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SUBSOIL AN IMPORTANT FACTOR IN THE GROWTH OF APPLE TREES IN THE OZARKS

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INTRODUCTION

Apple growing has been one of the important industries of southwestern Missouri and northwestern Arkansas for many years. Over the St. Louis-San Francisco Railway alone, according to the superintendent of refrigeration of that road, there were shipped out of this region from 1913 to 1925, inclusive, 39,313 carloads of apples. Over the Kansas City Southern Railway from 1922 to 1925, according to information received from the agricultural development agent of that line, there were shipped from the same region 1,295 carloads of apples. In addition, there were other carload shipments, the records of which were not obtained, and large quantities of apples were used at home, consumed by canneries, manufactured into evaporated apples, cider, and vinegar, and hauled by trucks into the regions of eastern Oklahoma and southeastern Kansas where but few apples are grown.

That a large number of the orchards now in bearing have been profitable is indicated by the good stand of trees, their well-kept appearance, and the extent of recent plantings which have increased from year to year. Many young orchards have not yet come into full bearing.

On the other hand, the poor stand of trees, small growth, and neglected condition of the trees in other orchards indicate that they have not been profitable. In all parts of the region there are orchards which have been practically abandoned, involving heavy economic loss. Many of these orchards have proved unprofitable because of diseases of various kinds, neglect, and the attempt to grow apples on a commercial scale by persons without the necessary experience, who do not realize the difficulties and expense of the undertaking.

During the progress of soil-survey work, however, it was observed that the better orchards are not uniformly distributed but are confined mainly either to certain localities or to well-defined situations. Representative areas of good orchards are around Republic and Marionville in Missouri and Springdale and Rogers in Arkansas. Hillside and other undulating or gently rolling situations throughout the area are universally recognized as supporting better orchards than level uplands. It was also noted that in those districts and those situations where apple growing is most successful the soil differs from that in places where the industry is less successful. This fact suggested a possible cause. The soils of the area were examined with this fact in mind, and an attempt was made to determine whether differences in those soil characteristics which may constitute factors favoring or inhibiting orchard success coincided with the differences in location or situation.

AREA STUDIED

The area studied covers about 4,000 square miles, including Newton, McDonald, Barry, Lawrence, and parts of Jasper, Greene, Christian, and Stone Counties in Missouri, and Benton and parts of Carroll and Washington Counties in Arkansas.

CLIMATIC CONDITIONS

The climate of the area is favorable to the growth of apple trees, the principal climatic drawback to successful apple production being occasional late spring frosts.

The average frost-free season ranges from 173 days at Mount Vernon, Mo., in the northern part of the area, to 197 days at Bentonville, Ark., in the southern part. Hence, the apple crop does not ordinarily suffer from shortness of the growing season. Sometimes, however, injury to the crop results from heavy frosts or freezing weather in the spring, following periods of warm weather, and from periods of dry weather in late summer and early fall.

During the last 30 years, for which only partial records are obtainable, freezing in the spring seems to have caused total loss of the apple crop in one year and heavy damage in one year. During other seasons there have been partial losses. Injury from frost is usually less severe in orchards of strong, vigorous trees than in orchards where the trees are in a weak and unhealthy condition.

The injury from the occasional periods of dry weather is always most severe in those sections where subsoil conditions are less favorable. That the susceptibility of the trees in sections and localities where apple growing is successful is slight is one of the facts indicating, as will be shown later, that soil character is an important, if not the most important, factor involved.

SOILS OF THE AREA

Upland soils of this area have been developed mainly from material accumulated by the disintegration of gray, hard, nearly pure limestone interbedded with thin layers of more resistant chert. The geologic processes of rock decay acting on these rocks produce reddish clay in which the chert fragments, which do not readily decay, are embedded. These chert fragments constitute the gravel that is present in the soils over the area. Some of this gravel is red or reddish brown, rather porous, and not extremely hard, and some is nearly white and very hard and breaks into sharp, flinty fragments. The thickness of this mantle of soil material varies widely, ranging from a few inches to several feet in extreme cases. This red clay

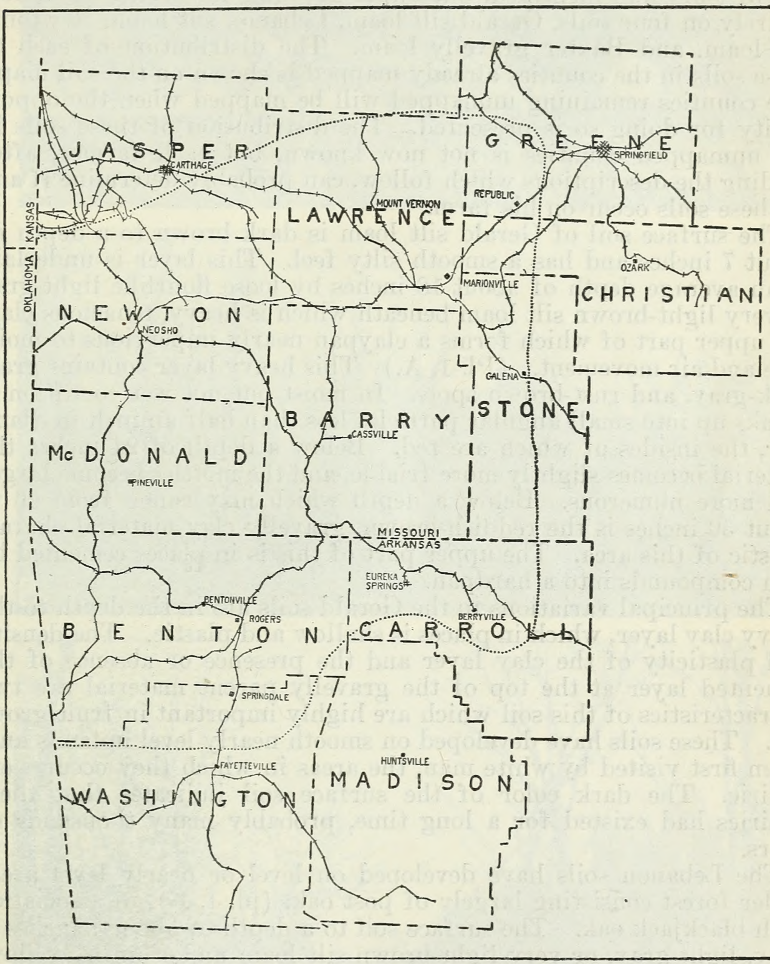


FIGURE 1.—Sketch map showing area studied in southwestern Missouri and northwestern Arkansas, indicated by dotted lines

material is not everywhere exposed at the surface, but it lies only a few feet beneath it and is seen in wells and other excavations.

Further weathering of the red soil material under varying conditions has resulted in the formation of soils which vary rather widely in their main characteristics. In general, soils of a region developed from similar parent material and under practically uniform general climatic conditions, as were the soils of this area, vary according to the character of the land surface and of the natural vegetation.

Grass vegetation usually produces a different soil from that produced by tree vegetation.

In this area soil mapping has been carried on in Lawrence, Newton, Barry, and Greene Counties in Missouri. During the progress of this work it is practically certain that the characteristics of all the highly important upland soils were determined. A rather large number of soils was identified, but apple growing is carried on almost entirely on four soils, Gerald silt loam, Lebanon silt loam, Newtonia silt loam, and Baxter gravelly loam. The distribution of each of these soils in the counties already mapped is shown on the soil maps. The counties remaining unmapped will be mapped when the opportunity for doing so is presented. The distribution of these soils in the unmapped counties is not now known, but each farmer, after reading the descriptions which follow, can probably determine if any of these soils occur on his farm.

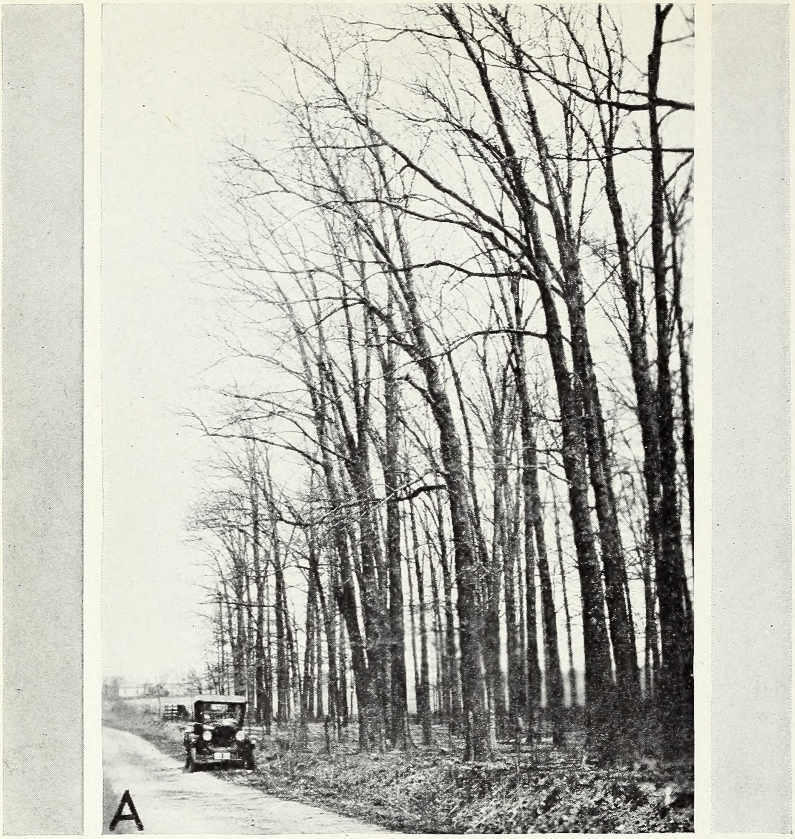
The surface soil of Gerald silt loam is dark brown to a depth of about 7 inches and has a smooth silty feel. This layer is underlain to an average depth of about 18 inches by loose flourlike light-gray or very light-brown silt loam beneath which is heavy, tenacious clay, the upper part of which forms a claypan nearly impervious to moisture and air movement. (Pl. 1, A.) This heavy layer contains gray, dark-gray, and rust-brown spots. In moist but not wet condition it breaks up into small angular particles less than half an inch in diameter, the insides of which are red. Below a depth of 24 inches the material becomes slightly more friable, and the mottles become larger and more numerous. Below a depth which may range from 26 to about 30 inches is the reddish-brown, gravelly clay material characteristic of this area. The upper part of this is in places cemented by iron compounds into a hardpan.

The principal variations in the Gerald soils are in the depth to the heavy clay layer, which in places is shallow and plastic. The density and plasticity of the clay layer and the presence or absence of the cemented layer at the top of the gravelly parent material are two characteristics of this soil which are highly important in fruit growing. These soils have developed on smooth nearly level uplands and, when first visited by white man, the areas in which they occur were prairie. The dark color of the surface soil indicates that these prairies had existed for a long time, probably many thousands of years.

The Lebanon soils have developed on level or nearly level areas under forest consisting largely of post oak, (pl. 1, B), in association with blackjack oak. The surface soil to a depth of about 7 inches is gray, light-gray, or very light-brown silt loam underlain by yellow, yellowish-brown, or slightly reddish-brown clay, less tenacious and sticky than the heavy clay layer in the Gerald soils. At a depth ranging from 20 to 30 inches this is underlain by a layer of mottled gray and rust-brown mixed clay and gravel compacted into a well-defined hardpan ranging up to nearly a foot in thickness. Beneath this lies the usual gravelly red clay of the area.

The Lebanon soils vary in color, in depth, and in thickness of the hardpan. The more yellowish soil is, as a rule, shallow, and it has the more highly developed hardpan. Reddish-brown areas are more friable and deeper, and in the forest there is a greater proportion of

A, A roadside cut showing impervious clay layer in Gerald silt loam, marked by the dark horizontal line.
B, Typical post-oak growth on Lebanon silt loam, where the soil is shallow and the hardpan highly developed.
C, Mixed forest growth characteristic of Baxter gravelly loam.



A, Tall, straight red oaks found in many places on the Newtonia soils.
B, Upturned stump of a blackjack oak which grew on Lebanon soil, showing root growth along top of the hardpan 24 inches below the surface.

blackjack oak. The post oaks on such soil grow taller and are more slender.

Baxter gravelly loam occurs principally on the slopes and supports a mixed forest growth in which large red oaks predominate but which includes chinquapin oaks, walnut, elm, dogwood, and a variety of other trees. (Pl. 1, C.) The surface soil consists of light-brown or slightly reddish-brown gravelly loam about 7 inches thick, beneath which is lighter reddish-brown gravelly loam which, at a depth of about 15 inches, grades into distinctly reddish-brown gravelly clay loam, heavier in texture and containing more chert gravel. At a depth of about 24 inches this grades into the red, gravelly clay of the area. The gravel found in this soil is, as a rule, reddish brown, rather soft, and somewhat porous. In no place is it cemented as in the Lebanon soils.

The principal variation in Baxter gravelly loam is in the depth to the underlying limestone or to thin layers of unbroken chert. On steep parts of the slopes, around the heads of small streams, and in other places the loose, friable material is shallow and the surface is very gravelly. In places, too, on the tops of ridges there is a tendency toward slight cementation. Such areas are intermediate between the Baxter and Lebanon soils.

Newtonia silt loam [1] consists of dark-brown or reddish-brown silt loam to a depth of 7 or 8 inches. Below this depth, the material is heavier and redder in color. Below a depth of about 15 inches is dull-red, friable silty clay loam which extends to a depth of about 30 inches. Below this depth the material has the same red color but is more friable and is underlain by heavy beds of gravel or by solid limestone. This red subsoil is in places 8 or 10 feet thick but in many places is more shallow. It contains no impervious clay layers or cemented hardpan like that found in the Gerald or Lebanon soils. Parts of the Newtonia soils were originally prairie land, and in such areas the soils are dark colored. In other parts they were forested. In places the forest growth consists of tall, straight red oaks, (pl. 2, A), but in other places is a mixed growth of large trees.

The most important difference in the character of the four soils described is in the subsoil. The subsoils of the Gerald and Lebanon soils are tight and nearly impervious and tend to restrict the free movement of moisture, air, and plant roots. In wet weather they become very wet, and in dry weather they dry out quickly.

In direct contrast, the subsoils of the Baxter and Newtonia soils are porous and friable, are not cemented, and allow the free movement of moisture and deep root penetration. For this reason these soils are much more able to withstand drought without injury to the crops.

For purposes of this study these soils, and all soils in fact, may be divided into two classes: (1) Those which have tight subsoils and (2) those which have open or friable subsoils. In soils of the first group the rooting of the trees is limited to a shallow surface layer in which the moisture may and often does become exhausted and in which the plant food, if not supplied by fertilization, soon becomes depleted.

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[1] In Newton and Barry Counties, Mo., this soil was correlated as Hagerstown. In Greene County, Mo., it was called Crawford, but it has recently been given the name Newtonia.

Soils of the second class allow much deeper rooting, supply more abundant moisture, and permit of the use of much greater natural food supplies.

ROOT GROWTH OF FOREST TREES

Pioneers in this area regarded the native forest trees as indicators of soil conditions. Walnut, red and white oak, large elm, dogwood, and some other trees were recognized as indicators of good soil. Blackjack-oak land was not believed to be so good, and post-oak ridges and prairies were left for open range. Later settlers, in selecting sites for orchards, were less discriminating. The level surface of the prairies and of the post-oak ridges seemed to them especially favorable for orchard planting, and such areas were so used to a great extent.

The root development of the forest trees may be seen in many places in roadside cuts and at the base of upturned stumps, which have been pulled in the building of roads, or of trees uprooted by storms.

Although the prairies are normally grasslands, in many places around the edge of the prairies low-growing post oak and small black hickory trees have encroached. Where these have been pulled in road building the roots in many places are found to have grown down to the top of the impervious clay layer where they have spread out as a mass of fine rootlets. These grow along the top of the clay but not far into it and form brushlike masses resembling "witches brooms" or rosettes like those frequently seen on the branches of trees in an unhealthy condition. Upturned stumps of trees which have grown on the Lebanon soils show that the roots grow to the top of the hardpan but not far into it. (Pl. 2, B.) In striking contrast, roots of trees on soils having open subsoils may be found in many places growing to a depth of many feet. Even where the soil is very gravelly but not cemented the roots find their way between and through the gravel. (Pl. 3, A.)

RELATION OF SUBSOIL TO STAND AND SIZE OF TREES

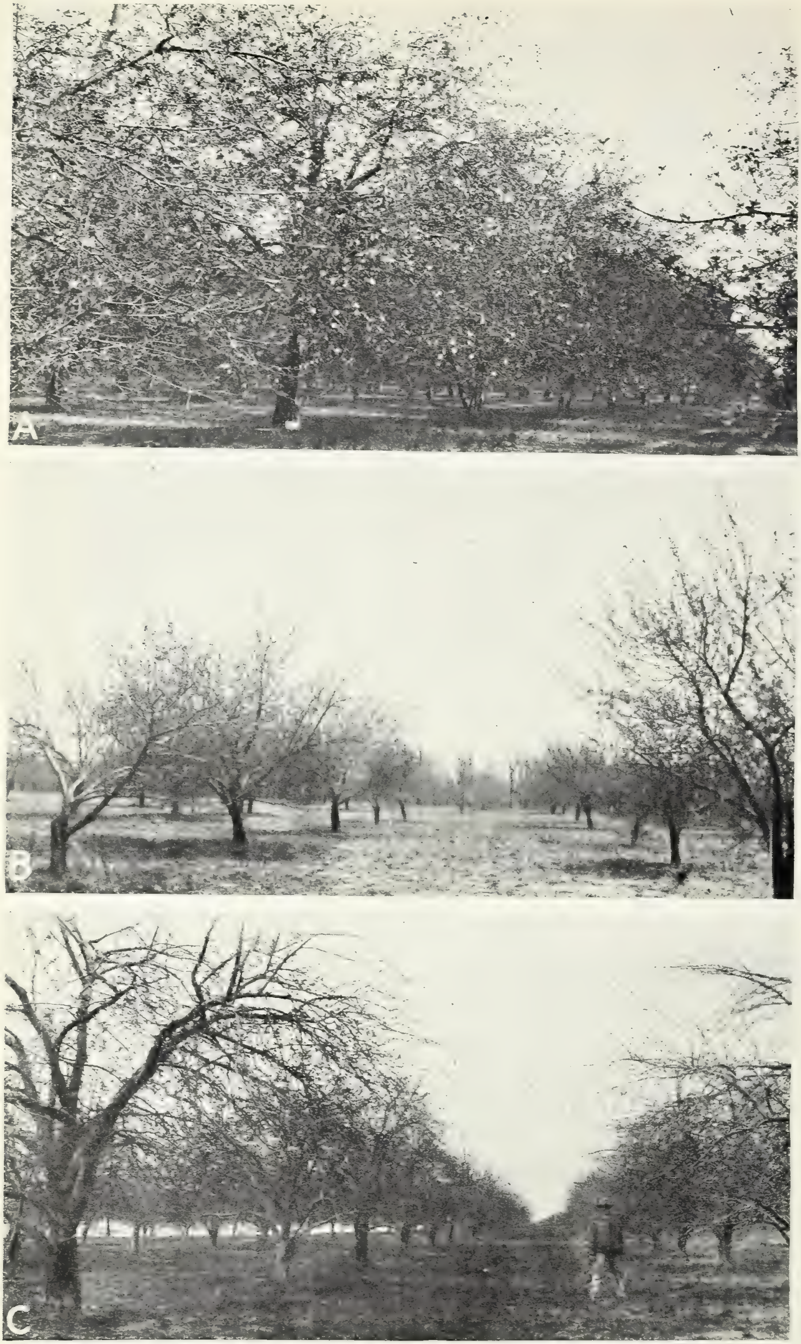
In order to determine the relation between subsoil and the stand and size of trees, counts to determine the percentage stand and measurement of trunks were made in a large number of orchards distributed through the area.

To determine the percentage stand orchards were selected in which the original plantings range in age between 15 and 25 years. In these, blocks of from 2 to 5 acres, as nearly as possible representative of the orchard as a whole, were selected and the trees of the original planting in fair or good bearing condition were counted. This number divided by the number originally planted was taken to represent the percentage stand of the orchard.

Where soil surveys had been made the soil type shown on the map was accepted in determining to which class the soils of the orchard belong. Where no such survey had been made the soil was examined to determine whether it had an open or tight subsoil.

Orchards were divided into two classes—commercial orchards in which the acreage ranges between 5 and 160 acres and domestic

A, Roots of a small red oak growing to a depth of 4 feet through the very gravelly subsoil of Baxter gravelly loam.
B, A 22-year-old commercial apple orchard on Gerald silt loam.



A, A 21-year-old commercial orchard on Newtonia silt loam.
B, Small 24-year-old commercial orchard on Lebanon soil with highly developed hardpan.
C, Commercial orchard (24 years old) on Baxter gravelly loam.

orchards in which the area is less than 5 acres. Three hundred orchards, more than one-half of which belonged to the commercial class, were counted. The average size of the orchards was about 30 acres.

The objection may be offered to these data that the stand of an apple orchard depends as much on the care which has been given it as on the soil on which it is planted. This is true, especially of orchards in the earlier stages of development. In the area studied there are good orchards which show a high percentage stand on soils of both groups and on each of the four principal soils considered. Some of the better orchards are on soils which are not most desirable for orchard planting, such as Gerald soil in which the clay layer is not highly developed or Lebanon soil where the hardpan has a deep soil covering. This is undoubtedly in a large measure due to good care and skillful handling. A poor stand may be due to disease, gnawing of rabbits, fire, or other causes, but a check of stand in a large number of orchards would determine if the subsoil is an important basic cause in determining the length of life and stand of trees.

The most striking fact brought out in this count is that the percentage stand in the area as a whole is low. Orchards seen from a distance or from the highway may seem to have a perfect stand, but on actual count many trees are found to be missing. The next most noticeable fact is that the percentage stand is lower in the small orchards than in the larger ones, due to the better attention given the larger orchards. Counts in the small orchards, however, gave much valuable information. In these the influence of soil conditions is more manifest than in orchards receiving better attention, and in most of them variation in stand can be traced directly to subsoil conditions.

The most striking variations in stand are on the Lebanon and Baxter soils. On Lebanon soils on top of ridges, where a highly developed hardpan lies near the surface, the stand is almost invariably poorest. Poor stands are frequently found on small areas of Baxter soils where the soil is very rocky or where underlying, unbroken chert beds are near the surface. In orchards planted partly on Baxter and partly on Lebanon soils the stand is better on the slopes where the Baxter soil occurs than on top of the divides or on flat areas which consist of Lebanon soil. In the Gerald soils the stands are usually poorest where the surface is extremely flat and drainage is poor. On the Newtonia soils there is much greater uniformity of stand than on the other soils. The subsoil conditions are the principal cause of lack of uniformity in stand.

Summarizing the results of these counts, the stand of orchards counted on different soils is as follows: Gerald soils, 70 per cent; Lebanon soils, 71 per cent; Baxter soils, 79 per cent; and Newtonia soils, 81 per cent. Soils having tight subsoils have 70.5 per cent of stand, whereas those having open subsoils have 80 per cent.

The size and appearance of the trees on soils having open subsoils, as compared with those on soils having tight subsoils, are even more striking than the difference in stand. Even in orchards which have received good care there is a close relation between the size of trees, diameter of trunk, and normal limb spread and subsoil conditions.

Trees planted on soils having deep, open, well-drained subsoils have larger and better-developed trunks, broader limb spread, and a much better general appearance than do trees planted on soils with tight subsoils. This is partly the result of having better surface soil which usually accompanies a well-drained subsoil. Variations in size of trees may in some places be due to differences in varieties, but where the same variety is grown on different soils the influence of the subsoil is noticeable.

Variations can best be illustrated by concrete examples. Near Sweetwater, in Newton County, Mo., a commercial orchard planted 24 years ago has not received good care. The main part of the orchard occupies the smooth top of a ridge. The soil is Lebanon, is shallow, and has a highly developed hardpan. Here the stand is poor, and the trees are small and stunted, with trunks averaging only 6 inches in diameter. On a slight slope in one part of the orchard the soil is a poor grade of Baxter gravelly loam. Here the stand of trees is better, the limb spread is broader, and the trunks average about 10 inches in diameter. Across the road on a better grade of Baxter gravelly loam in a fairly well cared for domestic orchard two years younger the stand is almost perfect and the trunks average about 12 inches in diameter.

South of Fairview in Newton County, Mo., a small commercial orchard 20 years old is partly on Gerald silt loam and partly on a poor grade of Baxter soil. In the entire orchard the trees are of the same variety and have received the same care. Trees on the Gerald soil have a small limb spread and average only 7 inches in diameter, whereas those on the Baxter soil have a much wider limb spread, average 10 inches in diameter, and bloom earlier.

On a small flat prairie northwest of Mount Vernon in Lawrence County, Mo., where the clay layer of the Gerald soil is very tight and impervious, a 20-acre apple orchard was planted 22 years ago and has received fair attention. The trees average only about 7 inches in diameter and have a small limb spread. (Pl. 3, B.)

Twenty-one years ago a commercial orchard was planted on Newtonia soil near Marionville, Lawrence County, Mo., and has received good care. It now has an almost perfect stand, and the trees have broad limb spread and trunks which average about 13 inches in diameter. (Pl. 4, A.)

Near Waddell in Newton County, Mo., a small commercial orchard was planted about 24 years ago on a post-oak flat with highly developed hardpan. Although the trees have received fair attention, the percentage stand is very low. The trees are small, with trunks that average only 6 or 8 inches in diameter. (Pl. 4, B.) The same year a commercial orchard was planted on very gravelly Baxter soil south of Aurora, Lawrence County, Mo., and received very good care. The percentage stand is high, the limb spread broad, and the trunks have an average diameter of about 13 inches. (Pl. 4, C.)

Examples of this kind showing the striking contrasts between orchards planted on soils with tight subsoils and with open subsoils are to be found throughout the area.

In these studies no attempt was made to collect data on yields or quality of fruit. The yield, however, is certainly much larger where the trees have been planted on the better soils. The general opinion expressed by orchardists is that the fruit is more highly colored and probably better flavored on good soils than on the poorer soils, especially the Gerald soils.

Ben Davis and Gano varieties were extensively planted in this area from 20 to 25 years ago, and most of the trees examined were of these varieties. However, a number of orchards of York Imperial, Jonathan, Winesap, and others were included, and the same relation was found between subsoil and the growth of trees.

SUBSOIL AND ROOT DEVELOPMENT OF APPLE TREES

In order to determine the effect of subsoil conditions on the root development of apple trees a further study was made. For this purpose there were selected apple orchards, situated on representative soils, in which the trees were between 20 and 25 years of age and had made a good normal growth. In each of these orchards a straight-walled excavation 30 by 48 inches was made. The soil was removed by layers, and from each layer the apple roots were carefully picked out, placed in paper bags, and numbered. Later they were washed, dried, and weighed. A few excavations were made near the trunks of trees and a few midway between four trees. The greater number, however, were made beneath the outer limb spread, in most places between 10 and 15 feet from the trunk, and these were made the standard for comparison. Forty such excavations, ranging in depth from 18 inches to 12 feet, were made.

The trees examined had trunks between 8 and 13 inches in diameter at the base. They had no central or tap roots but sent out from three to five large roots laterally a few inches below the surface. The largest roots exposed in the excavations were only from 2 to 4 inches in diameter near the trees, and 3 or 4 feet from the trunk they tapered to half that size. Roots 1 inch in diameter at the outer limb spread were rare. With the exception of these few larger roots and their main branches, the rootlets range in diameter from that of a lead pencil to that of a very fine thread. Small roots, however, are numerous, and when dry they weigh but little. This accounts for the very small weight of roots in the deeper layers.

These excavations afforded an excellent opportunity for study of methods of root growth and penetration. Apple-tree roots respond in a remarkable way to environment. They seem as sensitive to soil conditions as plants above ground are to heat and light. When the surface soil is broken apart masses of tender, light-colored rootlets are shown. These spread from ganglionlike centers and are so delicate that they are completely dried out by a few minutes' exposure to sun and air. Loose soil along old root channels, mellow soil where animals have burrowed, or surface soil covering draintile seems to be sought out and followed. Wormholes and cavities made by ants and other insects form tunnels which in places are almost completely filled with rootlets. The bark of oak roots from which the wood has decayed forms hollow cables inclosing small rootlets for long distances. Where porous chert is reached small roots wedge themselves between the masses, penetrate cavities, and spread a network of fine rootlets over the smooth surface, pushing their way between rocks and the surrounding clay.

It is a popular belief that the lateral root development of a tree corresponds closely to its limb spread, but these excavations indicate that it is probably much greater. Ideas of depth of root penetration are usually vague. Experienced orchardists expressed the opinion that midway between trees such as were examined roots would be found only within a few inches of the surface. Nearer the trees they thought they might extend to a depth of possibly 3 feet. Excavations in soils favorable for deep rooting showed at the outer limb spread roots at a depth of 8 feet, and midway between four trees, more than 20 feet from the trunks, roots 5 feet or more deep. These deeper rootlets in many places seem nearly free from feeder rootlets, but in some places small white rootlets which were apparently growing were found many feet below the surface when the tree above ground was dormant and the ground frozen.

In the Gerald soils it was found that where the clay layer is slightly friable and less tough and plastic than in the typical soil, the roots not only penetrate this layer but seem to make a larger growth below the tight clay than in it. On the other hand, where the clay layer is highly developed the roots do not reach far into it. Where there is a well-developed cemented hardpan a few roots grow for some distance into it but not through it.

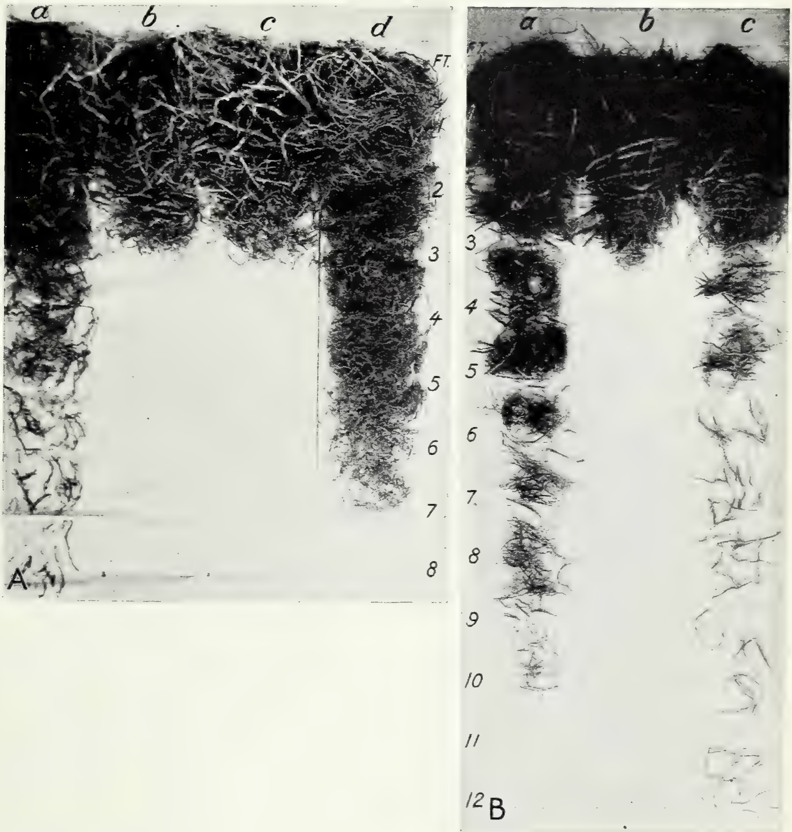
Since the downward development of roots in the Gerald and Lebanon soils is restricted by impervious subsoils, it might be concluded that lateral development would be correspondingly greater. In the trees examined, this was not the case. On the contrary, lateral development of roots on soils with tight subsoils seems to be less than on soils with open subsoils.

One other important observation was made. In soils having deep, well-drained subsoils all roots examined were found to be in a live, healthy condition. Even those which had become flattened and twisted in pushing through gravel had the reddish-brown bark and white inner layers characteristic of healthy roots. On the other hand, in the wet, poorly drained, and poorly aerated subsoils above impervious layers, many small dead roots were found. Numerous other roots were in an unhealthy condition, having enlargements from which grew masses of short fine rootlets.

In excavations made in soils having tight subsoils practically all roots were found within a soil layer extending from the surface to a depth of about 30 inches. In soils having open subsoils this layer, penetrated by the roots, was found to be more than twice as deep.

At a conservative estimate, each tree 20 or 25 years old planted on soil with open subsoil is able to draw on the moisture and plant-food resources of 5,000 cubic feet of soil. Trees of the same age planted on land with a tight subsoil are able to draw moisture and food from less than half that volume. In the area studied, an abundance of both the Baxter and Newtonia soils is available for orchard planting, but plantings are still being made on the less desirable soils.

The following tabulations give the weight of dry roots taken from excavations 30 by 48 inches in size, beneath the outer limb spread of trees. Each is fairly representative of all trees on similar soils where excavations were made.



A, Roots of apple trees placed in relative position from which taken.
B, Roots of apple trees placed to show depth of penetration.

Weight of dry roots in Newtonia silt loam 1½ miles north of Lowell, Ark. Tree 20 years old and 11½ inches in diameter.

Inches	Ounces
0 to 8	19
8 to 15	16¾
15 to 30	7¾
30 to 44	3
44 to 60	⅞
60 to 84	¾
84 to 96	¼
96 to 103	⅛

Weight of dry roots in Baxter gravelly loam, near McDowell, Barry County, Mo. Tree 25 years old, 12 inches in diameter.

Inches	Ounces
0 to 8	6
8 to 16	2½
16 to 30	2
30 to 45	1½
45 to 50	¾
50 to 70	¾
70 to 75	¼

Weight of dry roots in Lebanon silt loam, 6 miles west of Bentonville, Ark. Tree 23 years old, 8½ inches in diameter.

Inches	Ounces
0 to 10	12
10 to 17	6
17 to 30	5½
30 to 36	¾

Weight of dry roots in Gerald silt loam near Phelps, Lawrence County, Mo. Tree 23 years old, 9 inches in diameter.

Inches	Ounces
0 to 10	9
10 to 18	5½
18 to 24	14
24 to 30	¾

Wide variation in the weight of roots in the upper soil layers may be due to the presence or absence of large roots which happen to occupy the area excavated or may be due to heavy applications of manure which have stimulated heavy root growth near the surface. The depth of penetration into the deeper subsoil, even by very small rootlets which weigh but little when dry, is considered of much more importance.

From the foregoing tabulations it will be noted that in the Newtonia soils roots were found to a depth of more than 8 feet and in the Baxter soils to a depth of more than 6 feet, but that in the Lebanon soils they were found to a depth of only 3 feet and in the Gerald soils to a depth of only 30 inches.

It will also be noted that in the Newtonia and Baxter soils there is a fairly constant decrease in root growth downward, but that in the Lebanon and Gerald soils there is a tendency for development of heavy root growth immediately above the claypan or the hardpan, with a slight growth but a short distance below the impervious layer.

The roots from two 20-year-old trees, (*a* and *d*), which grew on Newtonia soils in comparison with two trees, (*b* and *c*), which grew on Lebanon soils are shown in Plate 5, A. (*a*, *b*, and *c*, Ben Davis, and *d*, Wealthy.) The roots were taken beneath the outer limb spread, from an excavation measuring 30 by 48 inches, were washed, dried, and arranged in the position in which they were taken from the ground, the depth being indicated in feet on the margin of the cut. Downward growth of roots in *a* was checked by a very heavy bed of gravel and in *d* by a layer of solid limestone. In *b* and *c*, downward growth was completely stopped by the hardpan of the Lebanon soils. In all excavations made in the Ozark area, even in the Baxter and Newtonia soils where roots were found to a depth ranging from 6 to more than 8 feet, downward growth seemed to be stopped by chert or limestone beds.

In order to determine if possible how deeply apple-tree roots might grow under the most favorable subsoil conditions and if heavy clay subsoils restrict deep growth in other regions as in the Ozarks, a few excavations were made in Knox silt loam, Grundy silt loam, and Summit clay loam in Jackson County, Mo.

Knox silt loam has a subsoil of uniform, open, silty texture to a great depth and is a productive apple soil. Grundy silt loam and Summit clay loam have heavy, compact clay subsoils and are used to a much less extent for apple growing. In Knox silt loam roots of trees from 20 to 25 years old, at the outer limb spread, were found to a depth of more than 12 feet and many probably grow much deeper. Maximum depth of penetration in the Grundy and Summit soils, on the other hand, was only about 40 inches. (Pl. 5, B.) The excavation, the roots from which are shown in Plate 5, B *a*, was extended to a depth of only 10 feet, but several roots were cut off in the bottom and undoubtedly go much deeper. Roots in *a* are from a Jonathan apple tree 20 years old, in *b* from a Jonathan probably nearly 30 years old, and in *c* from a Ben Davis about 25 years old. Roots shown in *a* and *c* are from trees on Knox silt loam and in *b* from Summit clay loam. The roots were treated as were those shown in Plate 5, A.

CONCLUSIONS

This study gives conclusive evidence that in the Ozark area of southwest Missouri and northwest Arkansas there is a very definite relation between subsoil conditions and the growth of apple trees; that on soils having open subsoils the tree roots penetrate deeper and that trees grow larger, produce better, and live longer than on soils with tight subsoils; that under favorable subsoil conditions apple trees root deeply, a tree 20 years old sending its roots into and commanding the moisture and plant-food resources of at least 5,000 cubic feet of soil, whereas on soil with a tight subsoil the supply volume is less than half as great; that root diseases are in many places an accompaniment of bad subsoil conditions; that in this area soils unsuited for orchard planting have been so used largely on account of their level surface, ease of cultivation, and sightliness rather than because of lack of better soils, of which there is a great abundance; and that the same differences in root development of trees in orchards planted on soils with open subsoils and on soils with tight subsoils exist in other areas as well as in the Ozarks.

The study, while calling attention to the importance of good care, emphasizes the fact that control of disease, cultivation, and fertilization, which may seem to overcome the handicap of tight subsoil when the orchard is young, can not overcome it as the trees become older and their demands greater.

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