CHAPTER II

SAMPLING

Owing to the marked differences between its major physiographic divisions, the State of Tennessee offers especial opportunity and favoring conditions for a study of the relation of plant and soil composition. Extending, as it does, from the Mississippi River eastward to the very summits of the Appalachian Mountains it presents many outstanding phases of physiographic and geologic structure accompanied by an equally marked variety in its soil classifications.

The systematic study of the geology of the state began with the appointment, in 1831, of Gerard Troost, professor of geology, mineralogy, and chemistry in the University of Nashville, as State Geologist. During his term of office Professor Troost[17] published a number of reports dealing with the geology of the state. His studies dealt largely with the paleontology of the region rather than its structural geology.

Safford,[18, 19] Curry,[20] Killebrew,[21] Ulrich,[22] and Jones[23] laid the foundation for our present-day knowledge of the structural geology of the state.

Modern knowledge of the stratigraphy of Tennessee begins with the work of Hayes and Ulrich.[24]

The latest and most authoritative publication is by Bassler,[25] who deals particularly with the Central Basin but correlates it with the other physiographic regions of the state.

In this study the soil and wood samples were selected on the basis of the major physiographic provinces. These differ fundamentally in their geological formations.[26] Safford recognized and named seven

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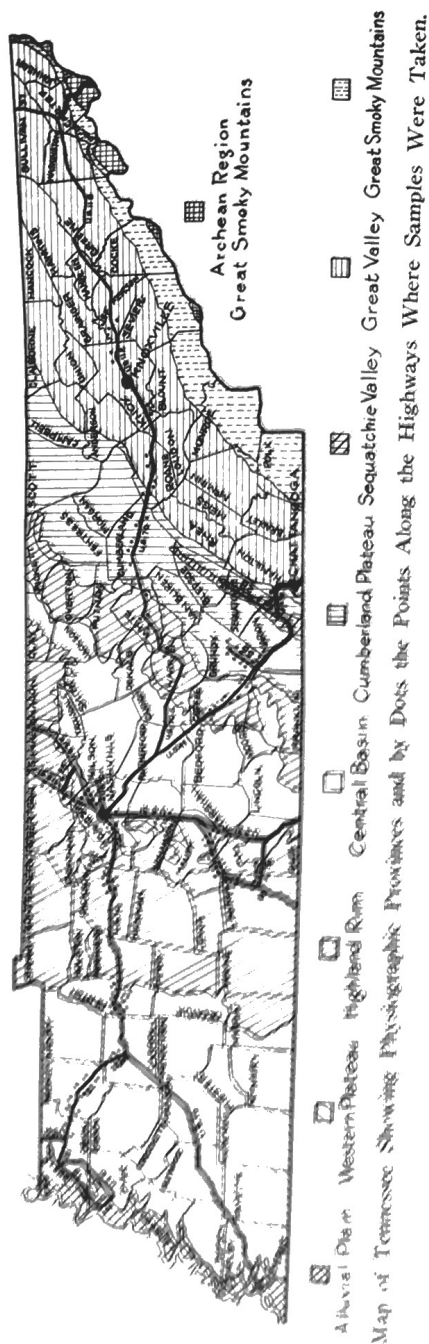
[22]Ulrich, E. O. 1888. A Correlation of the Lower Silurian Horizons of Tennessee. *The American Geologist.*

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Map of Tennessee Showing Physiographic Provinces and by Dots the Points Along the Highways Where Samples Were Taken.

Alluvial Plain   Western Plateau   Highland Rim   Central Basin   Cumberland Plateau   Sequatchie Valley   Great Valley   Great Smoky Mountains   Archean Region Great Smoky Mountains

of these provinces and his naming has been retained by all geologists who followed him.

SOIL SAMPLES

THE GREAT SMOKY MOUNTAINS

The Great Smoky Mountains are the easternmost of the physiographic divisions of Tennessee. This great uplift was formerly known as the Unaka Range, but Parkins and Glenn[27] suggested that the entire region be known as the Great Smoky Mountains with special names for local areas.

This geological province is the most rugged part of the state, including, as it does, the western ranges and rough lands of the Southern Appalachian System in Tennessee and North Carolina. This great mass, rising to altitudes from 4,000 to 6,500 feet above sea level and averaging twenty or more miles in width, is largely a metamorphic formation with igneous outcrops in some localities.

The rocks are largely granite, gneiss, schist, shale, slate, conglomerate and quartzite of Cambrian or pre-Cambrian origin.[28]

A number of Archean outcrops are found in the Great Smoky region. The most extensive is around Roan Mountain in the southern part of Carter County. Here the rocks are all crystalline, consisting of granites, gneisses, and schists.

The sandstones, quartzites, and conglomerates of the region form sandy and rocky soils. The slates and shales weather more readily into dark, clayey soils. In the Archean formations the schists form yellow, red, and brown clay soils and granite and gneisses form light-colored, porous, gravelly soils. In the Archean soils calcium is present only in minute quantities and, consequently, the p_H is very low, the soils being strongly acid. Fifteen samples were taken from the Roan Mountain region.

THE GREAT VALLEY OF EAST TENNESSEE

An eroded area of some forty-five miles in width and extending from northeast to southwest across the state between the Great Smoky Mountains on the east and the Cumberland Plateau on the west forms the Great Valley of Tennessee. South of Knoxville it is a fluted region of long, narrow ridges with somewhat wider intervening valleys running parallel to the Great Smoky Mountains. The ridges rise 1,000 to 1,300 feet above sea level and the valleys are some 100 to 200 feet lower. The underlying strata are sedimentary rocks of Paleozoic, mainly Ordovician, or Cambrian, age.

Tremendous pressure exerted on these strata has resulted in a series of sharply folded anticlines and synclines with much faulting. This

folding and faulting must have taken place slowly as erosion has, in many cases, entirely removed the anticlines.

The rock strata of the valleys are largely Knox dolomite and Chickamauga limestone. Many of the hills are sandstone and siliceous shale. The erosion of the soluble limestone and the resistance offered by the sandstones and shales have resulted in the succession of parallel ridges and valleys.

North of Knoxville, the Great Valley is somewhat wider and the exposures likewise are wider. On the northwest are the Clinch and Stone Mountains and on the southeast that part of the Great Smoky Range called the Bay Mountains. The fluted condition, so pronounced south of Knoxville, is not so evident. The valley is cut lengthwise by the Holston River, on either side of which are rather wide plateau regions and rolling hills.

The underlying rock formations are similar to those of the fluted region. In the valleys are found dolomite, limestone, and some shale. On the upland, bluish shales and sandstone predominate.

The soils of the Great Valley differ with the rock formations from which they are derived. Along the edges of the Valley the soil characteristics have been much modified by the deposition of materials carried down from the adjacent highlands. Clay soils are found in those valleys that are underlaid with limestone, dolomite, and Cambrian shale. The dolomite yields a cherty soil. On those hilltops that are underlaid with sandstones and shales, the soil is thin and, in many cases, the rock materials are not fully weathered down to soil. This soil contains much sand and shaly materials. The soils of the Valley north of Knoxville are derived from the same kinds of rocks as those of the fluted region. The limestone, dolomite, and shales are much more deeply weathered. In many localities the soil is a deeper red than is found south of Knoxville.

Fourteen samples were taken from the Great Valley. Of these ten were taken along U. S. Highway 70 between Rockwood and Knoxville, and four along U. S. Highway 11 from Knoxville to Greeneville. These samples represented the various soil types as sandstones, shales, limestones, and dolomite.

THE CUMBERLAND PLATEAU

The Cumberland Plateau lies on the west side of the Great Valley. It is a tableland[29] rising 2,000 or more feet above sea level and extending entirely across the state from northeast to southwest. Along U. S. Highway 70 the width is approximately 50 miles. The southern half of the plateau is split longitudinally by the Sequatchie Valley.

This upland is, geographically and geologically, a part of the Appalachian Plateaus which extend in a southwest direction through Pennsylvania, West Virginia, Kentucky, and Tennessee into Ala-

[29]Bassler, *op. cit.*, p. 13.

bama.[30] Its eastern edge is a high escarpment known as Walden's Ridge. The western edge has been deeply eroded by streams flowing across its margin. The steep ridges thus produced extend out onto the Highland Rim and are known as the Cumberland Mountains.

Geologically the region is Paleozoic. The surface rocks are chiefly sandstone of the Walden and Lookout formations. In places conglomerates and shales of the Pennsylvanian age are on the surface. Beneath the sandstones, shales, and conglomerates are beds of Mississippian limestone which are exposed in deep valleys cut into the tableland.

The great upthrust of the strata in the eastern part of the Plateau, isolated by the erosion of the Sequatchie anticline, and known as Walden's Ridge, has been eroded down more than 1,500 feet below its original height, resulting in the exposure on the surface of Bangor limestone. From Walden's Ridge the Plateau gradually slopes downward to the west to the escarpment, below which is the Highland Rim.

The rocks of the Cumberland Plateau are sedimentary, mostly sandstone and conglomerate. The lime, if ever present, has been leached out, leaving the insoluble siliceous base materials. The major portion of the area is covered with a sandy soil derived from the Walden and Lookout sandstones. In places some chert is mixed with the sand. Along Daddy's Creek and Mammy's Creek some alluvial deposits are found. Even this alluvial soil is almost entirely devoid of calcium compounds. Where erosion has exposed the Bangor limstones on Walden's Ridge calcareous soils are found. Owing to the nature of the bedrock and the leaching to which the province has been subjected, the soils have a low pH value.

Ten samples were taken on Cumberland Mountain near Monteagle. Of these eight were along State Highway 56 and two along U. S. Highway 41. Five samples were taken along U. S. Highway 41 on Walden's Ridge north of Chattanooga. From Bon Air to Ozone on U. S. Highway 70, ten samples were taken.

THE HIGHLAND RIM

The Highland Rim province has an area of 9,300 square miles, being the most extensive physiographic province in the state. It encircles the Central Basin, its surface being 300 to 500 feet above the latter and its average altitude being about 1,000 feet above sea level.

The rim is usually divided, according to its relation to the Central Basin, into the eastern, northern, and western portions. On the south the rim does not show in Tennessee, for the Central Basin extends through the valley of Elk River into Alabama. The formations of the Rim are all of the upper Paleozoic era, the surface formations being of the Mississippian system.[31] Underlying practically all

[30]Emerson, F. V. 1928. *Agricultural Geology,* p. 320. Chapman & Hall, London.

[31]Bassler, *op. cit.*, p. 15.

the region and outcropping on the escarpments overlooking the Central Basin are Warsaw, St. Louis, and Fort Payne limestones.

The eastern Highland Rim extends from the western foot of the Cumberland Plateau westward to the Central Basin. In places it is deeply cut by streams coming down from the Plateau.

The surface rock of the western portion of the eastern rim is largely the highly siliceous Fort Payne limestone. Further east the St. Louis limestone outcrops. This is a distinctly pure limestone and rather easily soluble.

The northern and western portions of the Highland Rim are much more deeply weathered and maturely dissected than is the eastern rim. On the inner edge there is a narrow fringe of Fort Payne chert with its characteristic "Barrens" and broader areas of St. Louis limestone back of it.

The soils of the rim give indisputable evidence of their origin. The siliceous Fort Payne limestone can be easily located by its weathered products, hard, angular pieces of chert in gray or almost white siliceous soil. This soil is waxy in consistency and almost devoid of calcium. Its pH is very low.

The soluble St. Louis limestone weathers to a deep red soil. This belt of red soil extends clear around the rim. On the north it is found about a mile south of White House. On the west it occurs just east of Burns. It is found about five miles north of Lawrenceburg and a mile south of Manchester. The highway crosses it or runs parallel to it from McMinnville to Sparta.

A number of soil samples were taken from each of these red soil localities. This red soil is very rich in iron and if there is any relation between the iron in the soil and the iron in the plant, one should be able to show a correlation from this red strip.

A total of forty-two samples was taken from the Highland Rim. Of these six were from the north, along Highway 25 and 31W, six from the west along Highway 70, twelve from the southwest along Highway 6, eight were from the southeast along Highway 31 and ten were from the eastern rim along Highway 70S.

THE CENTRAL BASIN

The Central Basin lies wholly within the Highland Rim. It extends lengthwise across the state from north to south. It is about 120 miles long from northeast to southwest and about 60 miles wide. Its margin is extremely irregular for the escarpment marking the junction of rim and basin has been deeply eroded. Outlying hills and residual knobs, left standing in the basin by the eroding back of the rim, are numerous.

The similarity of the Central Basin to the bed of a drained lake has led many geologists to regard it as such, but Bassler[32] says all the

[32]*Bassler, op. cit., p.* 16.

evidence points to its formation by the erosion of the rocks that once formed a plateau extending from the top of the eastern Highland Rim to the western. That is, the basin has been formed by the eroding away of the rim.

The surface rock of the Central Basin is Paleozoic, being largely Ordovician though the formations range from Ordovician to Mississippian.

Physically, the Sequatchie Valley is in no way connected with the Central Basin. It is a long, narrow cut in the Cumberland Plateau extending from the central part of the plateau southward to the Alabama state line. Geologically it is very like the Central Basin. It has been formed by erosion of the plateau down to the Ordovician limestones that are exposed in the basin. The bottom of the Sequatchie Valley and the bottom of the Central Basin are the same Ordovician formations.

The soil of the Central Basin is generally a brown-colored limestone soil. In some sections it is red. In some places beds of phosphate are abundant. Much of the soil is rich in potash. In the Sequatchie Valley the soil is also rich in lime and is brown to reddish-brown in color.

A total of twenty-five samples were taken from the Central Basin and seven samples were taken from the Sequatchie Valley. In the basin ten samples were taken north of Nashville, four samples along Highway 70W, five samples from the phosphate region around Mt. Pleasant, and five along the highway between Nashville and Columbia. In the Sequatchie Valley seven samples were taken north of Jasper.

THE PLATEAU OF WEST TENNESSEE

This province has for its eastern margin the hills of the Highland Rim bordering the Tennessee River flowing northward across the state. Its western border is the bluffs overlooking the Mississippi flood plain. The surface has a gentle slope westward. It is not deeply eroded and many of the streams are marshy. The formations are largely of recent geologic age, being Cretaceous, Tertiary, and Quarternary. However, outcrops of Devonian are to be found in places along the Tennessee River. The soils are sands, silt loams, and clays. Between McKenzie and Huntingdon the soil is a deep red, but in other sections of the province it is light or dark brown. In the Devonian exposure between Camden and the Tennessee River the soil is heavily laden with chert and contains little calcium. Twenty-four samples were taken from the region, ten of them being from the Devonian outcrop.

The Devonian formations are exposed in the "Harpeth Narrows," where the Harpeth River cuts through the Highland rim to the Cumberland River. Eight samples were taken from this locality and have been considered with the other Devonian samples.

MISSISSIPPI ALLUVIAL PLAIN

This narrow area is the most western physiographic province in the state. It is that portion of the alluvial flood plain of the Mississippi River lying on the eastern side of the stream. Its soil is alluvial. In places there is sand, but much of it is black, sticky soil, often called gumbo. It is slightly deficient in lime and so is slightly acid. Seven samples were taken from this province.

WOOD SAMPLES

Molisch[33] says that iron is found throughout the plant kingdom, but that usually it is in such small quantities that it cannot be determined by the ordinary tests. Hoffer[34] found that, in the corn plant, the iron content of the nodes was higher than was that of the internodes.

In this study it was decided to use wood as the plant tissue on which determinations of iron were to be made. Leroux and Leroux[35] have shown that the leaves of woody plants hold the most iron. However, leaves are rather evanescent things and, quite likely, their composition reflects the seasonal conditions under which they grow. Wood from the trunk of the tree was used for two reasons: first, any effect on the composition that might result from abnormal seasonal conditions could be offset by using wood having from four to six years growth in it. Second, if an antagonism exists between the calcium in the soil and the iron in the wood, one would expect the one to be replaced by the other. Uniformly, calcium is highest in the trunk of the tree. In case of a calcium deficiency in the soil, does the tree replace its calcium in part, at least, with iron?

TABLE 1

Ash and Iron Content of Woods

Name of Wood	Ash (with 10% H_2O)	Ash (Dry)	Fe_2O_3 in Ash	Fe_2O_3 in Wood	Fe in Wood
	%	%	%	%	%
Red Oak	.85	.94	0.21	.0020	.0014
White Oak	.37	.41	0.50	.0020	.0014
Yellow Pine	.55	.40	0.18	.0007	.0005
Long Leaf Pine	.41	.56	2.76	.0154	.0108
White Ash	.46	.48	2.92	.0140	.0098
Chestnut	.22	.24	2.65	.0064	.0044

[33]Molisch, Hans. 1913. *Michrochemie der Pflanze*, p. 39.
[34]Hoffer, *op. cit.*
[35]Leroux and Leroux, *op. cit.*

There is very little information available on the iron content of woods. Perhaps the most reliable data is found in the work of White[36] who gives the percentage of iron in wood ashes and the percentage of ash in the wood. From his figures it is possible to calculate the per cent of iron originally present in the wood. Such calculation has been made in table 1 which is based on White's figures.

The accuracy of his results may be questioned. He did not determine the amount of iron in the wood directly, but found it indirectly by calculation. At the time he did his work (1889) laboratory technics in michrochemistry had not been developed that would make possible a direct determination.

Campbell[37] found that the Osage orange is almost devoid of iron.

Oak wood was chosen for this study. White had shown that it contains fairly large quantities of iron and that, probably, the iron content of the different oaks was approximately the same. A second reason for choosing oak is that it is found very generally in all the physiographic provinces of Tennessee, while many other varieties of wood are indigenous to certain provinces only.

METHOD OF SAMPLING

Wood.—Wood samples were taken by cutting a cross-section from a young oak tree having from four to ten annular rings. This section was then sawed into pieces one-half to three-quarters inch in length. The ten gram sample was split out of these pieces.

Soil.—Soil samples were taken with a soil auger. Borings were made two feet deep where underground rock conditions would permit. If the rock was within two feet of the surface, the borings were made down to rock. Any leaves and other materials on the surface were removed. All the material from the borehole was saved, carefully mixed, and quartered down to a 100 gm. sample. From this sample the tests were run. Care was taken not to obtain samples where the soil had been disturbed or modified by grading, excavating, sliding, fertilizing, or other activity that might change it from its natural composition or position.

SUMMARY OF SAMPLING

The samples used in this study were secured on the basis of the major physiographic provinces of Tennessee. The soils of each province reflect the geology of the province in a very striking way.

One hundred and sixty-six samples were collected. They were distributed as follows: Great Smoky Mountains (Roan Mountain region), 15 samples; Great Valley of Tennessee, 14 samples; Cumberland Plateau, 25 samples; Highland Rim, 42 samples; Central Basin

[36]White, H. C. 1889. *Ash Analyses of Native Woods. Georgia Experiment Station, Bulletin 2.*
[37]Campbell, Carl G. 1931. *The Analysis of the Osage Orange.* Unpublished study at George Peabody College for Teachers. Nashville, Tenn.

calcium varies directly with the soil calcium and in cases of a calcium deficiency the plant may substitute some other metal for the calcium.

The distribution of iron in a plant has also received attention.

This study was made to determine what relationship, if any, exists between the pH, the organic matter, the iron, and the calcium of a soil and the iron in a plant growing in the soil.

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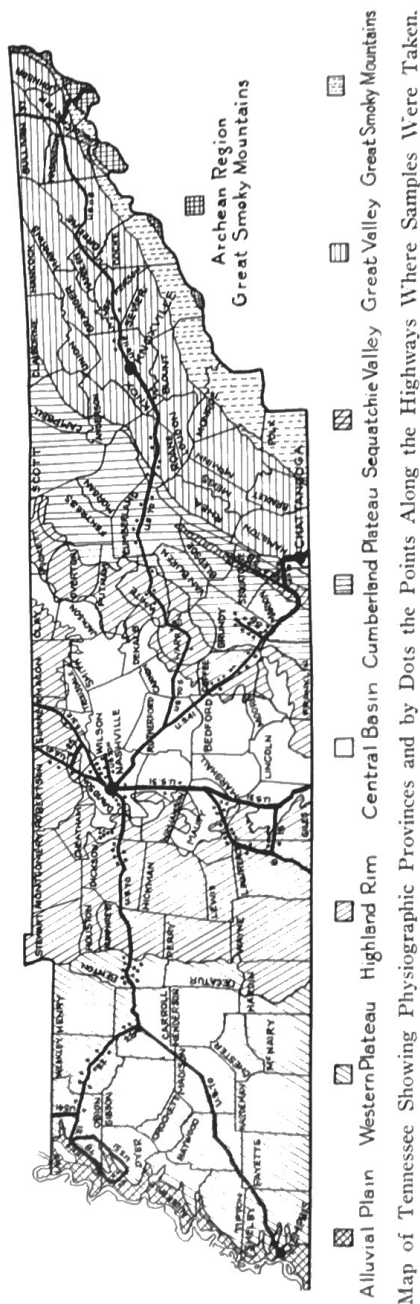
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The eastern Highland Rim extends from the western foot of the Cumberland Plateau westward to the Central Basin. In places it is deeply cut by streams coming down from the Plateau.

The surface rock of the western portion of the eastern rim is largely the highly siliceous Fort Payne limestone. Further east the St. Louis limestone outcrops. This is a distinctly pure limestone and rather easily soluble.

The northern and western portions of the Highland Rim are much more deeply weathered and maturely dissected than is the eastern rim. On the inner edge there is a narrow fringe of Fort Payne chert with its characteristic "Barrens" and broader areas of St. Louis limestone back of it.

The soils of the rim give indisputable evidence of their origin. The siliceous Fort Payne limestone can be easily located by its weathered products, hard, angular pieces of chert in gray or almost white siliceous soil. This soil is waxy in consistency and almost devoid of calcium. Its pH is very low.

The soluble St. Louis limestone weathers to a deep red soil. This belt of red soil extends clear around the rim. On the north it is found about a mile south of White House. On the west it occurs just east of Burns. It is found about five miles north of Lawrenceburg and a mile south of Manchester. The highway crosses it or runs parallel to it from McMinnville to Sparta.

A number of soil samples were taken from each of these red soil localities. This red soil is very rich in iron and if there is any relation between the iron in the soil and the iron in the plant, one should be able to show a correlation from this red strip.

A total of forty-two samples was taken from the Highland Rim. Of these six were from the north, along Highway 25 and 31W, six from the west along Highway 70, twelve from the southwest along Highway 6, eight were from the southeast along Highway 31 and ten were from the eastern rim along Highway 70S.

THE CENTRAL BASIN

The Central Basin lies wholly within the Highland Rim. It extends lengthwise across the state from north to south. It is about 120 miles long from northeast to southwest and about 60 miles wide. Its margin is extremely irregular for the escarpment marking the junction of rim and basin has been deeply eroded. Outlying hills and residual knobs, left standing in the basin by the eroding back of the rim, are numerous.

The similarity of the Central Basin to the bed of a drained lake has led many geologists to regard it as such, but Bassler[32] says all the

[32] Bassler, *op. cit.*, p. 16.

evidence points to its formation by the erosion of the rocks that once formed a plateau extending from the top of the eastern Highland Rim to the western. That is, the basin has been formed by the eroding away of the rim.

The surface rock of the Central Basin is Paleozoic, being largely Ordovician though the formations range from Ordovician to Mississippian.

Physically, the Sequatchie Valley is in no way connected with the Central Basin. It is a long, narrow cut in the Cumberland Plateau extending from the central part of the plateau southward to the Alabama state line. Geologically it is very like the Central Basin. It has been formed by erosion of the plateau down to the Ordovician limestones that are exposed in the basin. The bottom of the Sequatchie Valley and the bottom of the Central Basin are the same Ordovician formations.

The soil of the Central Basin is generally a brown-colored limestone soil. In some sections it is red. In some places beds of phosphate are abundant. Much of the soil is rich in potash. In the Sequatchie Valley the soil is also rich in lime and is brown to reddish-brown in color.

A total of twenty-five samples were taken from the Central Basin and seven samples were taken from the Sequatchie Valley. In the basin ten samples were taken north of Nashville, four samples along Highway 70W, five samples from the phosphate region arount Mt. Pleasant, and five along the highway between Nashville and Columbia. In the Sequatchie Valley seven samples were taken north of Jasper.

THE PLATEAU OF WEST TENNESSEE

This province has for its eastern margin the hills of the Highland Rim bordering the Tennessee River flowing northward across the state. Its western border is the bluffs overlooking the Mississippi flood plain. The surface has a gentle slope westward. It is not deeply eroded and many of the streams are marshy. The formations are largely of recent geologic age, being Cretaceous, Tertiary, and Quarternary. However, outcrops of Devonian are to be found in places along the Tennessee River. The soils are sands, silt loams, and clays. Between McKenzie and Huntingdon the soil is a deep red, but in other sections of the province it is light or dark brown. In the Devonian exposure between Camden and the Tennessee River the soil is heavily laden with chert and contains little calcium. Twenty-four samples were taken from the region, ten of them being from the Devonian outcrop.

The Devonian formations are exposed in the "Harpeth Narrows," where the Harpeth River cuts through the Highland rim to the Cumberland River. Eight samples were taken from this locality and have been considered with the other Devonian samples.

MISSISSIPPI ALLUVIAL PLAIN

This narrow area is the most western physiographic province in the state. It is that portion of the alluvial flood plain of the Mississippi River lying on the eastern side of the stream. Its soil is alluvial. In places there is sand, but much of it is black, sticky soil, often called gumbo. It is slightly deficient in lime and so is slightly acid. Seven samples were taken from this province.

WOOD SAMPLES

Molisch[33] says that iron is found throughout the plant kingdom, but that usually it is in such small quantities that it cannot be determined by the ordinary tests. Hoffer[34] found that, in the corn plant, the iron content of the nodes was higher than was that of the internodes.

In this study it was decided to use wood as the plant tissue on which determinations of iron were to be made. Leroux and Leroux[35] have shown that the leaves of woody plants hold the most iron. However, leaves are rather evanescent things and, quite likely, their composition reflects the seasonal conditions under which they grow. Wood from the trunk of the tree was used for two reasons: first, any effect on the composition that might result from abnormal seasonal conditions could be offset by using wood having from four to six years growth in it. Second, if an antagonism exists between the calcium in the soil and the iron in the wood, one would expect the one to be replaced by the other. Uniformly, calcium is highest in the trunk of the tree. In case of a calcium deficiency in the soil, does the tree replace its calcium in part, at least, with iron?

TABLE 1

Ash and Iron Content of Woods

Name of Wood	Ash (with 10% H_2O)	Ash (Dry)	Fe_2O_3 in Ash	Fe_2O_3 in Wood	Fe in Wood
	%	%	%	%	%
Red Oak	.85	.94	0.21	.0020	.0014
White Oak	.37	.41	0.50	.0020	.0014
Yellow Pine	.55	.40	0.18	.0007	.0005
Long Leaf Pine	.41	.56	2.76	.0154	.0108
White Ash	.46	.48	2.92	.0140	.0098
Chestnut	.22	.24	2.65	.0064	.0044

[33]Molisch, Hans. 1913. *Michrochemie der Pflanze*, p. 39.
[34]Hoffer, *op. cit.*
[35]Leroux and Leroux, *op. cit.*

There is very little information available on the iron content of woods. Perhaps the most reliable data is found in the work of White[36] who gives the percentage of iron in wood ashes and the percentage of ash in the wood. From his figures it is possible to calculate the per cent of iron originally present in the wood. Such calculation has been made in table 1 which is based on White's figures.

The accuracy of his results may be questioned. He did not determine the amount of iron in the wood directly, but found it indirectly by calculation. At the time he did his work (1889) laboratory technics in michrochemistry had not been developed that would make possible a direct determination.

Campbell[37] found that the Osage orange is almost devoid of iron.

Oak wood was chosen for this study. White had shown that it contains fairly large quantities of iron and that, probably, the iron content of the different oaks was approximately the same. A second reason for choosing oak is that it is found very generally in all the physiographic provinces of Tennessee, while many other varieties of wood are indigenous to certain provinces only.

METHOD OF SAMPLING

Wood.—Wood samples were taken by cutting a cross-section from a young oak tree having from four to ten annular rings. This section was then sawed into pieces one-half to three-quarters inch in length. The ten gram sample was split out of these pieces.

Soil.—Soil samples were taken with a soil auger. Borings were made two feet deep where underground rock conditions would permit. If the rock was within two feet of the surface, the borings were made down to rock. Any leaves and other materials on the surface were removed. All the material from the borehole was saved, carefully mixed, and quartered down to a 100 gm. sample. From this sample the tests were run. Care was taken not to obtain samples where the soil had been disturbed or modified by grading, excavating, sliding, fertilizing, or other activity that might change it from its natural composition or position.

SUMMARY OF SAMPLING

The samples used in this study were secured on the basis of the major physiographic provinces of Tennessee. The soils of each province reflect the geology of the province in a very striking way.

One hundred and sixty-six samples were collected. They were distributed as follows: Great Smoky Mountains (Roan Mountain region), 15 samples; Great Valley of Tennessee, 14 samples; Cumberland Plateau, 25 samples; Highland Rim, 42 samples; Central Basin

[36]White, H. C. 1889. *Ash Analyses of Native Woods. Georgia Experiment Station, Bulletin 2.*
[37]Campbell, Carl G. 1931. The Analysis of the Osage Orange. Unpublished study at George Peabody College for Teachers, Nashville, Tenn.

and Sequatchie Valley, 25 samples; Western Plateau, 42 samples, and Mississippi Alluvial Plain, 7 samples.

Oak wood was used, cross-sections being cut from young trees four to ten years old. Soil samples were taken to a depth of two feet or to rock. Samples were taken where there was evidence of no displacement and where there had been no modification by fertilizing, liming, or otherwise.

CHAPTER III

ANALYTICAL PROCEDURES

In the selection of analytical procedures care was taken to use only those that have been subjected to careful checking through extensive and well-established use.

The methods of analysis adopted by the "Association of Official Agricultural Chemists"[38] were used where possible. For other determinations methods that had been subjected to careful verification by other investigators were used.

DETERMINATION OF PH OF SOIL SAMPLES

The hydrogen ion concentration of the soil samples was determined by the quinhydrone electrode[39] and a Leeds and Northrup potentiometer. Clark and Collins[40] have worked out the practical details of the determination. Procedure: To 25 gms. of air dried soil in a pyrex beaker are added 25 cc. of distilled water and about 0.02 gms. of quinhydrone. The mixture is well stirred with an electric mixer for thirty seconds and then placed under the electrodes so that their tips will be in contact with the soil when it settles from suspension. After standing for thirty seconds the potentiometer is read when the solution has come to equilibrium.

Three determinations were made on each sample and the average taken unless one reading varied widely from the other two in which case the varying one was discarded.

DETERMINATION OF ORGANIC MATTER

Of the various methods that have been used for the determination of organic matter, those making use of the direct combustion of carbon[41] or its oxidation by a mixture of chromic and sulfuric acids are most widely used.[42] In this work the wet method devised by Knopp-Sabanin[43] and simplified by Schollenberger and Degtjareff[44] was used. This method is rapid, accurate, and easy of manipulation.

[38] Association of Official Agricultural Chemists. 1925. *Official Methods of Analysis. Second Edition.*

[39] Bauer, L. D. 1926. The Use of the Quinhydrone Electrode for Measuring the Hydrogen Ion Concentration of Soils. *Soil Science.* 21: 167-178.

[40] Clark, N. A., and E. R. Collins. 1927. The Quinhydrone Electrode and the Soil Reaction. *Soil Science.* 24: 453-463.

[41] Association of Official Agricultural Chemists. 1925. *Official Methods of Analysis.* p. 27.

[42] Mahin, E. G., and R. H. Carr. 1923. *Quantitative Agricultural Analysis,* p. 148.

[43] Degtjareff, W. T. H. 1930. Determining Soil Organic Matter by Means of Hydrogen Peroxide and Chromic Acid. *Soil Science.* 29: 208-245.

[44] Schollenberger, C. J. 1927. A Rapid Approximate Method for Determining Soil Organic Matter. *Soil Science.* 24: 65-68.

Reagents used.

1. A .3% solution of hydrogen peroxide containing 25 cc. sulfuric acid per liter.

2. Chromic acid solution prepared by dissolving potassium chromate equivalent to 18.88 gms. of chromic acid in hot sulfuric acid. After cooling the volume is made up to a liter with concentrated sulfuric acid.

3. Diphenylamine indicator prepared by dissolving 1 gm. of diphenylamine in 200 cc. of concentrated sulfuric acid and 40 cc. of water.

4. Standard ferrous ammonium sulfate solution made by dissolving 79.89 gms. of the salt in water containing 40 cc. of concentrated sulfuric acid and making the volume up to one liter with water.

Procedure.—To .20 gms. of the air dried soil were added 10 cc. of the hydrogen peroxide solution. The materials were well stirred and allowed to stand until the reaction was complete. When the action had ceased the contents of the flask were poured into a 400 cc. beaker. The flask was rinsed into the beaker and the contents made up to 250 cc. About .5 cc. of the diphenylamine indicator was added and the solution titrated with the ferrous ammonium sulfate. While it is possible to calculate the amount of carbon from the theoretical equation

$$3C + 3H_2O_2 + 2H_2CrO_4 + 3H_2SO_4 = Cr_2(SO_4)_3 + 8H_2O + 3CO_2$$

more accurate results are obtained by standardizing the chromic acid solution against pure sucrose. In this way the carbon equivalent of the chromic acid may be accurately determined. By making use of this factor and the fact that carbon represents 50% of the organic matter in soil,[45] the amount of organic matter in the soil may readily be determined. Carbon factor used: 1 cc. chromic acid equals 0.00116 gms. carbon.

DETERMINATION OF IRON AND CALCIUM IN SOIL

A large number of methods for the determination of iron and calcium in soils are in existence. Lemke[46] suggests the determination of the p_H of the soil and the calculation of calcium using a factor. Steenkamp[47] suggests the desirability of a colorimetric micro-determination of iron and calcium. He states that iron in the ferric state may be determined by producing an amethyst color with salicylic acid and the amount of calcium may be found by precipitating as calcium oxalate at p_H 4 and developing the color with bromcresol green.

[45]Read, J. W., and R. H. Ridgell. 1922. On the Use of the Conventional Carbon Factor in Estimating the Soil Organic Matter. *Soil Science*, 13: 1-6.

[46]Lemke, F. 1930. Significance of p_H and Calcium Content of Soil and Simple Laboratory Methods for Their Determination. *Deutcher Zuckerind*, 55: 559-562.

[47]Steenkamp, J. L. 1930. Microchemical Analysis of Soils. *Journal of South African Chemical Institute*, 13: 64-70.

Shedd[48] shows that the digestion of soils with N/2 nitric acid for five minutes gives results uniformly 94% of the total calcium in the soil.

It was believed that, wherever they were available, well standardized and generally accepted methods should be used in this work. For that reason, the methods given by the Association of Official Agricultural Chemists[49] were used in the determinations.

Reagents Used.

1. Hydrochloric acid diluted with an equal volume of water.
2. Dilute ammonium hydroxide.
3. Methyl red indicator.
4. Stannous chloride, 5% solution.
5. Mercuric chloride, 5% solution.
6. Standard potassium permanganate solution made by dissolving 3.1606 gms. of pure potassium permanganate in sufficient water to make one liter of solution. This makes approximately N/10 solution. The solution was allowed to stand 48 hours in the dark and then was filtered through asbestos. It was standardized against sodium oxalate. One cc. of permanganate was equivalent to 0.002 gm. of calcium or 0.005584 gm. iron.
7. Standard sodium oxalate prepared by dissolving exactly 6.7 gms. purest sodium oxalate in water and making up to one liter. This is an N/10 solution.
8. "Titrating Solution" containing 144 gms. of phosphorus pentoxide, 245 gms. of concentrated sulfuric acid and 67 gms. of manganous sulfate and sufficient water to make one liter of solution.
9. A 4% solution of ammonium oxalate.

Blank tests were run on all reagents used.

Procedure.—Weigh accurately 1 gm. of the sample of soil into an Erlenmeyer flask. Add 25 cc. of hydrochloric acid (1-1). Digest on hot plate for five minutes. Dilute with 25 cc. of 10% hydrochloric acid and heat to boiling. Filter and wash, using filtrate with washings for the determination of iron and calcium in the soil. Add a drop of methyl red and then add dilute ammonium hydroxide until the solution is distinctly basic and boil until the odor of ammonia is faint. Filter and wash thoroughly, adding the washings to the filtrate and washings precipitate for the iron determination and the filtrate and washings for the calcium determination.

Iron.—Dissolve the iron precipitate in 25 cc. of 10% hydrochloric acid and dilute to 50 cc. Heat almost to boiling and add, drop by

[48]Shedd, O. M. 1923. Effect of Absorption and Other Factors on Certain Plant Food Constituents Obtained in the Dilute Nitric Acid Digestion of Soils and an Improvement for Their Estimation. *Soil Science*, 15: 383-393.

[49]Association of Official Agricultural Chemists. 1925. *Official Methods of Analysis*, pp. 28-29.

drop, stannous chloride solution until the ferric chloride has just been reduced, this being evident by the disappearance of the red color. Add two more drops of stannous chloride and cool quickly. When cool add, all at once, 25 cc. of mercuric chloride solution and mix well. Dilute to 500 cc., add 50 cc. of the "titrating solution," and titrate at once with the standardized potassium permanganate solution to a faint pink color. Calculate the amount of iron in the sample from the amount of permanganate used.

Calcium.—Evaporate the filtrate containing calcium to 50 cc., cool, add 5 cc. of ammonium sulfide to precipitate any manganese that may be present, filter and wash with hot water. Discard the precipitate. Again evaporate to about 50 cc., make slightly alkaline with ammonium hydroxide and add, while still hot, ammonium oxalate solution, drop by drop with stirring, so long as any precipitate is formed. Allow to stand an hour and then filter. Wash the precipitate with hot water until the washings are free from oxalates. Discard filtrate and washings.

Pierce the point of the filter paper and wash as much as possible of the precipitate into an Erlenmeyer flask with hot water. Dissolve the remaining precipitate in 15 cc. of hot 25% sulfuric acid allowing it to run into the flask. Finally, wash the paper thoroughly with hot water, adding the washing to the flask also. Make up to 75 cc., heat to 90° C. and titrate with the standardized potassium permanganate solution. Calculate the amount of calcium in the sample from the amount of permanganate used.

DETERMINATION OF IRON IN THE PLANT

L. Leroux and D. Leroux[50] found that iron is very unequally distributed in different plant organs. In herbaceous plants the ash of the roots, and after the latter, the ash of the flowers, was found to be particularly rich in iron. In woody plants the ash of the leaves regularly held the most iron. The ash of the stems of all plants was richest in calcium.

The amount of iron in a plant is, even at its maximum, so very small that the ordinary gravimetric or volumetric methods are inadequate for its determination. Stokes and Cain[51] have developed a very sensitive colorimetric method that, because of its great accuracy even with very small quantities of iron, was used in these determinations.

Reagents used.

1. Standard Iron Solution: 0.863 gms. of ferric ammonium sulfate and 5 cc. of concentrated sulfuric acid were dissolved in sufficient

[50]Leroux, L., and D. Leroux. 1923. *Rev. Gen. Botany*, 25: 24-33; 57-70.
[51]Stokes, H. N., and J. R. Cain. 1907. On the Colorimetric Determination of Iron With Special Reference to Chemical Reagents. *U. S. Bureau of Standards, Bulletin 3.*

water to make one liter of the solution. This solution contains 0.1 gm. of iron per liter. For use dilute 5 cc. to 100 cc. Thus diluted, 1 cc. contains 0.000005 gms. of iron.

2. Sulfocyanic acid reagent:[52] a 7% solution of sulfocyanic acid is saturated with mercuric cyanate and an excess is left in the bottle. A trace of potassium persulfate is added to the solution.

3. Mercuric sulfocyanate: a hot solution of mercuric chloride (2 mols.) is poured into a solution of ammonium sulfocyanate (1 mol.) and cooled. The resulting crystals are filtered out and washed.

4. Amyl alcohol-ether solution: to 5 volumes of amyl alcohol are added 2 volumes of ether.

Procedure.—Thoroughly char 10 gms. of the sample at low red heat. Moisten with 1:1 nitric acid. Evaporate to dryness on the hot plate. Take up with 1:9 nitric acid and filter. Wash with 100 cc. of hot water acidified with nitric acid. Burn the residue and filter paper to a white ash and add to the filtrate and washings. Evaporate to 25 cc. Make up to 100 cc. with 1:9 nitric acid and allow to settle. Use supernatant liquid for determination of iron in colorimeter. The colorimetric reading is made by placing a standard iron solution (diluted 5 cc. to 100 cc.) in one tube of the colorimeter. Place sample of the unknown in the other tube. Add to each an equal volume of the amyl alcohol-ether and three drops of the sulfocyanate reagent. Mix well. Place in colorimeter and adjust tubes until color is same in both tubes. Read scales and calculate amount of iron in unknown.

Method of calculation of iron from colorimeter readings:

Scale readings—
  Standard............ 7.5
  Unknown 25.0
Concentration of iron in unknown is 75 / 250 of concentration in standard.
Concentration of iron in standard is .000,005 gms. per cc.
Concentration of iron in unknown is 75/250 of .000,005 gms. or .000,001,5 gms. per cc.
Iron in the 100 cc. of the unknown is 100 × .000,001,5 gms. or .000,15 gms.
Iron in 10 gms. of the original sample is 0.000,15 gms. or 1.5 × 10^{-5}%.

A Bausch and Lomb Duboscq type colorimeter was used in this work.

[52]Sulfocyanic acid was prepared by treating 100 parts of coarsely powdered ammonium sulfocyanate with a cold mixture of 65 parts by weight of concentrated acid and 100 parts of water. The solution was transferred at once to a separating funnel and extracted with three-fourths its volume of amyl alcohol. The amyl alcohol solution is shaken out twice with an equal volume of water. The two aqueous extracts are mixed giving approximately a 7% solution of the acid. See "On Sulfocyanic Acid," *U. S. Bureau of Standards, Scientific Paper* 54, pp. 157-158.

DETERMINATION OF CALCIUM IN WOOD

The calcium in the wood was determined by the method described by the Association of Official Agricultural Chemists.[8]

Reagents used.

1. Dilute hydrochloric acid, 1:4 and N/2 solutions.
2. Methyl orange indicator.
3. Dilute ammonium hydroxide, 1:1.
4. Oxalic acid, 2.5% solution.
5. Saturated ammonium oxalate solution.
6. Sodium acetate, 20% solution.
7. Sulfuric acid, 1:1 solution.
8. Potassium permanganate solution standardized against N/10 sodium oxalate solution. One cc. is equivalent to 0.002 gr. calcium.

Procedure.—Ten grams of the wood sample were ignited in a nickel crucible in a muffle at a dull red temperature until the residue was white. The residue was dissolved in dilute hydrochloric acid (1:4) and transferred to an evaporating dish and evaporated to dryness. Then the residue was moistened with concentrated hydrochloric acid, added 50 cc. water, filtered and washed, adding washing to filtrate.

To combined filtrate and washings added a few drops of methyl orange indicator and dilute ammonium hydroxide (1:1) until faintly alkaline. Added dilute hydrochloric acid (1:4) until faintly acid. Then added 10 cc. of N/2 hydrochloric acid and 10 cc. of 2.5% oxalic acid solution. Heated to boiling and added, with stirring, 15 cc. of a saturated solution of ammonium oxalate. Continued to heat until the precipitate was granular. Cooled and added 8 cc. of sodium oxalate solution and allowed to stand until precipitate was well settled. Filtered and washed with hot water until free from chlorides. Washed precipitate into beaker with hot water. Added 10 cc. of dilute sulfuric acid (1:1) and titrated with potassium permanganate. Finally added the filter paper to the solution and completed the titration.

Calculated the amount of calcium in 1 gm. of sample from the calcium equivalent of the permanganate (1 cc. of permanganate was equivalent to 0.002 gm. of calcium). Recorded results in per cent.

SUMMARY OF ANALYTICAL METHODS

Analytical methods were chosen that have been thoroughly proven either by recognized investigators or established agencies such as the Association of Official Agricultural Chemists. All chemicals used were the best reagent grade obtainable.

[8] Association of Official Agricultural Chemists, op. cit., p. 389-412.

CHAPTER IV

ANALYTICAL RESULTS

Table 2 gives the results of the analysis of the samples of soil and oak wood from the Mississippi Alluvial Plain. The pH range of the soils is not great. Since this is the flood plain of the Mississippi River and is subject to overflow, we would expect more uniformity in the pH, calcium, and iron in the soils due to the action of the flood water to equalize the distribution of these factors. All samples of soil were on the acid side of the pH range; a condition that is characteristic of swampy areas and of regions subject to overflow.

The organic matter is not low. The rapid growth of vegetation on these alluvial soils results in the rapid accumulation of humus in and on the soil. The iron content is high. Usually this would mean a

TABLE 2

Analyses of Woods and Soils, Mississippi Alluvial Plain

Sample Number	Soil				Wood	
	pH	Organic Matter	Fe	Ca	Fe	Ca
		%	%	%	ppm	%
21	5.41	2.35	2.685	0.600	4.00	0.32
22	5.00	1.82	2.57	0.56	5.00	0.36
23	5.42	1.68	2.62	0.61	4.70	0.30
24	5.64	2.60	2.605	0.685	4.40	0.30
25	5.82	1.72	2.57	0.58	4.50	0.33
26	5.55	1.59	2.55	0.603	4.60	0.40
27	5.60	1.48	2.70	0.66	4.40	0.40
MEAN	5.38	1.78	2.62	0.61	4.56	0.30

a red soil. These soils were black due, in part, to organic matter. The calcium content was uniformly less than .75 per cent. Like the calcium in the soil, the calcium in the wood is uniform, the range being only .08 per cent. The iron content of the wood is likewise uniform, the variation being less than one part of iron.

Table 3 gives the results of the analysis of soil and wood samples from the Western Plateau. The pH of all samples is on the acid side, the samples from the Devonian outcrops between Camden and the Tennessee River being most acid. The samples taken between Fulton, Kentucky, and Huntingdon, Tennessee, have an acidity about that of the Alluvial Plain. Two samples from the Harpeth Narrows have a much higher pH. These two samples were taken from the

valley of the Harpeth River just south of its entrance to the Narrows. The locality showed some evidence of overflow and it is possible that alluvial conditions produced a modification of natural soil conditions. This is borne out by the fact that the calcium content of these two samples was much higher than that of other samples either from the Plateau or from the Narrows. The Harpeth River flows into the Narrows from the limestone beds of the Central Basin and its waters carry some lime in solution.

TABLE 3

Analyses of Woods and Soils, Western Plateau

SAMPLE NUMBER	SOIL				WOOD	
	pH	Organic Matter	Fe	Ca	Fe	Ca
		%	%	%	p.p.m.	%
28	4.75	1.42	2.23	0.48	4.30	0.38
29	4.95	1.93	2.50	0.51	3.90	0.37
30	5.55	1.70	2.75	0.45	4.20	0.33
31	5.40	2.01	2.15	0.48	4.20	0.33
32	5.42	2.24	2.55	0.50	3.90	0.37
33	5.30	1.80	2.22	0.43	3.80	0.38
34	5.40	2.42	2.40	0.45	4.00	0.39
35	5.40	1.92	3.72	0.40	3.80	0.37
161	5.44	1.82	2.42	0.45	3.80	0.38
162	5.31	1.12	3.12	0.62	3.50	0.39
163	5.21	0.96	3.84	0.39	3.75	0.36
164	5.10	0.75	4.61	0.32	3.50	0.36
165	5.21	1.07	4.21	0.45	4.00	0.38
166	5.00	0.92	3.97	0.42	3.90	0.38
61	4.59	0.82	1.44	0.30	6.25	0.34
62	4.85	0.97	1.64	0.24	6.35	0.28
63	4.93	0.70	1.58	0.24	6.40	0.31
64	4.90	1.00	1.64	0.24	6.30	0.29
65	4.83	0.65	1.28	0.36	6.00	0.37
66	4.90	0.87	1.34	0.28	6.25	0.30
67	4.95	0.75	2.23	0.28	6.30	0.33
68	4.88	0.70	1.37	0.27	6.35	0.31
69	4.95	0.95	1.31	0.30	6.20	0.36
70	4.65	1.00	1.28	0.32	6.20	0.36
103	6.90	1.24	2.63	1.14	3.60	0.42
104	6.80	1.84	2.97	1.60	3.20	0.56
105	4.90	1.37	3.69	0.28	6.45	0.30
106	5.12	1.40	2.63	0.30	6.32	0.35
107	5.00	1.08	2.69	0.28	6.20	0.31
108	5.22	0.95	2.80	0.32	6.35	0.34
109	5.10	0.99	2.86	0.30	6.40	0.34
110	5.10	1.09	2.69	0.32	6.41	0.35
MEAN	5.19	1.27	2.52	0.42	5.06	0.36

Organic matter in the soils of the Western Plateau varies widely. The iron content covers a wide range. The samples taken from Mc-

Kenzie to Huntingdon were especially rich in iron. These samples were a deep red in color. With the exception of the two samples from the Harpeth Narrows, all these soils are deficient in calcium.

The calcium in the wood varies from .30 per cent to .56 per cent and the range in the iron content of the wood is very great, the sample with the highest iron content having more than twice the iron in the sample having the lowest content.

In table 4 is shown the results of analyses of samples from the Central Basin. Samples No. 40, 41, 42, 43, 44, and 45 were taken from the phosphate region at Mt. Pleasant. The calcium in the other sec-

TABLE 4

Analyses of Woods and Soils, Central Basin

SAMPLE NUMBER	SOIL				WOOD	
	pH	Organic Matter	Fe	Ca	Fe	Ca
		%	%	%	p.p.m.	%
1	5.91	1.23	2.08	1.23	2.90	0.45
2	7.12	2.75	1.65	3.02	2.50	0.65
3	7.40	2.87	0.78	1.99	1.50	0.62
4	7.47	3.25	3.12	1.87	2.25	0.60
5	7.04	2.00	3.02	1.55	2.25	0.55
6	7.02	3.86	3.24	1.62	2.00	0.57
7	6.98	2.77	3.57	1.24	2.80	0.46
8	7.65	1.89	3.15	1.88	2.20	0.60
9	7.34	2.01	2.79	2.59	2.50	0.64
10	7.56	1.99	2.82	1.78	2.20	0.58
36	6.92	1.92	2.90	1.10	2.75	0.43
37	6.99	1.92	2.68	1.24	2.50	0.45
38	6.75	2.00	2.79	1.70	2.10	0.46
39	7.12	1.78	3.12	1.64	2.10	0.58
40	6.82	2.10	3.02	0.96	3.25	0.43
41	7.01	1.48	2.23	1.42	2.20	0.51
42	6.70	1.33	2.68	1.21	2.65	0.47
43	6.92	1.23	2.56	1.11	2.75	0.47
44	7.60	1.20	2.22	2.01	1.50	0.63
45	6.90	1.60	2.48	1.46	2.10	0.49
56	6.97	1.25	1.10	1.35	2.60	0.49
57	7.00	1.92	0.90	1.15	2.90	0.42
58	7.45	0.92	2.30	1.50	2.22	0.50
59	6.69	1.00	1.30	1.28	2.40	0.48
60	7.40	1.82	0.95	1.80	1.50	0.59
96	6.75	2.26	2.05	1.20	2.70	0.46
97	6.85	1.59	2.90	1.20	2.85	0.45
98	6.88	2.35	2.77	1.24	2.70	0.44
99	7.02	1.72	2.22	1.50	1.85	0.53
100	6.70	1.25	2.50	1.25	2.60	0.46
101	6 75	1.42	2.10	1.11	2.62	0.42
102	6.65	1.10	2.15	1.23	2.60	0 47
MEAN	7.01	1.86	2.38	1.60	2.39	0.51

tions of the basin from which samples were obtained was largely in the form of calcium carbonate. There is, however, no noticeable difference in the analysis either of the soil or the wood from the phosphate and the carbonate regions. The soils deviate but slightly, either to the acid or the alkaline side, from a neutral condition. The iron

TABLE 5

Analyses of Woods and Soils, Highland Rim

SAMPLE NUMBER	SOIL				WOOD	
	PH	Organic Matter	Fe	Ca	Fe	Ca
		%	%	%	p.p.m.	%
11	5.12	1.21	1.56	0.10	7.50	0.22
12	5.15	1.12	1.80	0.12	8.30	0.25
13	5.26	0.97	1.42	0.22	8.00	0.30
14	4.75	1.11	1.16	0.20	8.60	0.29
15	4.92	0.72	0.95	0.18	7.80	0.25
16	5.24	1.01	4.12	0.20	6.50	0.28
17	5.42	1.45	1.79	0.22	7.00	0.30
18	5.55	1.50	4.41	0.21	6.90	0.30
19	5.61	1.87	4.32	0.28	8.70	0.32
20	5.21	1.22	1.21	0.33	7.70	0.35
46	4.90	0.75	1.00	0.18	8.10	0.24
47	5.15	0.95	1.05	0.12	8.20	0.22
43	5.12	1.00	1.40	0.16	8.00	0.23
49	5.40	1.20	0.90	0.20	7.10	0.28
50	5.50	2.00	3.70	0.15	6.90	0.23
51	5.30	0.65	1.00	0.15	7.10	0.23
52	5.50	1.60	1.20	0.25	7.00	0.30
53	5.40	1.40	0.90	0.22	6.50	0.31
54	5.55	1.20	2.90	0.25	6.10	0.30
55	5.20	1.00	3.20	0.20	6.60	0.26
71	5.40	1.20	4.65	0.45	5.80	0.39
72	5.60	0.95	4.48	0.38	5.92	0.36
73	4.90	1.00	2.90	0.25	6.26	0.32
74	5.50	1.25	4.65	0.55	5.50	0.39
75	5.40	1.10	3.75	0.40	5.95	0.38
76	5.55	1.05	3.20	0.45	5.70	0.37
77	5.80	0.95	2.80	0.38	6.00	0.38
78	5.65	1.30	2.65	0.32	6.15	0.35
79	5.83	1.18	2.87	0.58	5.22	0.39
80	5.90	1.32	3.00	0.65	5.30	0.39
111	5.27	0.88	1.62	0.30	6.00	0.35
112	6.10	1.12	1.85	0.36	6.00	0.36
113	5.50	1.00	1.12	0.24	6.40	0.30
114	5.52	0.21	6.92	0.20	6.64	0.28
115	5.62	0.34	8.68	0.20	6.45	0.26
116	6.23	0.64	5.40	0.50	4.50	0.35
117	7.02	1.34	1.40	0.78	4.40	0.41
118	5.35	0.44	4.80	0.30	5.50	0.34
119	6.30	0.56	3.78	0.42	4.50	0.37
120	6.72	0.84	3.87	0.44	4.80	0.38
MEAN	5.51	1.05	2.81	0.30	6.54	0.30

content of the soil varies widely. The calcium in the soil is uniformly high. The calcium in the wood is likewise high and the iron in the wood is uniformly low.

Table 5 gives results of the analyses of samples from the Highland Rim. With the exception of sample No. 117, all samples were acid, the PH dropping below 5 in four cases. Most samples gave a PH between 5 and 6.

A wide variation in the content of organic matter is evident.

Sample No. 16 was taken from the red strip just south of White House on the northern rim. Samples Nos. 18 and 19 were from the red strip just east of Burns on the western rim. Samples Nos. 71 and 72 were from the red strip north of Lawrenceburg on the southwestern rim. Nos. 74, 75, and 76 were from the red strip south of Manchester on the southeastern rim and Nos. 114, 115, 118, 119, and 120 were from the red strip on the eastern rim between McMinnville and

TABLE 6

Analyses of Woods and Soils, Cumberland Plateau

SAMPLE NUMBER	SOIL				WOOD	
	PH	Organic Matter	Fe	Ca	Fe	Ca
		%	%	%	p.p.m.	%
81	5.10	1.42	2.24	0.20	6.45	0.30
82	5.50	1.88	1.90	0.42	5.85	0.37
83	5.61	1.55	2.46	0.46	5.62	0.37
84	5.00	1.98	2.30	0.24	6.15	0.30
85	5.10	1.35	2.14	0.30	6.15	0.35
86	5.20	1.42	2.80	0.22	6.53	0.29
87	5.00	1.85	2.35	0.20	6.25	0.29
88	5.40	2.00	2.46	0.30	6.32	0.36
89	5.50	1.55	2.75	0.35	6.00	0.37
90	5.32	1.68	2.55	0.32	5.95	0.33
91	5.25	2.05	2.41	0.24	6.44	0.31
92	5.10	1.60	2.30	0.20	6.51	0.27
93	5.26	1.78	2.80	0.24	6.42	0.30
94	5.22	1.66	2.15	0.36	6.30	0.36
95	5.25	1.10	1.96	0.28	6.35	0.34
121	6.89	1.87	2.52	0.56	4.30	0.38
122	7.00	0.92	1.96	0.60	4.70	0.38
123	5.45	2.25	2.35	0.24	6.25	0.29
124	5.38	2.38	2.52	0.38	6.32	0.37
125	6.00	2.32	2.80	0.50	6.10	0.33
126	5.80	1.28	2.24	0.40	6.35	0.37
127	5.86	1.76	2.24	0.46	6.05	0.38
128	5.02	1.88	1.96	0.38	6.10	0.37
129	4.95	3.44	2.22	0.24	5.92	0.30
130	4.87	4.67	2.62	0.28	6.36	0.33
MEAN	5.44	1.91	2.36	0.33	6.07	0.34

Sparta. In all of these samples the iron is very high. In some samples taken from other sections of the rim the iron is low, in some cases being only one per cent or less.

The soils of the rim are uniformly low in calcium. This is to be expected in view of the high solubility of the St. Louis limestone and the low calcium content of the Fort Payne limestone that form the major portion of the bedrock of the region. Also, the elevation of the rim above the Central Basin gives opportunity for rapid leaching of the soil.

The calcium in the wood is uniformly low and the iron runs uniformly high, seven or more parts per million being not unusual.

Results of analyses of samples from the Cumberland Plateau are given in table 6. With the exception of sample No. 122, which had a pH of 7, all samples were acid. Sample No. 122 was taken in the Bangor limestone region in the eastern part of the Plateau. The iron in the soil is not high, the highest being 2.80 per cent. The calcium in the soil is low. The calcium in the wood is also low and the iron is high.

Table 7 shows the analyses of samples from the Great Valley of the Tennessee. Samples Nos. 131 to 140, inclusive, were taken between Rockwood and Knoxville. Samples Nos. 141 to 144, inclusive, were from northeast of Knoxville. Samples Nos. 132, 133, 135, 137, and 139 were from hilltops. The others were from valleys.

TABLE 7

Analyses of Woods and Soils, Great Valley of Tennessee

SAMPLE NUMBER	SOIL				WOOD	
	PH	Organic Matter	Fe	Ca	Fe	Ca
		%	%	%	p.p.m.	%
131	6.93	1.35	2.80	0.90	3.25	0.42
132	5.93	1.30	3.08	0.64	4.50	0.38
133	7.11	1.71	2.03	1.01	3.50	0.42
134	6.85	0.62	1.96	0.91	3.25	0.47
135	6.10	1.11	2.46	0.72	3.75	0.46
136	7.36	1.21	2.30	1.21	2.75	0.35
137	6.95	1.92	1.72	0.98	3.11	0.41
138	6.22	1.56	2.56	0.84	3.30	0.45
139	5.72	1.56	1.57	0.56	4.12	0.38
140	7.00	1.42	2.96	1.12	3.30	0.48
141	5.89	1.22	2.01	0.71	3.85	0.48
142	7.12	2.26	2.13	1.12	3.15	0.42
143	7.32	1.47	2.25	1.26	1.56	0.41
144	6.99	1.42	1.97	1.02	2.80	0.41
MEAN	6.65	1.44	2.27	0.93	3.29	0.43

All samples varied in pH, but little from the neutral point. Organic matter in all cases but one was above one per cent. The iron in the soil was normal. In general the calcium in the soil was higher north of Knoxville than it was south of that city.

In the Roan Mountain region of the Great Smoky Mountains (table 8), all soil samples were highly acid, the pH in most cases being below 5. The organic matter was much lower than in any of the other provinces. There was a wide variation in the iron content of the soil, the minimum being 1.17% and the maximum being 5.60%. The calcium was very low.

In the wood the calcium was uniformly low and the iron was uniformly high with no great variation in content.

TABLE 8

Analyses of Woods and Soils, Roan Mountain

SAMPLE NUMBER	SOIL				WOOD	
	PH	Organic Matter	Fe	Ca	Fe	Ca
		%	%	%	p.p.m.	%
145	4.84	0.42	5.32	.186	6.43	0.23
146	4.72	0.84	4.48	.167	6.40	0.25
147	5.00	0.72	3.92	.287	6.75	0.33
148	4.46	0.20	1.31	.162	6.47	0.24
149	5.24	1.13	1.92	.242	6.55	0.31
150	4.76	0.92	1.56	.289	6.66	0.33
151	5.12	1.26	5.04	.265	6.50	0.31
152	4.95	1.05	3.64	.307	6.95	0.36
153	4.92	1.12	5.60	.320	7.00	0.35
154	4.84	0.69	2.64	.220	6.50	0.30
155	4.98	0.87	3.37	.246	6.50	0.30
156	4.75	0.41	1.32	.180	6.40	0.26
157	4.78	0.47	1.17	.188	6.47	0.27
158	4.92	3.86	4.21	.203	6.60	0.30
159	5.03	0.65	3.62	.200	6.14	0.28
160	4.96	0.88	2.01	.206	6.55	0.28
MEAN	4.92	1.02	3.02	.230	6.34	0.29

The mean results of the analyses of samples from the various physiographic provinces are given below (table 9).

TABLE 9

Mean Results of Analyses of Woods and Soils

PROVINCE	SOIL				WOOD	
	PH	Organic Matter	Fe	Ca	Ca	Fe
		%	%	%	%	p.p.m.
Alluvial Plain	5.38	1.78	2.62	0.61	0.39	4.56
Western Plateau	5.19	1.27	2.52	0.43	0.36	5.06
Central Basin	7.01	1.86	2.38	1.60	0.51	2.39
Highland Rim	5.51	1.05	2.81	0.30	0.30	6.52
Cumberland Plateau	5.44	1.91	2.36	0.33	0.34	6.07
Great Valley	6.65	1.44	2.27	0.93	0.42	3.29
Great Smoky Mtns.	4.92	1.02	3.32	0.23	0.29	6.34

CHAPTER V

COMPARISON OF DATA

Any relations existing between the soil components and the plant constituents might be made evident by: (1) an examination of distribution charts on which are shown the percentage distribution of the various substances; (2) the determination of the mathematical
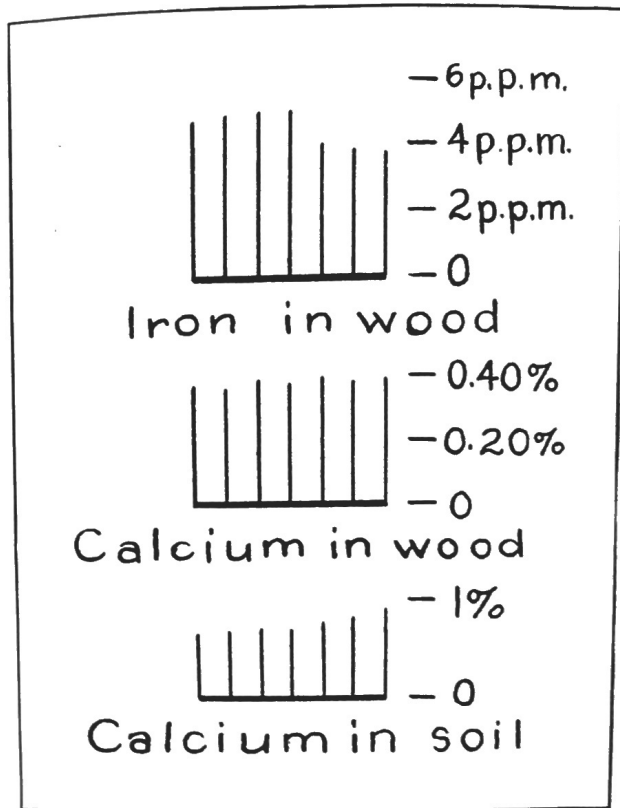
Fig. 1. Distribution of calcium in soil and calcium and iron in wood (*Mississippi Alluvial Plain*). Samples arranged in order of increasing calcium in soil.

correlation existing between the substances under consideration; and (3) by the plotting of a curve showing the relationship, if any, that exists.

(1) Distribution charts for the calcium in the soil and the calcium and iron in the plant are shown in figures 1-7. For each physiographic province the samples are arranged in the order of increasing calcium content of the soil. Thus there is an increase in the amount of soil calcium from the left to the right of the chart.

An examination of these charts showing the distribution of calcium and iron in the wood gives one the very definite impression that, in general, from left to right there is an increase in the amount of calcium and a decrease in the amount of iron. In the distribution chart for the Central Basin (Fig. 3) it is evident that, with the increase in calcium in the soil from left to right, there is a similar increase in calcium in the wood and a marked tendency for the iron in the wood to decrease. A similar general relationship becomes evident on ex-
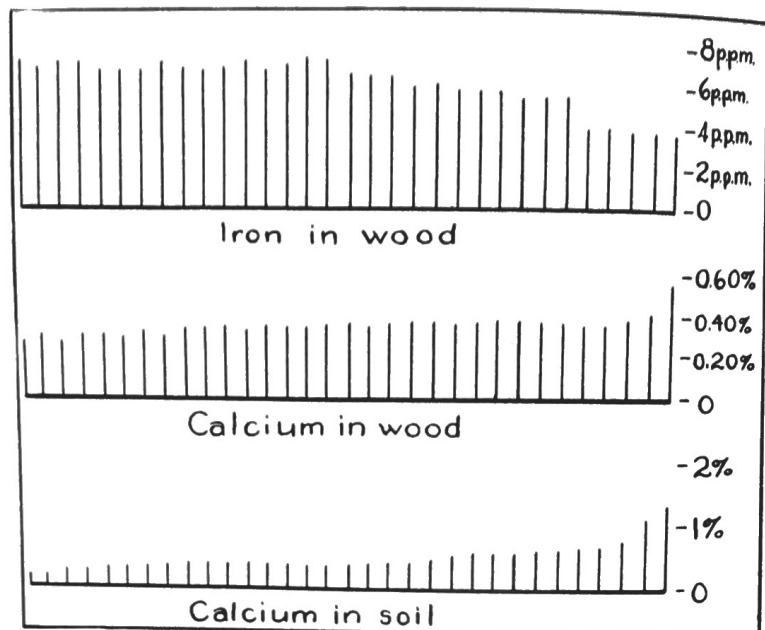
Fig. 2. Distribution of calcium in soil and calcium and iron in wood (*Western Plateau*). Samples arranged in order of increasing calcium in soil.

amination of the charts for the other physiographic provinces. The increase of calcium in the wood practically parallels the increase of calcium in the soil. While a specific inverse factor expressing the relation of the iron in the wood to the calcium in the soil in any one region is not evident, a general relationship clearly exists.

This general relationship is evidenced in another way. A comparison of the distribution charts for the various regions makes evident the fact that in those regions having a low calcium content in

the soil the calcium in the wood is low and the iron in the wood is high; and in those regions having a high calcium soil there is also a high calcium and a low iron content of the wood. The soil samples from the Central Basin all have a high calcium content. Oak wood from the Central Basin has a high calcium and a low iron content. The soil from the Highland Rim is very low in calcium, much lower than that of the Central Basin. The wood from the Highland Rim is very low in calcium and high in iron, the iron being much higher than in the wood of the Central Basin. The calcium in the soil of the Great Valley and the Mississippi Alluvial Plain is much higher than in the soils of Roan Mountain, the Western Plateau, or the Cumberland Plateau. The calcium in the wood from the Great Valley and the Mississippi Alluvial Plain is much higher than in the wood from Roan Mountain, the Western Plateau, or the Cumberland
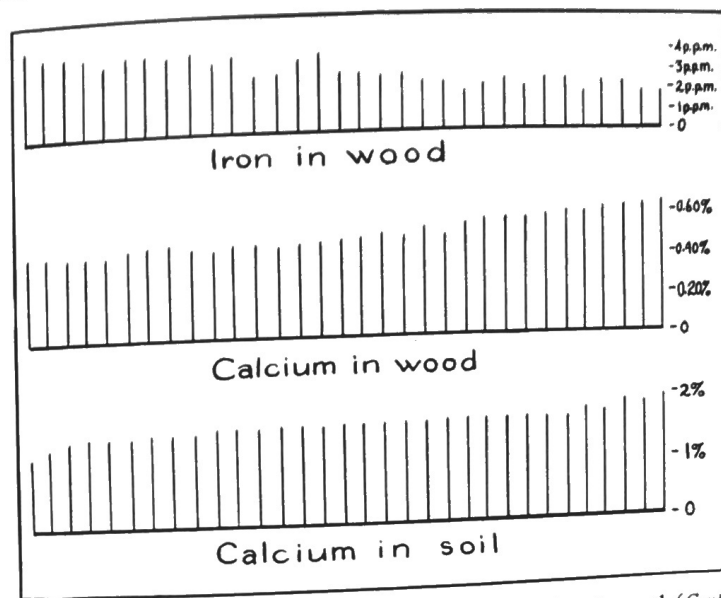

Fig. 3. Distribution of calcium in soil and calcium and iron in wood (*Central Basin*). Samples arranged in order of increasing calcium in soil.

Plateau. The iron in the wood from the first two regions is very much lower than in that of the last three.

The picture is clear. (a) As the calcium in the soil of a physiographic province increases the calcium in the oak wood grown in the soil likewise increases and the iron in the wood tends to decrease, (b) physiographic provinces having a high calcium soil have high calcium and low iron in the wood growing in the soil and those having a low calcium soil have low calcium and high iron in the wood.
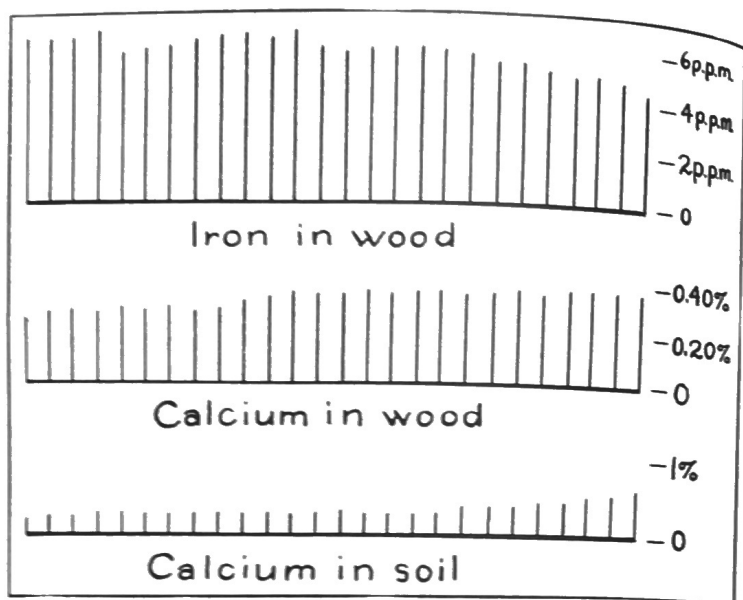
Fig. 4. Distribution of calcium in soil and calcium and iron in wood (*Cumberland Plateau*). Samples arranged in order of increasing calcium in soil.
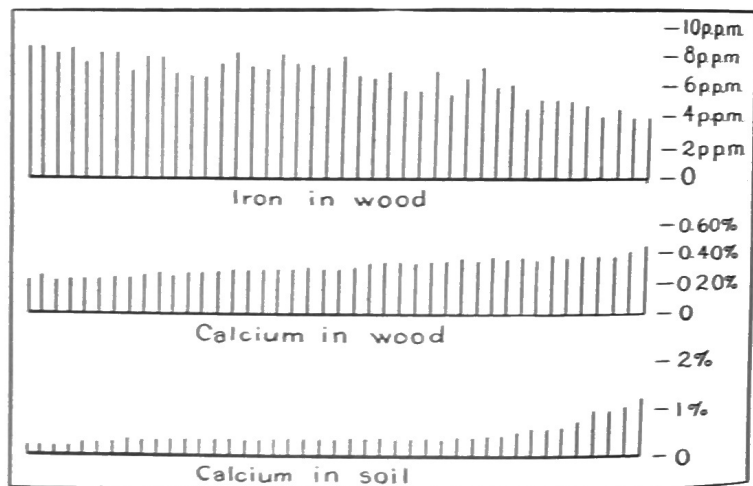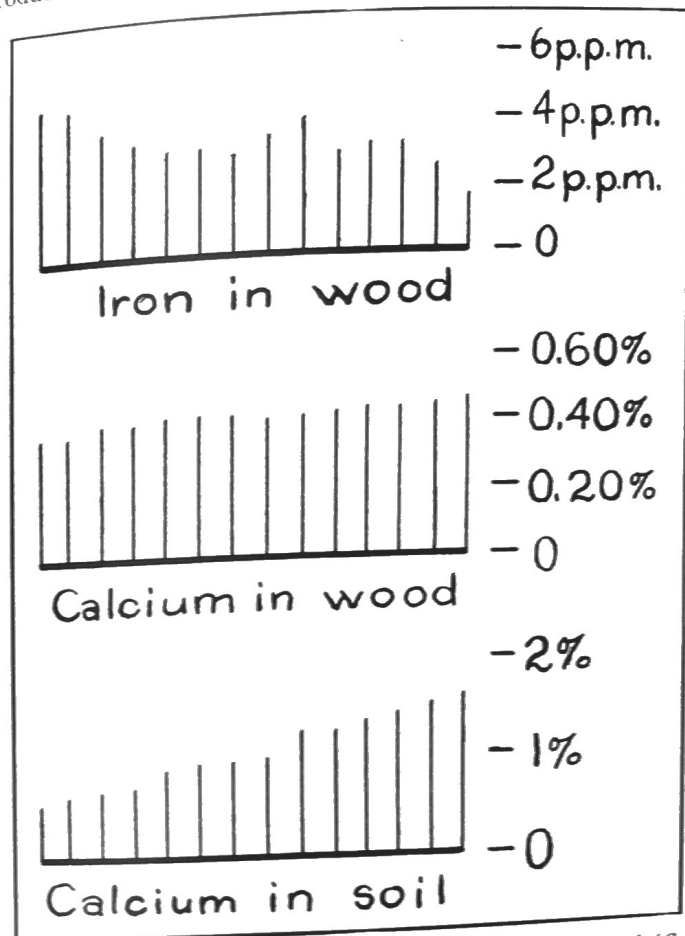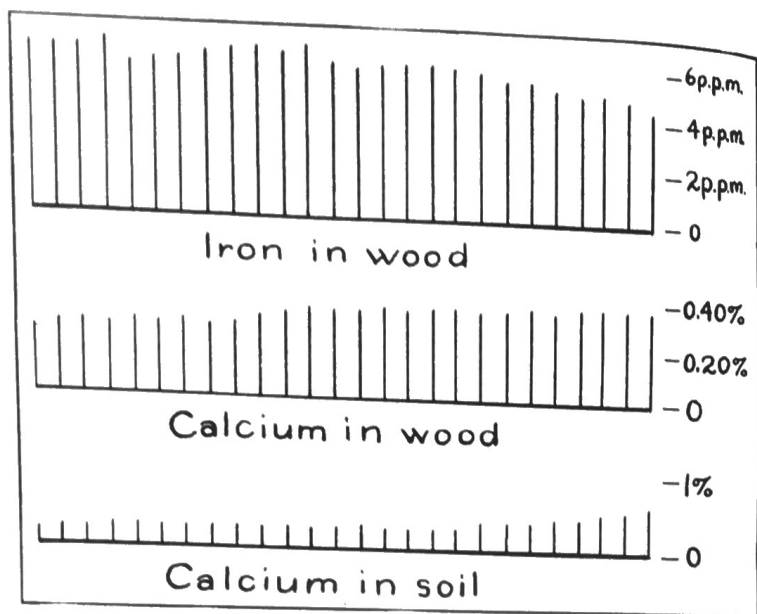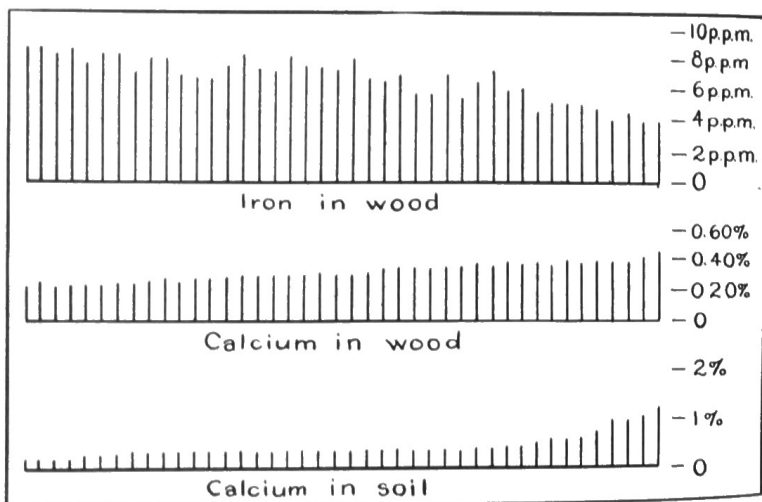

Fig. 5. Distribution of calcium in soil and calcium and iron in wood (*Highland Rim*). Samples arranged in order of increasing calcium in soil.

(2) A second method of showing any relation that may exist between the components of the soil and the constituents of the wood is by the calculation of the coefficient of correlation between the substances. This was done by making use of Karl Pearson's [54, 55] product-moment formula. The results are shown in tables 10 and 11.
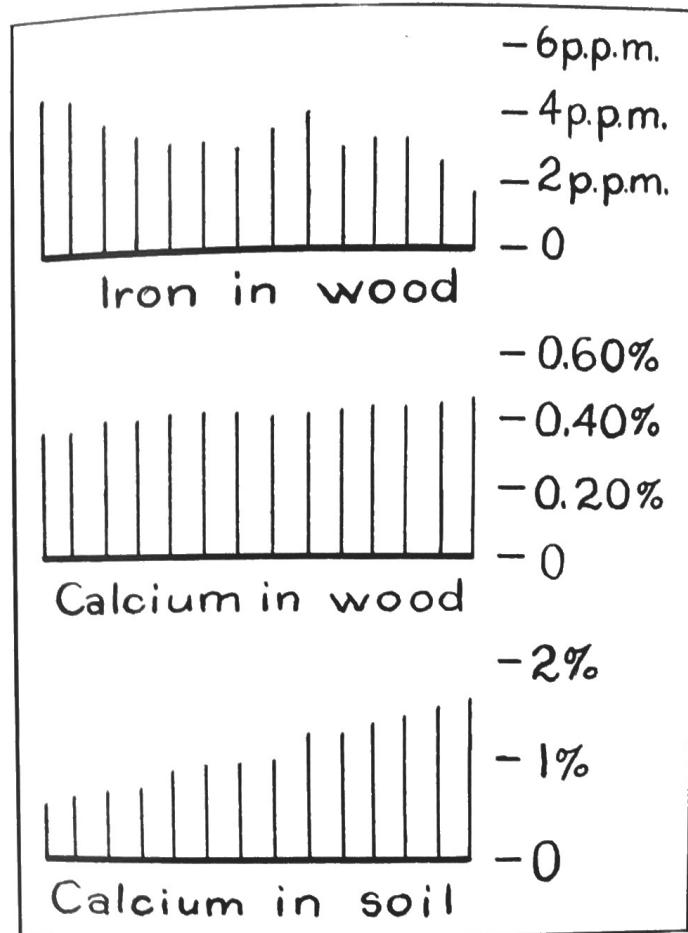

Fig. 6. Distribution of calcium in soil and calcium and iron in wood (*Great Valley of Tennessee*). Samples arranged in order of increasing calcium in soil.

[54]Garrett. H. E. 1926. *Statistics in Psychology and Education.* pp. 163-168. Longmans. Green & Co., New York.
[55]King. W. I. 1924. *Elements of Statistical Method.* p. 200. The Macmillan Co., New York.
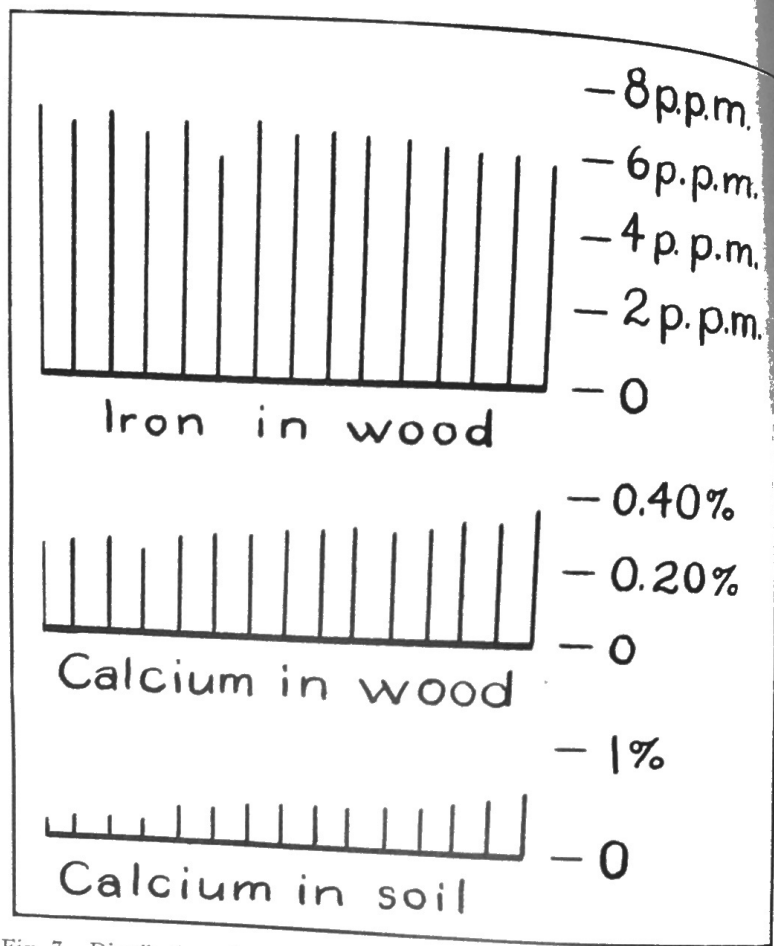
Fig. 4. Distribution of calcium in soil and calcium and iron in wood (*Cumberland Plateau*). Samples arranged in order of increasing calcium in soil.

Fig. 5. Distribution of calcium in soil and calcium and iron in wood (*Highland Rim*). Samples arranged in order of increasing calcium in soil.

(2) A second method of showing any relation that may exist between the components of the soil and the constituents of the wood is by the calculation of the coefficient of correlation between the substances. This was done by making use of Karl Pearson's [54, 55] product-moment formula. The results are shown in tables 10 and 11.

Fig. 6. Distribution of calcium in soil and calcium and iron in wood (*Great Valley of Tennessee*). Samples arranged in order of increasing calcium in soil.

[54]Garrett, H. E. 1926. *Statistics in Psychology and Education*, pp. 163-168. Longmans, Green & Co., New York.
[55]King, W. I. 1924. *Elements of Statistical Method*, p. 200. The Macmillan Co., New York.

Fig. 7.　Distribution of calcium in soil and calcium and iron in wood (*Roan Mountain*).　Samples arranged in order of increasing calcium in soil.

TABLE 10
Correlation Between Calcium in Wood and Calcium in Soil

	r
Alluvial Plain	.87
Western Plateau	.90
Central Basin	.88
Highland Rim	.89
Cumberland Plateau	.91
Great Valley	.92
Roan Mountain	.86
All Samples	.89

r = coefficient of correlation
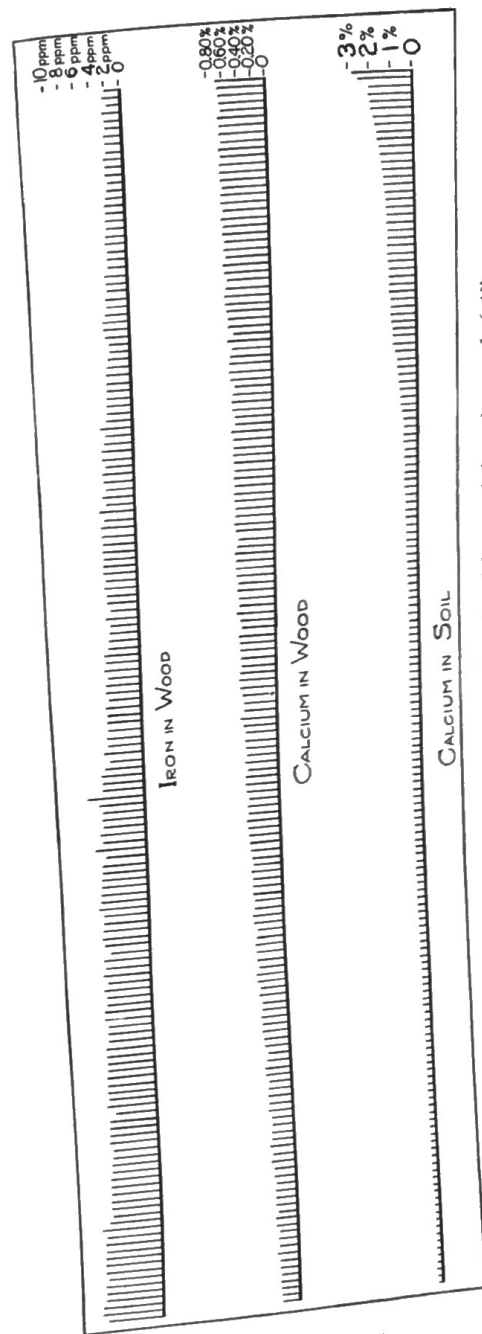
Fig. 8.　Distribution of calcium in soil and calcium and iron in wood (*All Samples*).　Arranged in order of increasing calcium in soil.

It is evident from table 10 that there is a very high positive correlation between the calcium in the soil and the calcium in the wood.

Table 11 shows the correlation between the iron in the wood and the pH, the organic matter, the iron and the calcium in the soil.

The correlation between the pH of the soil and the iron in the wood is uniformly negative and uniformly high. No correlation exists between the organic matter in the soil and the iron in the wood for the value of "r" is, in most cases, much below .50. The same thing is true of the iron in the soil and the iron in the wood.

The correlation between the calcium in the soil and the iron in the wood is negative and high in all cases. This negative correlation explains the correspondingly high negative correlation between the pH of the soil and the iron in the wood. A low pH means an acid soil and a decrease in the acidity is accompanied by an increase in pH. But acidity is decreased by increasing the amount of calcium or other

TABLE 11

Correlation Between Iron in Wood and Other Factors

PROVINCE	PH OF SOIL	ORGANIC MATTER IN SOIL	IRON IN SOIL	CALCIUM IN SOIL
	r	r	r	r
Alluvial Plain	−.72	.40	.10	−.57
Western Plateau	−.59	−.35	−.44	−.62
Central Basin	−.78	.16	−.39	−.76
Highland Rim	−.61	−.13	.22	−.60
Cumberland Plateau	−.83	.17	.12	−.77
Great Valley	−.66	−.19	−.02	−.88
Roan Mountain	−.54	−.26	−.22	−.71
All Samples	−.68	−.12	−.17	−.73

r = coefficient of correlation

base-forming substances in the soil. Thus an increase in calcium is accompanied by an increase in pH and the coefficient of correlation between the calcium in the soil and the iron in the wood will be reflected in the coefficient of correlation between the pH of the soil and the iron in the wood. In other words, a high negative correlation exists between the pH of the soil and the iron in the wood because a high negative correlation exists between the calcium of the soil and the iron in the wood.

A special determination was made of the correlation between the soil components and the iron in the wood in samples from the red strip of the Highland Rim. Here there is an unusually high per cent of iron in the soil. If such a condition reflects itself in the iron of the plant, it should be evident in the correlation. The results of this correlation are shown in table 12.

TABLE 12

Correlation of Iron in Wood of Red Strip, Highland Rim, and Other Factors

	r
pH of Soil	− .68
Organic Matter in Soil	− .14
Iron in Soil	.12
Calcium in Soil	− .71

r = coefficient of correlation

The correlation of the pH of the soil and the iron in the wood closely approaches that of the calcium in the soil and the iron in the wood. In the case of the iron in the soil and the iron in the wood, the value of r is so low that, evidently, no correlation exists. The conclusion may be safely drawn that the iron content of the soil has no effect on the iron content of the oak wood growing on it. Neither does any correlation exist between the organic matter in the soil and the iron in the wood.

As in the case of the physiographic provinces in general, an inverse correlation exists between the calcium of the soil and the iron of the wood of the red strip and, consequently, a similar inverse correlation exists between the pH of the soil and the iron of the wood.

The relation between the calcium and iron of the wood is shown in table 13.

TABLE 13

Correlation Between Calcium and Iron in Wood

	r
Alluvial Plain	− .59
Western Plateau	− .66
Central Basin	− .70
Highland Rim	− .72
Cumberland Plateau	− .50
Great Valley	− .86
Roan Mountain	− .51
All Samples	− .65

r = coefficient of correlation

While the variation between the various provinces is rather high, it is evident that an inverse relation exists as the correlation is high and negative in all cases. This relation would naturally follow if there is an antagonism between the calcium in the soil and the iron in the wood and the calcium in the wood varies directly with the calcium in the soil. When the calcium in the soil is low the wood tends to replace the calcium with iron.

(3) A third method of showing relationship, either direct or inverse, between the components of the soil and the constituents of the wood is by means of a curve.

In figure 9 the percentage of calcium in the soil is plotted as abscissa and the percentage of calcium in the wood as ordinate. An almost straight line is the result, indicating that the calcium of the wood is, practically, a linear function of the calcium of the soil.

In a similar way the mean calcium content of the soil of each physiographic province was plotted as abscissae against the mean iron content of the wood as ordinates. The result is shown in figure 10. For iron values in the wood less than 5 parts per million and calcium content of the soil greater than 0.35%, the curve is exponential and follows the equation[56]

$$Y = Ka^{-x}$$

where x is the amount of calcium in the soil, Y is the amount of iron
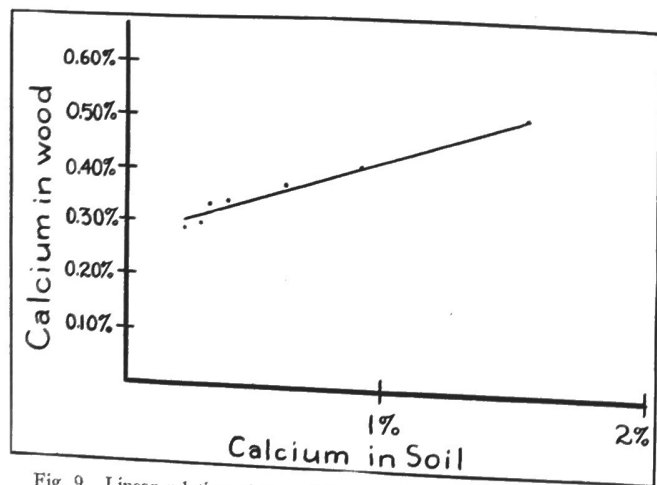
Fig. 9. Linear relation of the calcium in soil to the calcium in wood.

in the wood and K and a are constants. The constant, a, closely approaches the base of the system of natural logarithms. The curve does not follow this equation for iron values greater than 5 parts per million and calcium values less than 0.35%. This may, in part, be accounted for by the fact that, in many of the samples from Roan Mountain, the Highland Rim, and the Cumberland Plateau, the amount of calcium was so small that the experimental error in its determination is manifest in the location of the curve.

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[56]Rietz, H. L. 1924. *Handbook of Mathematical Statistics*, p. 62. Houghton Mifflin Book Co., New York.

SUMMARY OF EXPERIMENTAL RESULTS

Distribution charts for the various physiographic provinces indicate that the calcium in the wood varies directly with the calcium in the soil and that there is an antagonism between the calcium in the soil and the iron in the wood. Those provinces having a low calcium content in the soil have a low calcium and a high iron content in the wood and those having a high calcium in the soil have a high calcium and a low iron content in the wood.
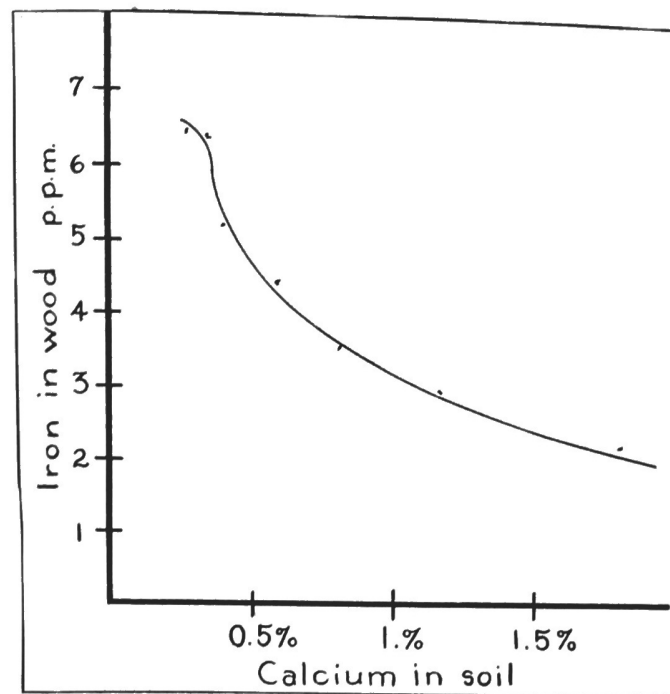

Fig. 10. Exponential relation of the calcium in soil and iron in wood.

Correlations determined by Karl Pearson's product-moment formula show a high positive correlation between the calcium of the soil and the calcium of the wood. They show no relation between the organic matter or iron in the soil and the iron in the wood. There is a very evident inverse correlation between the calcium in the soil and the iron in the wood. This inverse correlation results in a corresponding inverse correlation of the p_H of the soil and the iron of the wood.

The relation of the calcium of the wood and the calcium of the soil is a linear one while the antagonistic relation of the iron of the wood and the calcium of the soil is logarithmic, excepting, possibly, those cases where the calcium content of the soil is less than 0.35%.

CHAPTER VI

CONCLUSIONS

The problem of soil and plant antagonisms is one that has claimed the attention of many investigators. Man's dependence on the plant world makes important any knowledge dealing with the relation of plants to any element of their environment. Our knowledge of climatic effects on the growth and development of plants has evolved through centuries of observation. The effect of certain soil conditions is also evident to the most casual observer. Other soil and plant relationships can be brought to light only by the application of the most careful scientific tests. Yet all these relationships are important. This study was made with the hope that something might be added to this important field of knowledge.

Soil samples were collected from the highly diversified physiographic provinces of Tennessee. At the same time samples of oak wood growing in the soil were collected. The pH of the soil and the per cent of organic matter, iron, and calcium in it were determined. The amount of calcium and of iron in the oak wood were likewise determined. A study of the relationships existing leads to the following conclusions:

(1) A very evident antagonism exists between the calcium in the soil and the iron in the wood. Oak wood growing in soils having a high calcium content has a low iron content and wood growing in soils having a low calcium content has a high iron content.

Distribution charts showing the amount of calcium in the soil and the iron in the wood make this relationship evident. As the calcium of the soil increases, the iron in the wood tends to decrease. The negative correlation between the calcium and iron is not a perfect one, being from — .57 to — .88 for the various provinces.

This relationship may be expressed by an exponential curve fitting the equation

$$Y = Ka^{-x}$$

where x is the amount of calcium in the soil, Y is the amount of iron in the wood and K and a are constants.

(2) The amount of calcium in the oak wood varies directly with the amount of calcium in the soil. The positive correlation is high, being approximately .90. Pugsley and McKibbin[57] have found that the calcium in timothy and red clover hay varies directly with the calcium in the soil. Brown[58] has shown that the same relation exists for apples. Reed and Haas[59] state that the calcium

[57]Pugsley and McKibbin, *op. cit.*

[58]Brown, *op. cit.*

[59]Reed, H. S., and R. C. Haas. 1923. Effect of Sodium Chloride and Calcium Chloride Upon the Growth and Composition of Young Orange Trees. *Calif. Agr. Exp. Sta., Technical Paper*, No. 4.

in orange trees varies with the calcium in the soil and that there is strong evidence that, where the calcium in the soil is low, the tree will substitute magnesium for the calcium.

This study leads to the conclusion that the calcium in oak trees varies directly with the calcium in the soil. Furthermore, when the calcium of the soil is low the oak tends to substitute some iron for the calcium.

(3) There is a very clear negative correlation between the p_H of the soil and the amount of iron in the oak wood growing in the soil. This correlation is not perfect, being from $-.54$ to $-.83$ for the various provinces. This antagonism between p_H of the soil and the iron in the wood is due to the antagonism between soil calcium and wood iron since, as Mann[60] has shown, the p_H of a soil is largely determined by its calcium content.

(4) No relationship exists between the amount of iron in the soil and the amount of iron found in the wood. Even an abnormally high iron content in the soil is not reflected in the amount of iron taken up by the wood.

(5) No relationship exists between the organic matter in the soil and the iron in the wood.

A possible explanation of the antagonistic relationship existing between calcium in the soil and iron in the wood is to be found in the work of a number of investigators. Mann[61] has shown that for p_H values above 4 the availability of iron in the soil decreases rapidly with increase of calcium in the soil and the attendant increase of p_H. Lemanczyk[62] found that the absorption by roots consists of two phases, absorption of molecules and absorption of ions with the former predominating. Absorption from solutions of electrolytes is influenced by the nature of the electrolytes, by ratio of concentration of equally charged ions, and by the antagonistic action of ions. Magistad[63] has shown that an antagonism exists between iron and calcium in base exchange in soil, iron tending to liberate the calcium.

In view of these studies it is probable that high calcium in the soil results in low iron in the wood due to decreased availability of iron in the soil and an antagonistic action in the absorption of iron ions and calcium ions, the calcium ions predominating in effect.

The question may be raised whether the action is a reversible one and subject to the Mass Action Law. If so, low soil calcium would permit exchange of iron for calcium in the wood and high soil calcium

[60]Mann, *op. cit.*, p. 125.
[61]Mann, *ibid.*, p. 125.
[62]Lemanczyk, K. 1926. Absorption of Potassium Salts by the Root Systems of Plants. *Academie Polonaise, Bulletin*, 1926, B, pp. 1109-1155.
[63]Magistad, O. C. 1928. The Action of Aluminum, Ferrous and Ferric Iron and Manganese in Base Exchange Reactions. *Arizona Agricultural Experiment Station, Technical Bulletin*, 18, pp. 445-463.

would drive the action in the opposite direction, thus increasing the amount of calcium and decreasing the amount of iron in the wood. Individual divergencies in the iron in the wood from the general relationship between iron and calcium are probably due to the influence of other ions that may be present in the sample.

During the investigation of this problem a number of others have arisen. It is hoped that future investigators in this field may find it desirable to follow up one or more of them. Some of these problems are:

(1) What is the percentage of calcium, phosphate, iron, and magnesium in different kinds of wood growing in the same soil? Microchemical methods already developed or in process of development make possible exceedingly accurate determinations that could be used in such a study.

(2) An antagonism exists between the calcium in soil and the iron in oak wood. Does such an antagonism exist in other woods?

(3) What relationships, as yet undetermined, exist between other soil components, as phosphate, magnesium, etc., and other constituents of wood?

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