ACID SOILS IN OKLAHOMA

Where They Are Located, and How They Form

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LOCATION AND DEVELOPMENT OF ACID SOILS IN OKLAHOMA

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Soil Scientist

This bulletin showing the location of acid soils in Oklahoma is based on analyses of 21,792 surface soils and a comparison of 3,259 surface and 3,259 subsurface soils. The analyses were made in the Oklahoma Agricultural Experiment Station Soils Laboratory. The bulletin also contains information on the cause and development of acidity under the various soil and climatic conditions found in Oklahoma.

Soil acidity is a good indication of soil deterioration. As acidity increases, the availability of many plant nutrients gradually declines to a point where fertilizers are neded to maintain crop yields. Soil acidity slows up the rate at which some of the plant nutrients in the soil are changed into a form usable by plants. In moderately to strongly acid soils, chemical fixation greatly reduces the availability of soluble phosphate fertilizer. Furthermore, an acid soil condition restricts the growth of some of the legume crops that should be planted to increase the productivity of nitrogen-deficient soils. (About one-third of the original nitrogen in Oklahoma soils disappeared during the first fifty years of cropping.)

The harmful effect of soil acidity can generally be corrected by applying agricultural limestone in the proper quantity as shown by a soil analysis. Where lime is difficult to obtain or transportation costs are high, it may be necessary to use acid-tolerant legumes in cropping systems, with proper fertilizer treatment to maintain the productivity of the land.*

* See Okla. Agri. Exp. Sta. Bul. B-316, *Crop Adaptation to Soils of Varying Acidity or Alkalinity.*

GENERAL LOCATION OF ACID SOILS IN OKLAHOMA

Percentage of Acid Soils by Counties

Results of acidity tests on soil samples collected from different Oklahoma counties are shown in Appendix Table I and Figures 1 and 2. About one-third of the samples were collected in connection with soil surveys and cooperative field experiments conducted by the Experiment Station. The remainder were analyzed for farmers, county agents, and others.

The intensity of acidity today is probably greater than is shown in Appendix B and Figures 1 and 2. The samples tabulated were analyzed over a period of fifteen years, and soils in some areas which were slightly acid fifteen years ago are moderately acid now.

The data given here provide the best information at present available concerning the distribution of acid soils throughout the State. However, the percentage given for each county may be affected to some extent by the relative number of samples from upland or bottomland. For example, data from Muskogee county indicate a higher percentage of neutral and alkaline soils than adjacent counties. This percentage would probably be reduced if acidity tests were made on all farms in the county. A large number of the samples from this county

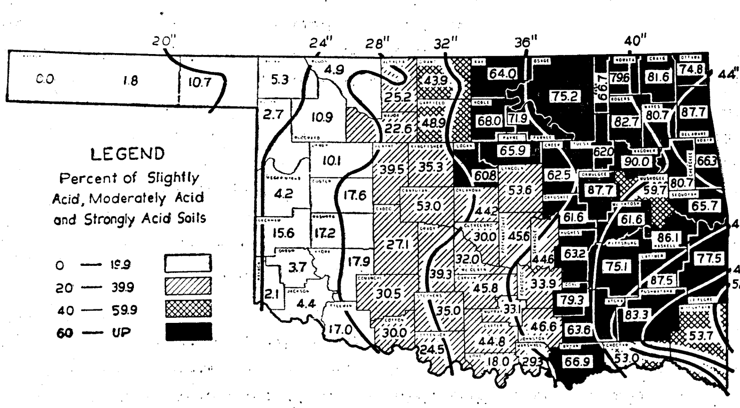

Fig. 1. Soil Acidity in Relation to Rainfall.

This map shows the percentage of soils from each county that were acid, and also the average annual rainfall in various parts of the State. Very little harmful acidity occurs in western Oklahoma where rainfall averages less than 28 inches. (Rainfall data from **p. 1073, U. S. D. A. Yearbook,** Climate and Man 1941.)

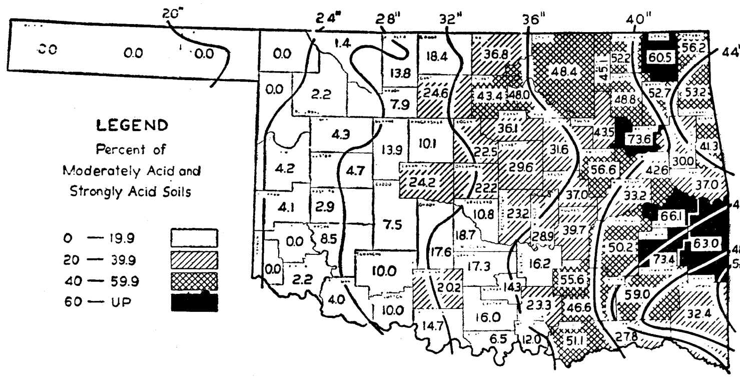

Fig. 2. Percentage of Moderately to Strongly Acid Soils, by Counties. The percentage shown for each county indicates the proportion of that county's soils on which crop yields could be improved by applying agricultural limestone, using phosphate fertilizer where needed, and growing legumes. The percentages shown are probably low rather than high. The intensity of acidity in each county is shown in more detail in Appendix Tables I and II.

were collected by individuals interested in increasing the yields of vegetable crops and alfalfa, normally planted on bottom-land soil.

Figure 1 shows, by counties, the percentage of surface soil samples which were acid. It also shows the effect of climatic conditions, principally rainfall, on the development of soil acidity. A high percentage of the surface soils in north central and eastern Oklahoma are acid. Very little acidity occurs west of a north-south line separating Blaine and Caddo counties from Dewey, Custer and Washita counties.

There is no sharp boundary between the non-acid soils and the area where soils begin to be slight to moderately acid, because of variations in soil texture. In drier areas, more acidity appears in sandy soils than in fine textured soils. In western Oklahoma, acid soils are found principally on sandy land originally covered with blackjack or shinnery oak. Deeper penetration of soil moisture and little or no erosion of the surface soil under virgin conditions is responsible for more extensive leaching on this type of land.

Percentage of Moderately Acid and Strongly Acid Soils

Figure 2 shows the percentage of surface soils in each county which were more than slightly acid. Many eastern Oklahoma soils which were slightly acid ten or fifteen years ago when the earlier samples were taken are now moderately acid or strongly acid, due to the leaching effect of rainfall and continued production of soil depleting crops. In most counties, the amount of limestone applied to date has not been enough to reduce the percentage greatly.

Slight acidity in a surface soil with a neutral or slightly alkaline subsoil is not a serious problem except when weeds or a nurse crop are competing with young legume plants for moisture and plant nutrients. Very satisfactory yields of lime-loving crops such as alfalfa or sweet clover can be produced on such soils without liming, if a stand can be obtained.

When both surface and subsurface soils are slightly acid, better yields of lime-loving crops will be obtained by applying agricultural limestone. All moderately or strongly acid soils need lime for the best growth of any legume, although acid-tolerant legumes will make some growth without the addition of lime.

Surface and Subsurface Acidity*

Data on the relative acidity in surface and subsurface soils in various sections of Oklahoma are given in Appendix A, Table I. This information was obtained from analyses of 6,518 samples.

The reaction of the subsoil is especially important when lime-loving crops such as alfalfa and sweet clover are to be planted. Fertility is very low in a strongly acid subsoil. The greater the depth of the acidity, the lower is the availability of plant nutrients within the zone of root penetration. Where erosion has exposed strongly acid clay subsoils, it is difficult to establish a vigorous vegetative cover because of the unfavorable physical structure of the soil and low availability of plant nutrients.

In central Oklahoma, slightly acid surface soils usually have neutral or slightly acid subsoils. This considerably reduces the problem of soil improvement. In eastern Oklahoma, about 15 to 20 percent of the subsoils are deeply leached and high in acid content. Soil improvement on this type of land is usually expensive, because larger quantities of plant nutrients must be supplied to increase or maintain crop yields. Strongly acid subsoils not only lack lime, but are also low in available phosphorus and are frequently deficient in available potasium and magnesium; therefore plants must obtain a high percentage of their nutrients from the surface soil.

* Additional data, and discussion by areas, will be found in Appendix A, page 21.

FACTORS AFFECTING ACIDITY OF SPECIFIC AREAS

The best way to find out whether a field needs lime is to have a chemical test made on one or more samples of soil.* It is helpful, however, to have some knowledge of how soil acidity develops to aid in interpreting information obtained from soil tests. Such knowledge is also helpful in determining whether a test may be necessary, and in planning cropping systems for different types of land. The following section of this bulletin was prepared to give such information.**

The Chemical Nature of Soil Acidity

How Soils Become Acid

Soil acids† are formed when calcium (lime) and other basic elements are removed from neutral or alkaline minerals (such as feldspar and mica) by water which contains carbon dioxide and other solvents such as nitric acid. Alumino-silicic acid is responsible for most of the acidity in Oklahoma soils. Organic acids are present in leached surface soils, but are relatively unimportant under average conditions.

The rate of formation of soil acidity depends upon (1) the rate of leaching and (2) the quantity of basic elements such as calcium, potassium and magnesium originally present in the soil. Under natural conditions, the rate of leaching will be affected by the kind of vegetative cover, the topography, the character of geological material on which soils are formed, the ratio between rainfall and evaporation, and the time factor on soil development.

Cultivation of virgin land indirectly increases the quantity of acid alumino-silicates in the soil. This is because more of the nitrogen in the soil organic matter is changed to nitric

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* Tests for soil acidity can be made by county agents, vocational agriculture teachers or soil conservation district technicians. These individuals can arrange to have additional tests made by the Experiment Station Soils Laboratory if there is some indication that lack of other plant nutrients may be limiting plant development.

** Additional information on the handling of acid soils will be found in the following bulletins of the Oklahoma Agricultural Experiment Station: B-312, *Effect of Fertilizers on Soil Acidity and Olkalinity;* B-315, *Soil Reaction and Availability of Plant Nutrients;* and B-316, *Crop Adaptatoin to Soils of Varying Acidity or Alkalinity.*

† Soil acids differ from acids commonly found in a chemical laboratory because they are relatively insoluble in water. All acids have one character in common. They contain hydrogen in replaceable form. However, the replaceable hydrogen is not responsible for the acitivity of an acid; it is merely associated with acidity. Hydrogen has the properties of a relatively weak base, being replaced by more active bases usch as calcium, potassium, ammonia, magnesium, manganese, and iron. As soil acidity increases, the calcium, magnesium and potassium content decreases. Maganese and iron alumino-silicates appear in increasing quantities. This principle is used as the basis of the Comber test for soil reaction.

acid as a result of increased biological activity. The increase in the carbonic, nitric and other acids produced by the more rapid decay of soil organic matter increases the rate of removal of calcium from the calcium alumino-silicates. The calcium salts of these acids are readily removed by leaching, or are absorbed by plant roots. The relatively insoluble hydrogen alumino-silicates accumulate in the soil, making it more acid.

Soil acidity is also increased when that portion of the nitrogen in legume residues which came from the air is changed to nitric acid as the legume residues decay.

As soil acidity increases, the availability of calcium is gradually reduced. Plant roots obtain calcium and other basic elements from contact with non-acid particles or from the capillary water. As the number of acid particles in a soil increases and the number of non-acid particles decreases, plant roots come in contact with less calcium and other basic materials. Furthermore, soil acids can absorb calcium from the capillary water.* Therefore they compete with plant roots for basic elements by removing them from the capillary water before it reaches the root hairs.

When acid formation has gone far enough so lime-loving plants** fail to get sufficient calcium from the soil, crop yields can be increased by liming the soil.

pH: The Measure of Active Acidity in Soil

The acidity or alkalinity of a soil—called "reaction" by the chemists—is frequently indicated by a series of numbers called pH values. These values are determined by using an indicator solution which will change color within a certain pH range, or by electrical measurement. The neutral point, which is neither acid nor alkaline, is indicated by a pH of 7.0. (In soil the neutral pH range varies from 6.7 to 7.3). A pH less than 7.0 indicates the presence of acidity and a pH of more than 7.0 indicates an alkaline condition. A pH of 5.0 is ten times as acid as a pH of 6.0. A pH of 9.0 is ten times as alkaline as a pH of 8.0.

The approximate relation between pH values and soil reaction is given in Table I.

* When the calcium is present in the capillary water as calcium bicarbonate.

** For a list of plants adapted to different degrees of acdity, see Okla. Agri. Exp. Sta. Bul. B-216. *Crop Adaptation to Soils of Varying Acdity or Alkalinity.*

Aluminum Toxicity in Acid Soils

Strongly acid soils frequently contain harmful concentrations of soluble aluminum salts. More soluble aluminum will be found in fine textured soils with a pH value below 5.0 than in sandy soils with the same degree of acidity. Soils which have a pH between 5.5 and 8.0 will not have any appreciable quantity of soluble aluminum salts in the water films surrounding the soil particles.

The addition of sufficient quantities of limestone to raise the pH value of a strongly acid soil to 5.5 will remove soluble aluminum from the soil solution. This treatment alone will not produce maximum crop yields because strongly acid soils are normally deficient in available phosphorus. The addition of a soluble phosphate fertilizer to a strongly acid soil will precipitate the soluble aluminum from the soil solution, but this procedure is more expensive than an application of lime.

Corn plants suffer from aluminum toxicity when the pH value of the soil is 5.0 or less. When soluble aluminum salts are absorbed by corn roots in low concentrations which do not seriously injure the root cells, they move into the stalk where some of the aluminum is precipated as the hydroxide and accumulates in the lower nodes of the corn plant. This accumulation restricts the normal flow of water from the roots to the leaves. Under such conditions growth is poor and yields are low.

Grain sorghums are more sensitive to soluble aluminum than corn. Barley is very sensitive to small quantities of soluble aluminum salts.

Soluble manganese salts may also be present along with soluble aluminum compounds in strongly acid soils. When lime is applied to an acid soil to maintain a favorable condition for crop growth, thes compounds will not exist in harmful concentrations.

TABLE I. Relation of soil reaction to pH values.
(Tentative classification.)

Degree of Soil Acidity or Alkalinity	pH Range*
Strongly alkaline	Above 8.5
Moderately alkaline	7.9-8.5
Slightly alkaline	7.3-7.9
Neutral	6.7-7.3
Slightly acid	6.1-6.7
Moderately acid	5.5-6.1
Strongly acid	4.9-5.5
Very strongly acid	Less than 4.9

* Each grouping occupies .6 of a unit on the pH scale.

Factors Affecting Development of Soil Acidity

The appearance of harmful acidity in a soil will depend upon the original quantity of basic elements in the soil and the rate at which the basic elements are removed by leaching and cropping. Under semi-arid conditions, such as in western Oklahoma, a soil will remain neutral or alkaline indefinitely because the soluble alkaline products of weathering are not removed by rainfall. Where rainfall is more plentiful, soils of varying acidity are produced, depending upon such factors as rate of erosion, variation in soil texture, slope, cropping system, and type of original vegetative cover.

The Effect of Rainfall

Winter rainfall is more important than summer rainfall in developing soil acidity. Much of the rain falling during the summertime is absorbed by a dry soil and does not move downward into the subsoil. When a vigorous growth of vegetation is present, a high percentage of the water absorbed by the soil is returned to the air by transpiration or evaporation. During the wintertime, evaporation and transpiration losses are low; consequently, rain falling on a moist soil will carry dissolved salts into the subsoil.

Oklahoma soils may be classified into two major groups depending upon the chemical character of soil profile development as affected by limited or extensive leaching. These groups are called (1) lime accumulating soils which form under the influence of low rainfall (pedocals), and (2) leached soils which are found in the humid area (pedalfers). The line separating these two groups of soils occurs somewhere between the 98th and 99th meridians in Oklahoma. It is closely associated with the line indicating an average annual rainfall of 28 inches, as shown in Figure 1, page 6.

Caliche or Gypsum Indicates Unleached Soil. No acidity will be found in soils containing caliche or gypsum on or near the surface of the ground. Caliche, a form of calcium carbonate,* is commonly observed as a white or grayish band in many soil profiles in western Oklahoma (See Figure 3). It is present because rainfall during past centuries has not been sufficient to leach it into the deeper subsoil. Surface or subsurface soils containing an abundance of calcium carbonate will have a pH value above 8.0.

* The term caliche is also used to describe calcium carbonate deposits of sedimentary origin.

As the depth from the surface of the ground to the top of the caliche horizon increases, it is an indication that more leaching of the surface soil has occurred. The depth of leaching gradually increases from west to east across the state because of the increase in average annual rainfall. At Stillwater a layer of caliche about 12 inches thick is found 6 or 8 feet be-

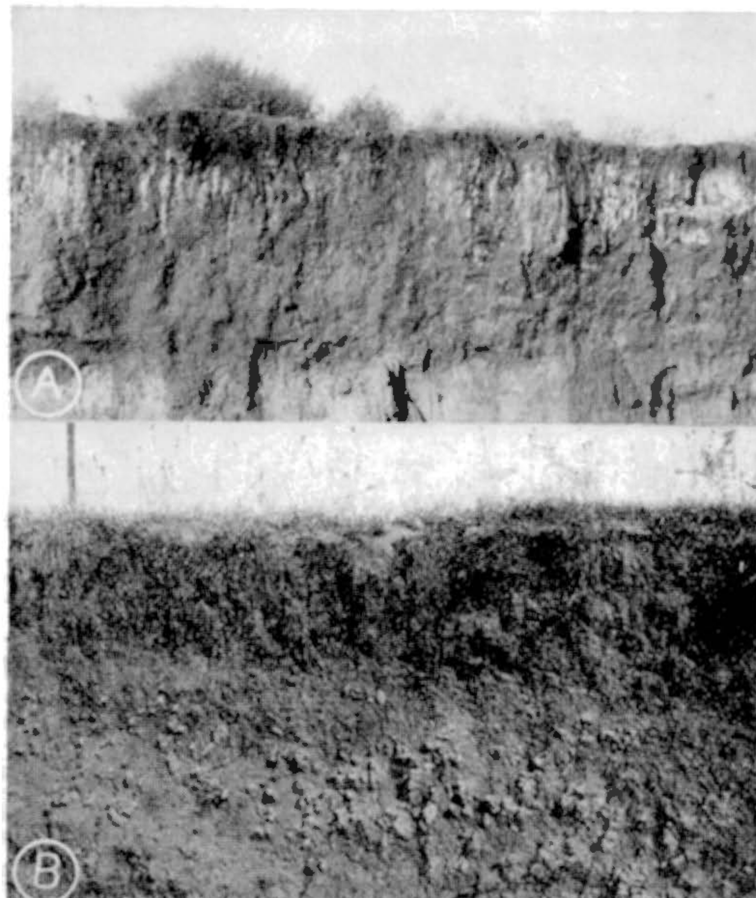

Fig. 3. Caliche Shows Soils Are Not Leached.

These soil profiles show the accumulation of large quantities of calcium carbonate in subsurface horizons during the process of soil development. The upper profile, A, is located north of Frederick in Tillman County, Oklahoma. The lower profile, B, was observed north of Drummond in Garfield County, Oklahoma. Rainfall has not been sufficient to leach the calcium carbonate in these soils to a greater depth.

low the surface of Kirkland soils, which are old soils occurring on gentle slopes. A less extensive layer appears at a higher elevation. The surface soil of this area is moderately acid and limestone must be applied to grow good crops of alfalfa and sweet clover.

Gypsum is abundant in several geological formations in the western part of the state and appears on or near the surface of the ground in many localities. This mineral is relatively soluble in water* as compared with other mineral matter occurring in soils. It is not usually found in the upper part of a soil profile except in areas where erosion removes the surface soil as rapidly as it is formed. In many soil profiles gypsum will be found beneath the zone of lime accumulation. In eastern Oklahoma gypsum crystals are occasionally observed in the subsoil of planosols** or in poorly drained bottomland where an impervious layer of clay prevents rain from moving downward through the soil profile.

Old Soils Are More Acid Than Young Soils. The effect of lime on the formation of soil acidity in regions of similar climatic environment depends upon soil porosity and the rate of geological erosion.

Some erosion occurs on all areas of sloping land unless the soil is very sandy. Run-off water has eroded the land surface in many stream valleys in Oklahoma while adjacent areas of sandy land have remained relatively static because the rain was absorbed by the soil.

Water passing through a soil over a long period of time removes soluble material and leaves an acid residue which is frequently very low in available plant nutrients. Consequently, sandy soils deteriorate more rapidly than fine textured soils, under similar conditions.

On areas where geological erosion continues to remove the surface soil at the same rate that weathered rock is changed into soil, unweathered minerals are being continually introduced into the soil profile. These unweathered minerals keep the nutrient supply of the soil at a high level. Under such conditions a vigorous growth of natural vegetation is maintained because the age of the soil has remained relatively constant and no increase in acidity has occurred.

* The solubility of gypsum in distilled water is about 2200 parts per million as compared with 15 parts per million for calcium carbonate. The solubility of calcium carbonate can be increased to approximately 1000 parts per million if the distilled water is saturated with carbon dioxide.

** Very old soils in which development has been restricted by the formation of an impervious clay layer in the subsurface portions (B horizon) of the soil profile.

Young soils which have developed on weathered limestone in eastern Oklahoma usually are not acid although soil on adjacent areas of weathered sandstone or shale may be strongly acid. The high content of calcium in the residue which is left after the limestone is dissolved by weathering, and the fine texture of the surface soil which retards the downward movement of rainfall, are responsible for this condition.

Soils in low bottomlands are younger and are also less acid than soils on adjacent stream terraces or uplands in the central and eastern part of the state.

THE EFFECT OF SLOPE

Slope is a good index of the age of the soil on upland areas derived from similar geological material. Soils on gentle slopes are always older than soils on moderate to steep slopes. The rate of geological erosion is more rapid on the steep slopes. The effect of slope on soil acidity, therefore, depends on whether or not deep leaching has occurred on adjacent areas of more level land.

In semi-arid regions, moderate to steep slopes are less acid than gentle slopes. Loss of surface soil is greater as a result of geological erosion on moderate to steep slopes. Consequently, unweathered soil material is continually being exposed which prevents the development of harmful acidity.

In regions of more abundant rainfall the soil on a moderate to steep slope may be just as acid and sometimes more acid than soil on a gentle slope (unless the subsoil is impervious to water). When the downward movement of rain is not restricted, weathering processes gradually remove a large quantity of lime and other basic elements from the subsurface layers to a depth of several feet. When sloping areas gradually recede as a result of surface erosion, the leached subsoil becomes a part of the soil profile. Under such conditions it will be very acid and low in available plant nutrients. A poor vegetative cover appears on many areas of sloping land under virgin conditions because of the effect of deep leaching.

Soils occurring on gently sloping land in north central Oklahoma are more acid than soils occurring on more rolling land in the south central area. The higher acidity is due quite largely to the differences in the age of the soil, although some of the weathered material on which many south central Oklahoma soils have developed is higher in calcium carbonate content. The rolling topography of south central Oklahoma prevents or retards the development of soil acidity because geological erosion has been too rapid to permit much acidity to form. Consequently, the need for lime in that part of the state is not so high as on the undulating to gently sloping topography occurring in the north central and eastern part of the state.

Relatively level land in areas where leaching occurs is more likely to be more acid than on adjacent slopes, although the level land may produce a larger yield of acid-tolerant crops because it has a deeper soil and contained more organic matter under virgin conditions. Eventually, however, when the organic matter is reduced to a point where legume rotations must be used to improve crop yields, the level land will require more lime to grow crops like sweet clover than will be needed on sloping areas.

Bottomlands Vary in Reaction. An exception to the statement that level soils are likely to be more acid than adjacent slopes in areas of higher rainfall is often found along the larger streams that flow eastward from the subhumid part of Oklahoma. Many of the bottom and low terrace soils along these streams are not acid because overflow has deposited silt and clay containing unweathered minerals high in calcium and other basic elements.

Along smaller streams which originate within the higher rainfall area of the state, high bottomlands are often moderately acid and occasionally strongly acid. Exceptions to this general statement may be found where bottomland soils have developed on sediment washed from limestone areas or from shales and sandstones containing a considerable quantity of calcium carbonate. Overflow water and sediments from such areas will continue to replenish the quantity of lime in bottomland soils as rapidly as it is leached downward by rainfall.

The Effect of Accelerated Erosion

The effect of accelerated erosion on a cultivated soil depends upon the character of the subsoil. If the subsoil is not acid and is gradually mixed with the surface layer as a result of plowing, it tends to reduce the acidity of the soil. If the subsoil is more acid than the surface layer and is mixed with the surface soil as a result of plowing, then the acidity will be increased. Appendix Table I shows that subsoils may be more acid or less acid than surface soils. In central Oklahoma, eroded clay soil is likely to be less acid than the original surface layer. Eroded sandy land will have about the same acidity as the uneroded soil. In eastern Oklamoma, a sandy loam soil frequently will be very strongly acid in both surface and subsurface layers; consequently, an eroded area on this type of land will be very strongly acid regardless of the amount of erosion.

Figure 4 shows three conditions which may develop when different soil types are affected by accelerated erosion. In all three instances the surface layer is only slightly acid, but the subsurface layers vary in degree of acidity. Profile No. 1 would become less acid as erosion continues; the acidity in profile No. 2 would not change, and profile No. 3 would become more acid. When erosion removes the surface soil from a profile similar to No. 3, more limestone would be needed to correct the acidity in a layer 6 or 7 inches deep than would be required to neutralize the acidity in an adjacent area of uneroded soil.

The differences shown in Figure 4 also explain why subsoil samples should be taken when soils are collected for analysis. The subsoil samples show what physical and chemical conditions plant roots will encounter as they grow downward.

	PROFILE NO. 1	PROFILE NO. 2	PROFILE NO. 3
SURFACE SOIL	SLIGHTLY ACID	SLIGHTLY ACID	SLIGHTLY ACID
SUBSURFACE SOIL	NEUTRAL	SLIGHTLY ACID	MODERATELY ACID
SUBSOIL	ALKALINE	SLIGHTLY ACID	STRONGLY ACID

Fig. 4. Effect of Erosion on Soil Acidity.

This figure illustrates important variations in the vertical distribution of acidity in three soils which have the same degree of acidity in the surface layer. Severe sheet erosion would produce two important changes in the reaction of these profiles. Profile No. 1 would become less acid, profile No. 2 would not be changed by accelerated erosion, whereas profile No. 3 would become more acid as erosion continued to remove the surface soil more rapidly than soil formation occurred.

In regions of abundant rainfall, many surface soils and deep subsoils are not as acid and contain a larger quantity of available plant nutrients than the intermediate zones between them. This condition is most frequently found in soils which have developed under the influence of a forest cover. Where this intermediate zone is exposed by accelerated erosion or by excavation (as on sloping roadside banks) an area of non-productive soil may be observed with a vigorous growth of vegetation such as Korean lespedeza above and below the less productive area.*

The Effect of Cultivation

Cultivation increases the acidity of a soil as a result of the more rapid decomposition of soil organic matter. Carbonic and nitric acids remove calcium and other basic elements from the clay minerals, and form a hydrogen clay. This can be shown by comparing the results of chemical tests on soil samples collected from adjacent areas of virgin and cultivated land not affected by erosion. In many areas sweet clover will often grow in fence rows when it will not grow on cultivated land a few feet away. This difference is due to an increase in the acidity of the cultivated land, due to the combined effect of leaching, removal of plant nutrients by soil depleting crops, and more rapid decomposition of soil organic matter.

The change in soil reaction due to tillage and crop removal depends upon the quantity of basic material in the soil in relation to the amount of nitric and carbonic acid produced from the decomposition of organic matter. Over a 50-year period an unfertilized wheat plot on the Oklahoma Agricultural Experiment Station farm has changed from slightly acid (pH 6.1) under virgin conditions to strongly acid (pH 5.1) as a result of the continued production of wheat. This soil has lost about 1300 pounds of total nitrogen as a result of cultivation. It would require 4625 pounds of limestone to neutralize the nitric acid produced by the oxidation of soil organic matter containing that amount of nitrogen.

A garden soil is normally less acid than soil collected from cultivated land, because garden soil has usually received more liberal applications of organic fertilizer such as barnyard ma-

* This zone is called the A_2 horizon in a soil profile. Plant roots extract nutrients from this zone. These nutrients are carried upward and accumulate in the leaves and stems. When the leaves and stems fall to the surface of the ground, these nutrients accumulate in the surface soil. Water carries soluble plant nutrient from the A_2 horizon of a soil profile into the subsoil during periods of abundant rainfall. This process eventually develops a very infertile horizon between the surface and subsurface soil.

nure. When barnyard manure is completely decomposed by soil organisms, it will leave an alkaline residue. A continuous wheat plot receiving barnyard manure at the average rate of 3.6 tons each year now has a pH of 5.6, whereas the unfertilized soil has a pH of 5.1. The soil which has not been fertilized is five times as acid as the plot receiving farmyard manure. Wood ashes scattered on garden soils will also neutralize soil acidity because they contain approximately 55 percent of calcium carbonate.*

The Effect of Natural Vegetation

Natural vegetation tends to retard the development of acidity. The leaves and stems of plants contain mineral nutrients which were absorbed from the soil by plant roots. Under natural conditions these leaves and stems accumulate on the surface of the ground. Non-leguminous plants return more non-acid-forming than acid-forming elements to the surface layer of soil when they decay, thus tending to neutralize the leaching effect of rainfall.

The natural vegetative cover is frequently an accurate index of soil leaching on sandy land in western Oklahoma. Sage brush is found on the non-acid, young, sandy soils. On the older, more acid sandy land, species of oak occur. Sand bluestem will be observed on both areas because it is adapted to either slightly acid or slightly alkaline land.

Grassland.—Acidity develops less rapidly in grassland soils than under forest cover. In a prairie soil, the abundant development of grass roots in the surface foot (0 to 12 inches deep) tends to keep the upper portion of the soil profile dry during the growing season because of a rapid transpiration of moisture from the grass blades. Consequently, the moisture holding capacity is usually high and very little leaching occurs from summer rainfall. In the sub-humid and arid sections of the Great Plains area, winter rainfall seldom moistens more than one or two feet of surface soil, so it causes very little leaching. In eastern Oklahoma, more winter rainfall occurs and the prairie soils are more acid than in the central and western part of the state.

The difference in the acidity of grasslands developed on different types of weathered soil material is illustrated by two soil types in eastern Oklahoma. Black clay soils of the Summit

* The effect of various fertilizers on soil reaction is discussed in more detail in Okla. Agri. Exp. Sta. Bul. B-312, *Effect of Fertilizers on Soil Acidity and Alkalinity.*

series developed on weathered limestone under the influence of tall grasses. These soils are not acid in any portion of the soil profile. Adjacent grassland soils of the Bates series developed on standstone and are thoroughly leached to a depth of several feet.

Forest.—In a mature forest soil under virgin conditions, the subsurface layer is more acid than the surface or subsoil. Roots are not so numerous in the surface horizon as they are in grassland. Leaf litter also prevents evaporation of surface moisture. Chemical weathering proceeds at a more rapid rate because of the greater amount of moisture in the soil, and more leaching occurs because less water is required to satisfy the water-holding capacity. The higher percentage of acidity found in Stephens County soil (Appendix Table II and Figure 1) is due principally to the influence of forest cover on a large area of non-calcareous sandstone which underlies a considerable portion of that area.

Soil acidity usually develops more rapidly under a pine forest than under many types of deciduous forest because pine needles contain a much lower percentage of calcium than do leaves from deciduous trees.

APPENDIX A

Surface and Subsurface Acidity, by Areas

Data on the amount of acidity in surface and subsurface soils from different parts of Oklahoma are given in Appendix Table I.* Most of the surface soils were obtained from cultivated fields and represent a layer about six inches deep. Subsurface soils were usually collected at a depth of twelve to fifteen inches below the top of the ground. The reactions of the surface and subsurface soils from each area were separated into seven groups as shown in the table. No attempt was made to group individual pairs of samples according to the reaction of surface and subsurface layers, since the data were compiled to show the general trend of acidity and alkalinity in surface and subsurface soils from different localities.

Northeast Oklahoma.—Many of the young prairie soils in northeast Oklahoma have developed on weathered limestone or calcareous shale and have not been affected very much by leaching. These soils vary from slightly acid to slightly alkaline in the surface and are usually non-acid in the subsoil. Some of the bottomland soils in this area are non-acid in both surface and subsurface layers. The numbers of surface and subsurface soils which were neutral were practically the same. More slightly acid and moderately acid surface soils were found than slightly acid and moderately acid subsurface soils. This is a characteristic of youthful soil profiles. Soils in this area which developed on sandstone or other porous material are usually deeply leached. More subsoils than surface soils were moderate plus to strongly acid. Such a condition indicates extensive leaching.

In the northern Ozark area of northeast Oklahoma, soil development has occurred principally on cherty limestone. The surface inch of these undisturbed forested soils is frequently non-acid, but the subsurface layers are strongly acid. When the forest is cleared and the land is used for the production of cultivated crops, the acid subsurface layers are mixed with the non-acid surface layer, and lime-loving crops which will frequently grow on newly cleared land cannot be grown on the cultivated areas without treatment. Removal of plant nutrients by leaching has decreased the small quantity of available calcium and other bases originally present in many of the cultivated soils. Consequently, crop production is relatively low, due principally to the direct or indirect effect of soil acidity on the availability of plant nutrients. There are

*Pages 24 to 26.

some areas of sloping land occuring on weathered limestone in the stream valleys which are not acid and are very productive because geological erosion has continued at a rate equivalent to or in excess of the rate of leaching.

About fifteen percent of the soils collected from this region are so severely leached that the cost of soil improvement will be very high in relation to the immediate return from crops.

Black clay soils which developed on weathered limestone or calcareous shale are usually not acid, but occasionally dark-colored soils associated with these black clay soils may be quite acid. A study of these areas will usually show that the dark-colored acid soils have developed on weathered shale which probably contained considerable quantities of iron sulfide and very little calcium carbonate before the sedimentary formations were affected by soil forming processes. Shales associated with coal deposits frequently contain large quantities of iron sulfide. The iron sulfide decomposes in the presence of water and air to form a hydrated oxide of iron and sulfuric acid. The sulfuric acid reacts with calcium combined with clay minerals in the soil material to form gypsum and an insoluble acid residue. Strip pits have been examined where iron sulfide has been present in the shale and a very strongly acid condition has been produced in the spoil banks by weathering processes. A vegetative cover does not appear on many of these acid areas for a long period of time. Spoil banks containing considerable quantities of calcium carbonate in the shale provide a favorable reaction for the growth of shrubs and trees which grow better than grass on these areas. Sweet clover planted on several non-acid spoil banks from coal strip pits in eastern Oklahoma has made a vigorous growth.

Southeast Oklahoma.—The soils in southeast Oklahoma developed principally under the influence of oak, hickory and pine forests. Many of the soils on sloping areas are very shallow and are suitable only for forest production or pasture. The orange and yellow subsoils commonly observed are an indication of excessive leaching. Both surface and subsurface layers are acid and low in available plant nutrients, especially phosphorus, if the subsoil is yellow. The cost of soil improvement in relation to income received from this type of land is usually high as compared with other soils in this area. Red and brown subsoils in this climatic region are usually not so acid, have a more favorable soil structure, and normally contain a larger quantity of available mineral nutrients for plant growth than yellow subsoils.

Gray subsoils with orange and black mottling are frequently observed on poorly drained land in eastern Oklahoma. The acidity of gray subsoils will vary, depending upon the amount of leaching which occurred before the poorly drained condition developed.

Important variations between the reaction of surface and subsurface soils in southeastern Oklahoma were principally in the strongly acid group, where the percentage of strongly acid subsurface soils was much higher than the percentage of strongly acid surface soils. Over 23 percent of the subsoils collected from cultivated land in this area have been thoroughly leached, and a considerable portion of the basic elements originally present has been carried below the zone of root penetration.

North Central Oklahoma.—In north central Oklahoma, many moderately acid surface soils had neutral or alkaline subsoils. Very few of the profiles were more acid in the subsurface layers than in the surface soil. Lower rainfall in the central part of the state has resulted in less leaching; consequently, many of the shallow soils (found principally on the steeper slopes) are not acid in either the surface or subsurface horizons. Less than six percent of the soils in this area have suffered severely from subsoil leaching. Phosphorus fertilization is needed, especially on sloping land, to increase the production of legumes such as hairy vetch and sweet clover.

South Central Oklahoma. Young sandy soils occurring in the Cross Timber area of central Oklahoma make up a considerable portion of this region. Although many of these soils are very low in natural productivity, soil acidity is not so important as a deficiency of phosphorus and organic matter in the improvement of crop yields. Eight percent of the subsoils and only three percent of the surface soils tested have lost a high percentage of the basic elements originally present in them.

Western Oklahoma.—The subsurface soils collected from northwest Oklahoma were more alkaline than subsurface soils from the southwest part of the State. Fine textured soils in this region are normally not acid in either surface or subsurface layers. A few sandy soils in the eastern part of this area were moderate-plus to strongly acid in both surface and subsurface horizons, but the number of acid soils in western Oklahoma is relatively insignificant so far as the total area of cultivated land is concerned.

*Appendix Table I.—Reaction of surface and subsurface soils secured from various sections of Oklahoma.**

County	Basic		Neutral		Slight		Slight+		Moderate		Moderate+		Strong		Total No. of samples
	Sur.	Sub.	Sur.	Sub.	Sur.	Sub.	Sur.	Sub.	Sur.	Sub.	Sur.	Sub.	Sur.	Sub.	
Northeastern Oklahoma															
Adair			3	2	3	5	2	2	7	4			3	5	36
Cherokee	21		6	6	8	10	1		1		1	2		1	38
Craig	11	16	12	7	15	8	7	5	12	19	5	3	8	12	140
Delaware	4	3	11	11	48	31	31	23	39	37	9	17	11	31	306
Mayes	11	13	5	9	15	11	14	8	24	13	6	10	13	24	176
Muskogee	1	1	4	1		3							1	1	12
Nowata	2	2	1	1	1	10	1	7	13	3	4	2	6	3	56
Okmulgee				4	10	5	4	5	15	14	5	9	8	5	84
Ottawa	1	1	3	6	4	4	2	1	1		1		1	1	26
Rogers	4	4	19	24	22	23	19	23	36	27	7	13	43	36	300
Tulsa	23	30	24	19	27	20	5	9	43	42	11	8	28	33	322
Wagoner			1	3	7	5	1	1	3	6	4	4	11	8	54
Washington	7	6	6	3	1	7	4	5	18	15	2	2	21	21	118
	66	76	95	96	161	142	91	89	212	180	55	70	154	181	1668
Southeastern Oklahoma															
Atoka			2	4	3	2	4		3	2	11	4	2	13	50
Bryan	1	2	1		2	2	1		3	2	1			3	18
Choctaw	7	2	3	3	3	1	4	2	4	5	2		6	16	58
Haskell			1	1	1									1	4
Latimer			2	1	3	2		1	4	5	3	5	13	11	50
Le Flore	13	14	18	10	10	5	1	2	22	20	3	2	58	72	250
McCurtain		1	1						1	1	1			1	6
McIntosh	12	4	12	14	5	5	12	13	6	10	2	4	3	2	104
Pittsburg	5	7	5	8	6	6	1	5	13	7	10	1	16	22	112
Pushmataha					1	1	1	1	2	1		1			8
Sequoyah	3	2	8	4	4	5	1	1				1	1	4	34
	41	32	53	45	38	29	25	25	58	53	33	18	99	145	694

* Based on 6,518 surface and subsurface samples analyzed in the Soils Laboratory of the Oklahoma Agricultural Experiment Station.

** Most of the surface soils were obtained from cultivated fields and represent a layer about six inches deep. Subsurface soils were usually collected at a depth of 12 to 15 inches below the surface of the ground.

Appendix Table I.—(Continued)

County	Basic		Neutral		Slight		Slight+		Moderate		Moderate+		Strong		Total No. of samples
	Sur.	Sub.	Sur.	Sub.	Sur.	Sub.	Sur.	Sub.	Sur.	Sub.	Sur.	Sub.	Sur.	Sub.	
North Central Oklahoma															
Creek	4	3	13	8	13	13	7	5	6	11	4	6	11	12	116
Kay	14	41	34	43	47	51	20	8	37	22	6	1	10	2	336
Lincoln	6	9	10	10	18	19	10	10	25	22	5	11	29	22	206
Logan	13	17	15	15	17	18	12	12	10	4	4	3	1	3	144
Noble	2	10	3	15	10	16	12	4	20	4	5	3			104
Okfuskee	3	5	2		2	1		3	3	2	1				22
Oklahoma	26	33	26	29	11	12	7	5	8	8	8	3	12	8	196
Osage	2	2	3			2	3	1				1		2	16
Pawnee	5	9	5	6	8	9	8	9	15	12	6	1	4	5	102
Payne	11	23	13	28	38	47	43	36	32	20	10	5	15	3	324
	86	152	124	154	182	170	122	93	156	105	49	34	82	57	1566
South Central Oklahoma															
Carter	8	8	16	16	12	18	10	3	4	1		3	2	3	104
Cleveland	8	5	3	13	8	9	7	1	2						56
Coal	1			1	6	8	5	3	20	13		3	7	11	78
Garvin	7	4	4	5	1	4	1		6	5		1	1	1	40
Hughes		1	1			2	6	1	6	9					26
Johnston	10	6	4		5	6	2		6	8		5		2	54
Love	19	18	5	6	2	4	3	2	4	4	1				68
Marshall	8	4	3	2	2	1		2		2	2	2		2	30
McClain									1					1	2
Murray	12	8	3		7	6	7	9	11	10		4		3	80
Pontotoc				2	2										4
Pottawatomie	9	13	9	5	8	7			5	4			8	10	78
Seminole	9	7		1				1							18
	91	74	48	51	53	65	41	22	65	56	3	18	18	33	638

APPENDIX B

Acidity of Surface Soils, by Counties

*Appendix Table II.—Classification of surface soils collected from Oklahoma counties according to their degree of acidity.**

County	No. of Samples	Soil Reaction						
		Basic	Neutral	Slightly acid	Slight+ acidity	Moderately acid	Moderate+ acidity	Strongly acid
Adair	104	17	18	18	8	21	1	21
Alfalfa	159	86	33	15	3	15	1	6
Atoka	88	21	11	14	1	24	1	16
Beaver	28	23	2	3	0	0	0	0
Beckham	224	142	47	25	1	3	0	6
Blaine	129	49	29	30	3	12	3	3
Bryan	172	35	22	24	3	34	14	40
Caddo	384	170	110	66	9	18	1	10
Canadian	575	154	116	119	47	85	19	35
Carter	469	119	140	111	24	56	4	15
Cherokee	30	2	4	13	2	5	0	4
Choctaw	183	43	43	42	4	24	3	24
Cimarron	11	8	3	0	0	0	0	0
Cleveland	304	148	65	47	11	20	0	13
Coal	140	13	16	23	10	38	2	38
Comanche	151	78	27	29	2	11	2	2
Cotton	130	65	26	19	7	9	1	3
Craig	152	14	14	27	5	53	5	34
Creek	842	143	173	202	58	120	14	132
Custer	153	103	23	15	5	4	2	1
Delaware	423	20	32	108	38	113	11	101
Dewey	69	48	14	4	0	1	0	2
Ellis	110	102	5	3	0	0	0	0
Garfield	601	208	99	126	20	80	4	64
Garvin	214	76	40	54	7	18	2	17
Grady	535	214	111	95	21	47	10	37
Grant	239	93	41	55	6	29	1	14
Greer	134	94	35	5	0	0	0	0
Harmon	48	44	3	1	0	0	0	0

Appendix Table II.—(Continued)

County	No. of Samples	Soil Reaction						
		Basic	Neutral	Slightly acid	Slight+ acidity	Moderately acid	Moderate+ acidity	Strongly acid
Harper	114	101	7	3	0	2	0	1
Haskell	115	7	9	20	3	22	2	52
Hughes	413	90	62	77	20	70	14	80
Jackson	90	67	19	2	0	0	0	2
Jefferson	102	46	31	10	0	11	0	4
Johnston	73	27	12	15	2	11	0	6
Kay	736	161	104	165	35	115	10	146
Kingfisher	326	134	77	75	10	21	0	9
Kiowa	201	114	51	14	5	8	4	5
Latimer	120	5	10	16	1	11	4	73
Le Flore	267	28	32	35	4	35	8	125
Lincoln	672	183	129	116	45	90	12	97
Logan	342	79	55	104	27	36	9	32
Love	61	32	18	7	0	4	0	0
Major	177	95	42	22	4	10	1	3
Marshall	56	26	15	10	0	5	0	2
Mayes	368	34	37	84	19	79	15	100
McClain	128	55	32	16	1	12	1	11
McCurtain	108	34	16	14	9	11	0	24
McIntosh	193	27	47	73	12	30	5	29
Murray	175	83	34	26	7	16	2	7
Muskogee	568	121	108	87	10	96	4	142
Noble	369	68	50	70	21	82	7	71
Nowata	226	16	30	39	23	46	8	64
Okfuskee	232	47	42	51	6	46	10	30
Oklahoma	1576	594	286	276	71	168	23	158
Okmulgee	212	6	20	44	22	49	14	57
Osage	521	85	44	112	28	140	29	83
Ottawa	210	17	36	22	17	43	13	62

Appendix Table II.—(Continued)

County	No of Samples	Soil Reaction						
		Basic	Neutral	Slightly acid	Slight+ acidity	Moderately acid	Moderate+ acidity	Strongly acid
Pawnee	492	84	54	79	39	97	31	108
Payne	1315	250	198	287	105	244	40	191
Pittsburg	378	51	43	70	24	80	6	104
Pontotoc	295	129	66	46	6	24	3	21
Pottawatomie	384	134	75	73	13	37	4	48
Pushmataha	78	7	6	14	5	17	8	21
Roger Mills	48	37	8	0	1	1	0	1
Rogers	393	23	45	89	44	86	24	82
Seminole	249	92	46	34	5	27	2	43
Sequoyah	73	11	14	18	3	8	0	19
Stephens	163	69	37	18	6	18	3	12
Texas	56	52	3	1	0	0	0	0
Tillman	100	60	23	12	0	2	1	2
Tulsa	1160	263	178	182	32	243	30	232
Wagoner	220	9	13	28	8	31	9	122
Washington	423	79	62	69	22	92	15	84
Washita	175	109	36	22	3	2	0	3
Woods	144	127	10	3	2	2	0	0
Woodward	92	60	22	7	1	1	0	1
Grand Total	21,792	6360	3696	3920	1016	3121	472	3207

' A majority of the soil tests were made with .04% brom cresol purpleindicator. The Comber method for soil acidity was used on a few of the earlier samples collected.

12/47—7½M