is to use all of these methods together in determining fertilizer needs.

Soil Tests

A soil test is the cheapest, most convenient way to determine fertility needs. It is also the most accurate way with the exception of extensive field trials.

A soil test is designed to do three things. It will determine general needs for the primary nutrients, as well as for soil amendments. It will determine the proper nutrients to apply for the correct nutrient balance. In irrigated areas, it can be used to determine the accumulation of soluble salts in the soil due to the use of low-quality irrigation water.

By determining nutrients needed and the proper ratio, soil tests can be used to determine how to make the most profit from money invested in fertilizer. In this way, soil tests are good investments.

Soil tests can benefit farmers, fertilizer dealers, bankers and others concerned with more profitable and efficient fertilizer use. Actually, soil tests can serve as a form of credit insurance for lending agencies.

If soil tests are to be valuable, soil samples must be taken properly. Fertilizer recommendations based on a soil test can be no better than the soil sample. The results of chemical tests on poorly taken samples may be misleading. Before taking samples, contact your county agricultural agent for information on how to take samples, or write to the Soil Testing Laboratory, College Station, Texas.

In addition to soil tests, it is necessary to know the past cropping history of the field, past fertilizer usage, soil type and texture and general physical condition of the soil to determine fertility needs. Without this information, soil tests are of little value. Before submitting samples to the Laboratory, fill out a soil sampling information sheet and submit it with the sample.

Plant Analysis

Plant analysis can be used to supplement soil analysis as a basis for fertilizer recommendations. To test the plant tissue, a certain part of the plant, such as a certain leaf, the petioles or the whole plant, usually is sampled.

The chief difficulty at present with plant analysis is that optimum nutrient levels have not been established in plants at the various stages of growth. Without a knowledge of these levels, it could not be known whether a level would be deficient or adequate.

Field Trials

Field trials are the final test in determining the value of the grade and amount of fertilizer used. Unfertilized strips of four to six rows or 20 feet in width should be left across the field. Double the normal rate being used or decrease it by half the normal rate on several rows to see if a different rate would be more profitable. These strips will indicate whether the fertilizer pays. If check strips are used, be sure to select a strip that is representative of the field.

Fig. 9. Leaving a check strip will tell whether fertilizer pays.

Deficiency Symptoms

Deficiency symptoms often help diagnose a situation and aid in determining fertility needs. When a plant develops deficiency symptoms, the nutrient shortage is severe and should be corrected immediately if there is still time during the growing season. The deficiency usually cannot be corrected until the following season.

Deficiency symptoms often are similar to the effects of a lack of moisture on plant growth. A lack of moisture causes wilting of the younger leaves of the plant first, with severe moisture deficiency causing the whole plant to wilt and die. Dying or "burning" of lower leaves is caused by some deficiency and not lack of moisture.

The following outline* gives a key for determining the cause of deficiency symptoms.

A. Effects general on whole plant or localized on older, lower leaves.

1. Effects usually general on whole plant, although often manifested by yellowing and drying of older leaves.

a. Foliage light green. Growth stunted, stalks slender and few branches. Leaves small, lower ones lighter yellow than upper. Yellowing followed by a drying to a light-brown color, usually little dropping of leaves. *Nitrogen deficient.*

b. Foliage dark green. Retarded growth. Lower leaves sometimes yellow between veins but more often purplish, particularly on petiole. Leaves dropping early. *Phosphorus deficient.*

2. Effects usually local on older, lower leaves.

a. Lower leaves mottled or freckled, usually with dead areas near tip and margins. Yellowing beginning at margin and continuing toward center. Margins later becoming brown and curving under and older leaves dropping off. *Potassium deficient.*

b. Lower leaves chlorotic and usually dead in late stages. Chlorosis between the veins, veins normal green. Leaf margins curling upward or downward or developing a puckering effect. Dead areas developing between the veins very suddenly, usually within 24 hours. *Magnesium deficient.*

B. Effects localized on new leaves.

1. Terminal bud remaining alive.

a. Leaves chlorotic between the veins, veins remaining green.

(1) Dead spots usually absent. In extreme cases, death of margins and tip of leaf, sometimes extending inward, developing large areas. Larger veins only remaining green. *Iron deficient.*

Note: Certain cultural factors, such as high pH, overwatering, low temperature and nematodes on roots may cause identical symptoms. However, the symptoms are still probably of iron caused by these factors.

(2) Dead spots usually present and scattered over the leaf surface. Checkered or finely netted effect produced by even the smallest veins remaining green. *Manganese deficient.*

b. Leaves light green, veins lighter than areas between veins. Some dead spots. Little or no drying of older leaves. *Sulfur deficient.*

2. Terminal bud usually dead.

a. Death at growing tip and margin of young leaves. Young leaves often definitely hooked at tip. Death of roots actually preceding all of the above symptoms. *Calcium deficient.*

b. Breakdown at base of young leaves. Stems and petioles brittle. Death of roots, particularly the root tips. *Boron deficient.*

Methods of Applying Fertilizer

Several factors determine the method of applying fertilizer. Soil type, soil texture, type of crop grown, kind and amount of fertilizer, soil reaction and season are some that need to be considered.

*Taken from Ohio State Agricultural Experiment Station Bulletin No. 611

Fig. 10. Pastures and small grains can be fertilized with a drill-type distributor.

Principles to remember when applying fertilizer are:

1. Nutrient elements will not be taken up by the plant if they are in dry soil; therefore, fertilizer should be placed so that it usually is in moist soil during the growing season.

2. Some plant nutrients are soluble and move with the soil solution. Nutrients in sandy or light-textured soils are apt to be leached below the root zone under heavy rainfall or irrigation. Most nutrients will not move a great distance in loams or heavier-textured soils except under conditions of very heavy rainfall and leaching.

3. Some soils will fix phosphorus and make it less available, thus reducing its efficiency.

4. In areas where erosion is a problem, fertilizer applied at or near the surface is subject to loss by erosion or runoff of surface water.

5. Excessive concentration of soluble materials too near the seed or young seedlings could cause injury.

Broadcasting

Broadcasting on the surface and disking in or turning under is a method of fertilizer application. This method is satisfactory for broadcast crops on acid soils and usually works well for row crops in acid soils. This method may encourage excessive early weed growth if the fertilizer is disked in. Broadcasting probably would not be suitable on alkaline soils, where phosphorus fixation may be a problem. Crops suited to this method of application might be small grain, legumes and grasses.

Banding

Banding means placing the fertilizer in one or two bands 2 to 3 inches to the side of the seed and 3 to 6 inches deep. In certain areas such as the High Plains, fertilizer should be 5 to 10 inches to the side and approximately 5 inches deep. (Remember that fertilizer must be in moist soil to be effective.) Banding is satisfactory on nearly all soils, especially where phosphorus fixation might be a problem.

Drilling

Applying fertilizer with an attachment on the drill is a good method for crops seeded with a drill. It combines the good features from both broadcasting and banding.

Sidedressing

Sidedressing is a useful method in several situations. It should be restricted to nitrogen and potassium. Where leaching is a problem on sandy soils, nitrogen and potassium can be applied as a sidedressing after the crop is up rather than prior to planting. This would help minimize the danger of loss by leaching. Since phosphorus moves very little in the soil, it should seldom be applied as a sidedressing, unless it can be placed deep.

Sidedressing allows the farmer to wait until later in the season to see what moisture conditions are likely to be. A portion of the N and all of the P_2O_5 and K_2O can be applied at planting time. If soil moisture is favorable within 30 days or so after planting, sidedress with additional N.

When sidedressing, do not put the fertilizer too deep in the soil or too close to the row, since roots may be damaged by the equipment. Do not wait too late in the season to sidedress, since additional moisture often will be needed to move the nitrogen into the root zone.

Topdressing

Topdressing small grains, legumes and grasses is an excellent way to provide supplemental nutrients. Using a drill attachment or some other method of getting the fertilizer into the soil might be desirable, but the damage to the plants generally would not offset the slight advantage over topdressing.

Applying in Irrigation Water

Applying fertilizer in irrigation water is another method. Nitrogen applied in this manner generally would be satisfactory, except for alkaline soils where some loss of nitrogen may occur as ammonia. Phosphorus applied in irrigation water generally would be undesirable, since it tends to stay on the surface of the soil and would be of little value to plants. This method often results in uneven distribution of the fertilizer since the water often is not spread uniformly over the field. It has the advantage of being easy to handle, convenient, fast and economical.

Foliage Application

Foliar application of nutrients has little value as a means of supplying all the plants' needs. The quantity of the major nutrients needed generally is so great that many applications would be necessary to supply a sufficient amount. This would make the cost prohibitive. However, for the application of trace elements, foliar feeding generally is satisfactory.

Time of Application

The main point to consider in when to apply fertilizer is whether the plant nutrients in the fertilizer will be available for plant use when needed. Nitrogen and potassium leach out of sandy soils; hence, on these soils they should be applied just prior to or at planting, or as a sidedressing. On medium and heavy-textured soils, nitrogen and potassium move with soil water, but usually not out of the root zone; hence, they generally can be applied at any time without danger of loss from leaching. Since phosphorus moves very little in the soil, there is little chance of loss due to leaching. Phosphorus fixation could be greater in certain soils if applied too far in advance of the time it is needed.

Economic considerations also help determine when to apply fertilizer. Applying fertilizer ahead of planting means that the money invested in fertilizer will be tied up longer. However, fertilizer often is cheaper in "off-seasons" and it might save money to apply fertilizer several months in advance of planting, even though leaching or fixation might cause slight loss. Field work might be at a minimum prior to the growing season, thus allowing the use of machinery and labor which otherwise would be idle. The crop to be fertilized also influences time of application.

Economics of Fertilizer Use

Profits from fertilizer are determined by factors such as the particular crop to be grown, type of season, soil type, and past management. One of the most important factors is the amount of fertilizer used. For instance, three different rates of fertilizer, such as 100, 200 and 300 pounds of a 10-20-10, could be used under the same conditions with all three returning a profit. However, one of these three rates will give the highest profit per acre.

How can an individual farmer determine the right amount to use to obtain the most profit? This will depend on the soil type, climatic conditions expected, past management and *the amount of capital the farmer has to invest.*

The effect of environmental factors and soil conditions on fertilizer response is known generally. Soil tests can indicate the amount of fertilizer to use for a given response. The final amount of fertilizer to use depends on economic conditions. Besides *yield* increases to be expected, other factors which determine the rate to use are the *cost* of the fertilizer, *price* expected for the crop and level of *capital* available.

Estimating Yield

Most crops respond to fertilizers. Field tests show that a general type of "yield increase curve" is obtained similar to the one for corn shown in Figure 11. This curve shows that yields continue to increase as more fertilizer is used up to a certain point; then they start to decrease. Note that each additional unit of fertilizer that is applied gives a smaller increase than the previous one. For example, the first 30 pounds of nitrogen gave a 10-bushel increase. The next 30 pounds gave 7 additional bushel of corn. This same general type of "yield increase curve" will hold for other crops such as cotton, grain sorghum and forage.

The "yield increase curve" varies with the soil type and climatic conditions. Field fertilizer experiments give the general type of "yield response curve" to expect for various soil types and climatic conditions.

Estimating Price of Crop

Estimating the price you will receive for your crop may be difficult. In some instances, you know what price to expect because of price supports and contract agreements. In other cases, you'll have to look at the situation—crop prospects, anticipated market conditions and farm outlook.

In any case, the most profitable rate of fertilizer to use will depend on the price to be expected for the crop. If prices appear to be good, more fertilizer can be used profitably. If prices are uncertain and apt to be low, fertilizer use would not be as profitable and less should be applied.

After estimating prices and if the yield increases to be expected are known, line A in Figure 11 could be converted to a "returns" curve by multiplying the expected price times the yield. In this example, the price of $1.20 per bushel was used.

Estimating Cost

The costs of producing the crop also influence the most profitable rate of fertilizer to use. Certain fixed costs are associated with the growing of a crop. The land has to be plowed, seedbed prepared, seed purchased and planted, the crop cultivated, insects and diseases controlled and the crop harvested. These costs are fairly constant and can be estimated.

The costs of the fertilizer and of handling and application depends on the amount of fertilizer to

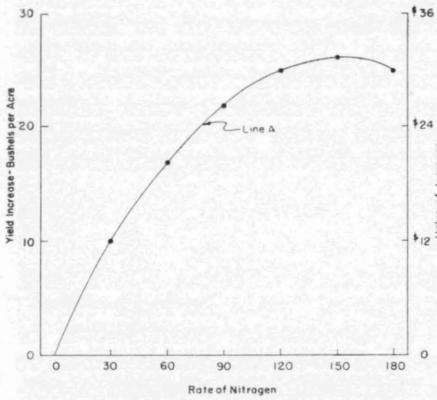


Fig. 11. Nitrogen effects on yield.

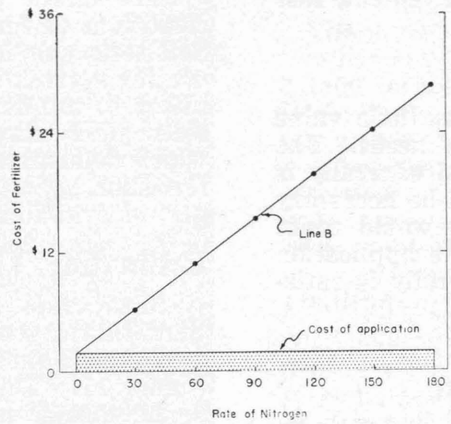


Fig. 12. Cost curve for nitrogen.

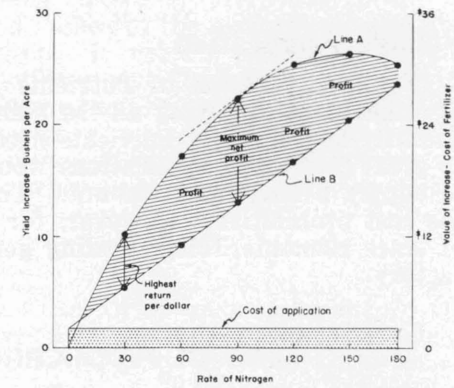


Fig. 13. Profits from fertilizer use.

be used. This amount also can be determined since it is known how much is applied and how much it costs to handle and apply it. Figure 12 shows how these costs increase with increasing fertilizer use.

Estimating Profit

The "yield value curve" and cost line can be put together as in Figure 13. Then profits from fertilizer use can be determined by the difference between the yield value curve and the cost line, or the cost of producing the crop and the returns from it. This is shown on Figure 13 as the difference between line A (the yield value curve) and line B (the cost line). This shows the profits that might be expected from fertilizer use.

The important consideration now is—what rate will give the most profit per acre? Look at the Table 3 below for the example here. It is 90 pounds of nitrogen for an increased profit of $11.40 per acre. This is the point at which the yield value curve and cost line are the greatest distance apart. As fertilizer use is increased or decreased from this point, profits will decrease. For example, 60 pounds of nitrogen gave $9.90 profit per acre and the 120-pound rate gave a $10.50 profit per acre. It is desirable to fertilize at the rate which will return the most profit per acre if capital is available.

Table 3. Effect of Rates of Nitrogen Fertilizer on Yields of Corn.[1]

Rate of N	Yield[2]	Yield Inc.	Value of Inc.	Cost of fert.	Return per $	Profit per A.
0	87					
30	98	10	12.00	6.00	2.00	6.00
60	104	17	20.40	10.50	1.95	9.90
90	109	22	26.40	15.00	1.75	11.40
120	112	25	30.00	19.50	1.55	10.50
150	113	26	31.20	24.00	1.30	7.20
180	112	25	30.00	29.00	1.05	1.00

[1]Corn valued at $1.20 per bushel. Fertilizer valued at 15¢ per pound of nitrogen plus $1.50 for application cost, interest, etc.

[2]Yield data adapted from Texas Agricultural Experiment Station PR 1913.

Fertilizer rates are not the most profitable if maximum yields are produced. In our example, 150 pounds of nitrogen gave the highest yield of 113 bushels per acre with a return of $7.20 per acre from the use of fertilizer. The most profitable rate in the example, giving a return per acre of $11.40, was 90 pounds of nitrogen per acre. Hence, from the standpoint of fertilizer use, it is desirable to stop fertilizing before maximum yields are obtained.

Available Capital

If capital is limited, it would be advisable to fertilize at a rate short of maximum net profit. If capital is available, it is more profitable to fertilize at a rate which will give maximum net profit.

Look at the example again. Ten acres are to be fertilized. If capital is available, 90 pounds per acre of nitrogen would be used and it would cost $150 to fertilize the 10 acres. But only $60 is available to spend on this 10 acres. Should the entire 10 acres be fertilized at a rate for less than the maximum net profit or should the rate for maximum net profit be used only on a few acres? Simple arithmetic advises spreading as much fertilizer per acre over the whole 10 acres that the $60 would allow. Over 10 acres, at 30 pounds nitrogen per acre, total return would be $120 or $60 profit. Fertilizing for maximum profit, or 90 pounds of nitrogen per acre under this situation, would mean fertilizing 4 acres (at $15 per acre) with a total return of $105.60, or a profit of $45.60. The lowest profitable rate to use is exemplified in Figure 3. This is the rate which would give the highest return per dollar invested. Below this rate, fertilizer would be less profitable.

Even though operating capital for fertilizer is short, returns from fertilizer use would justify borrowing the funds needed.

Why Test Soil?

If the final rate of fertilizer to use depends on cost of fertilizer, capital available and price of crop, why bother to test the soil? A soil test, together with other information about the field, will indicate the type of yield increase curve to be expected. Figure 14 shows how yield response curves will vary with soil test levels. Curve A shows yield increases that might be expected with a low soil test. Maximum net profit would be obtained at a rate of slightly over 80 pounds of nitrogen per acre. Under the same conditions, if the soil test was medium, curve B, maximum profit comes at about 65 pounds of nitrogen per acre. On soils testing high, curve C, yield increases would not be great enough to be profitable. Thus, soil tests are necessary as the starting point on determining fertility needs.

Soil test recommendations issued by The Texas A. & M. College System are based on an average price relationship. If the price expected for the crop will be less than normal, decrease the rate of application somewhat. If fertilizer prices go down, or if you get an extra "good buy" on fertilizer, increase the recommended rate.

Soil test recommendations also are based on average management. If a better-than-average job of controlling insects and weeds is done, and if water is put on at just the right time, more fertilizer than was recommended will pay off.

Unless irrigation is used, the average rainfall for the area influences the fertilizer rate. If soil moisture is above average at the beginning of the season, increase the normal rate. If winter and

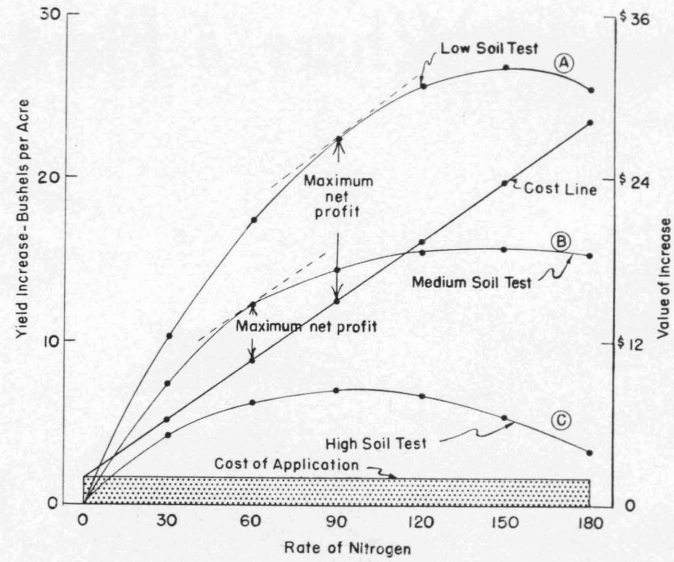
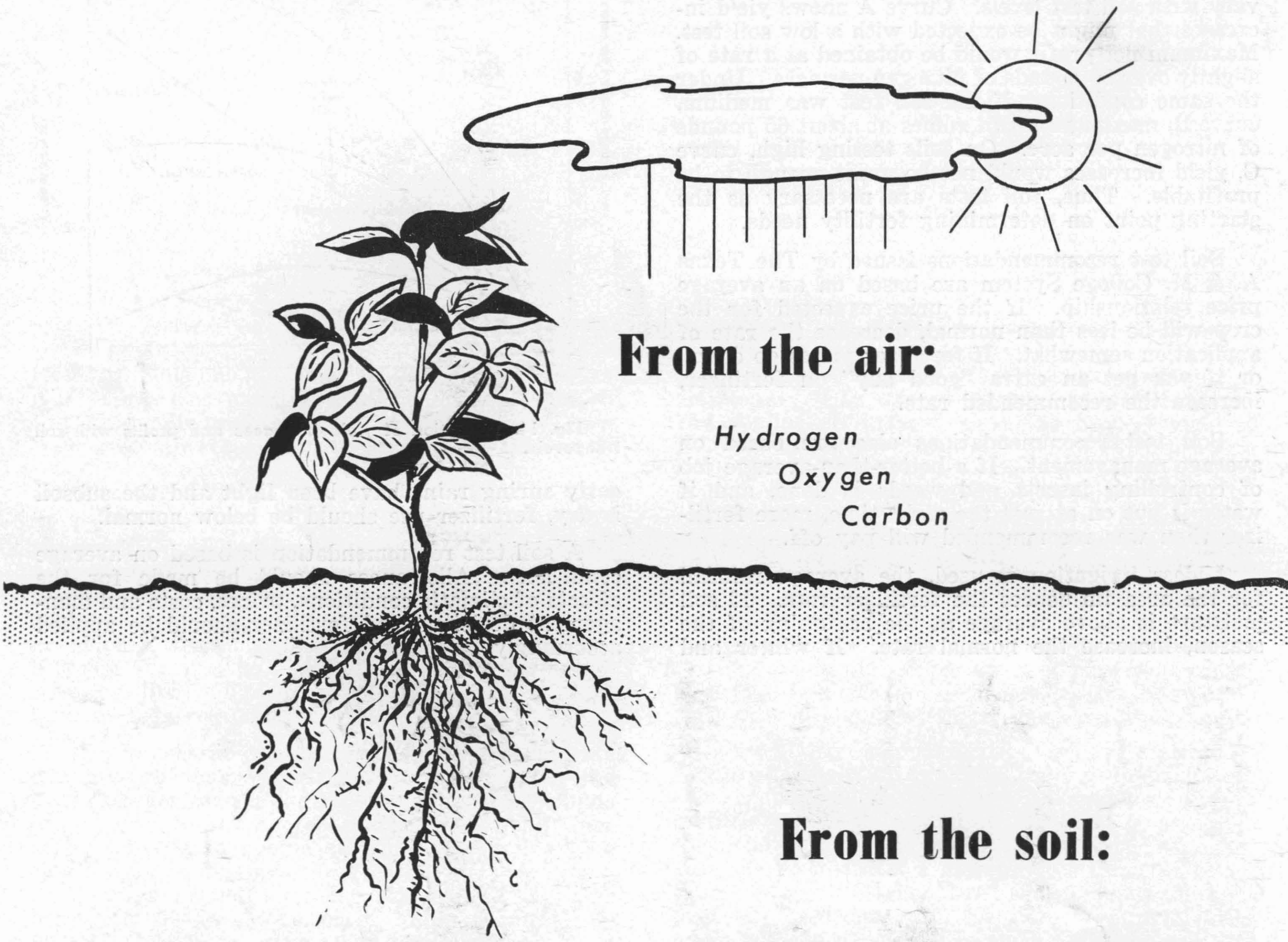


Fig. 14. Variation of yield increases and profits with soil test levels.

early spring rains have been light and the subsoil is dry, fertilizer use should be below normal.

A soil test recommendation is based on average conditions. Allowances should be made for the effects of climatic conditions, prices, costs and management decisions and fertilizer should be applied accordingly.

Where a Plant Gets its Nutrients



From the air:

Hydrogen
Oxygen
Carbon

From the soil:

PRIMARY PLANT NUTRIENTS	SECONDARY PLANT NUTRIENTS
Nitrogen	Magnesium
Phosphorus	Calcium
Potassium	Sulfur

TRACE ELEMENT PLANT NUTRIENTS

Manganese, Cobalt, Zinc, Iron, Copper, Molybdenum, Boron, etc.

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