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Seasonal and Profile Variations in Oxygen Content of Forest Soils Under Mature Loblolly Pine (Pinus Taeda L.) Stands.

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SEASONAL AND PROFILE VARIATIONS IN OXYGEN CONTENT OF FOREST SOILS UNDER MATURE LOBLOLLY PINE (*Pinus taeda* L.) STANDS

A Dissertation

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ABSTRACT

Seasonal and profile variations in oxygen content of forest soils under mature loblolly pine (*Pinus taeda* L.) stands was studied on the Louisiana State University Lee Memorial Forest in southeastern Louisiana. An attempt was also made to relate the oxygen content to soil moisture, to soil physical properties such as texture, porosity, and bulk density, and to fluctuations in the water table.

Nine circular quarter-acre plots were selected at different locations in even-aged loblolly pine stands. The soil oxygen content was measured with an oxygen meter at two-week intervals at each soil depth. The measurements were started on April 4, 1970, and continued for a year to determine the seasonal pattern of oxygen changes in the soil.

Weekly soil moisture measurements were made with a neutron soil moisture probe in access tubes previously installed in the center of each plot. On plots where a free water table was present, a drain-pipe was installed and depth to the water table was measured biweekly. Soil samples were collected from each plot and from each soil depth for the determination of bulk density, texture, and porosity in the laboratory.

An analysis of variance was used to determine the effect of changes in season and soil depth on oxygen

content. The relationships between soil oxygen content and soil moisture, texture, porosity and bulk density were evaluated using linear correlations.

It was concluded that the oxygen content in the forest soils under these mature loblolly pine stands varied throughout the year. Usually, the oxygen content was lower in winter and in early spring and increased as the growing season progressed. Oxygen content also changed with soil depth, generally decreasing with increasing depth into the soil profile.

It was also concluded that the oxygen content in these forest soils was mainly influenced by soil moisture, water table, rainfall, slope, and both capillary and non-capillary porosity. As soil moisture increased, even as a result of rises in the water table or by heavy rainfall, the soil oxygen decreased. The study indicated that slope also affected the soil oxygen content, probably being related to soil moisture increases down the slope. A significant relationship was found between soil oxygen content and capillary and noncapillary porosity. As the capillary porosity increased, the soil oxygen content decreased, whereas as the noncapillary porosity increased, the oxygen content in the soil profile increased also.

The results of this study indicate that mature loblolly pine trees are probably rather tolerant to low soil oxygen content. Low soil oxygen content in the winter and early

spring or in subsoils (below 4 feet) apparently has not been detrimental to the growth of these loblolly pine trees. Optimum growth of loblolly pine trees perhaps depends more on the proper balance of soil oxygen and soil moisture content throughout the growing season rather than on a minimum level of oxygen alone.

INTRODUCTION

Adequate soil oxygen is needed for normal root growth for most plants and soil oxygen influences plant production in a large number of ways. Numerous reports have shown that decreasing the oxygen supply to the root systems results in decreased respiratory activity, reduced water and nutrient absorption, and reduced rooting depth and plant growth of various plants (Harris and Van Bavel 1957a, Kramer 1949, 1950, 1969; Kohnke 1968, Lawton 1945, Letey et al. 1962b, Patrick 1971, Williamson 1964, and others). But the requirement of soil oxygen for optimum root development and plant growth varies greatly with species and age of the plant (Leyton and Rousseau 1958). Some species can survive with only 1 or 2 percent[a] oxygen (Cannon 1925), but more than 10 percent and less than 21 percent is required for good growth for most plants (Boynton et al. 1938, Kohnke 1968, Kramer 1969, and Leyton and Rousseau 1958).

In the soil air the oxygen content is usually lower and carbon dioxide content is higher than in atmospheric air, because the respiration of plant roots and

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[a] Throughout this paper, soil oxygen is expressed as a percentage of the soil air volume; e.g., 10 percent oxygen content means that 10 percent of the total air volume in the soil is oxygen.

microorganisms living in the soil remove oxygen and release carbon dioxide. Under good aeration, the oxygen content in the soil approaches that of atmospheric air (21 percent by volume); whereas under poor aeration conditions, the oxygen content is generally decreased. Carbon dioxide content is increased with poor aeration, especially under waterlogged conditions. Under natural conditions, it is not the excess of carbon dioxide that retards plant growth but the lack of oxygen (Kramer 1950, Russell 1952, Unger and Danielson 1965). Many trees may suffer from lack of adequate soil oxygen in the field, at least part of the growing season (Kramer 1950). Many reports have been published on the relationship of soil oxygen to root growth and plant development, but most of this research was done with herbaceous species grown in sand or solution cultures; very little has been done with tree seedlings. As a result, much of the information concerning the importance of soil oxygen to tree growth is based on inference rather than quantitative data obtained from the field. Despite the lack of field verification, the large amount of quantitative information concerning soil oxygen and crop growth seems to lead to the conclusion that soil oxygen content is one of the most important factors affecting tree growth and timber production.

It is generally accepted that changes in soil physical properties, such as soil moisture content, texture and

structure, result in changes in soil oxygen content (Russell 1952). But there is a surprising lack of quantitative data to prove these relationships. In order to explain satisfactorily how soil oxygen content limits root growth and development of trees, more extensive experiments are needed and more basic information must be obtained directly from the forests.

The main purpose of this study was to measure the oxygen content in several soil types under mature (39 to 48 years old) loblolly pine (*Pinus taeda* L.) trees and to find out how it changes with season, with soil depth, and with depth to the water table. An attempt was also made to relate the soil oxygen content to such soil physical properties as moisture content, texture, structure, porosity and bulk density. The results of this study should provide basic information about the root growth conditions of forest trees and thus be useful to the better understanding of the growing conditions required by trees. A knowledge of factors influencing root development should also contribute to our understanding of natural soil productivity for forest growth.

REVIEW OF LITERATURE

Characterization of the Soil Air and Oxygen Content in the Soil Profile

The composition of soil air differs from atmospheric air. The soil air contains more CO_2 and less O_2, because the plants and microorganisms living in the soil utilize oxygen from the soil air and give off CO_2 into it. In spite of the difference in composition, soil air exhibits the same characteristics of a gas as does atmospheric air. The soil air has a low density, low viscosity, and low thermal conductivity (Russell 1952).

The content of soil oxygen varies with season and soil depth (Boynton and Reuther 1938, 1939; Russell 1952; Unger and Danielson 1965). In general, oxygen content declines and carbon dioxide increases as the soil depth increases (Franken 1968), and this can be greatly marked in heavy or badly drained soil. Boynton and Reuther (1938) reported that the oxygen content in a silt loam soil is usually low in winter and in early spring and increases as the season progresses.

The Importance of Soil Oxygen to Root Growth and Development of Plants

The importance of soil oxygen for root growth has been

known since the respiration process of plants was determined. Direct evidence for the necessity of adequate oxygen for normal functioning of roots has been confirmed repeatedly by many scientists. Comprehensive reviews of the literature on the relationships of soil oxygen to root growth and development of plants were published by Clements (1921), Cannon (1925), Russell (1952), and Grable (1966). From the information contained in those reviews, the conclusion is that soil oxygen influences root growth, water uptake by roots, nutrient absorption and availability, root morphology, disease incidence, and auxin metabolism of various plants.

Plant Requirements for Soil Oxygen

When the oxygen content in the soil is limited, root growth and activity are generally restricted (Hopkins et al. 1950, Kramer 1951, Patrick et al. 1969), but the soil oxygen requirements for plant growth vary with plant species and age (Hopkins et al. 1950, Grable 1966, Kramer 1949 and 1969, Vlamis and Davis 1944).

It has been established that 3.5 percent oxygen in the soil air was deficient for normal growth of sweet orange seedlings and that growth was reduced significantly within 3 weeks both in acid and in calcareous soils (Wallihan et al. 1961). Yelenosky (1964) found that American elm (*Ulmus americana* L.) seedlings were the most

tolerant to low oxygen and tulip-tree (*Liriodendron tulipifera* L.) seedlings the least tolerant, while swamp white oak (*Quercus bicolor* Wild.), sugar maple (*Acer saccharum* Marsh.) and flowering dogwood (*Cornus florida* L.) were intermediates. The seedlings of loblolly pine, short-leaf pine (*Pinus echinata* Mill.) and pond pine (*Pinus serotina* Michx.) are resistant to low soil oxygen (Hunt 1951). However, there is evidence of increasing tolerance to oxygen deficiency with age (Grable 1966, Leyton and Rousseau 1958). The variation in oxygen requirements among different species and of different ages is not fully understood yet. Several investigators have suggested that oxygen may move down from the shoot of the plants to the root system (Arikado 1955, Brown 1947, Cannon 1932, Laing 1940a and 1940b, Leyton and Rousseau 1958), so it is very difficult to determine the minimum and maximum soil oxygen requirements for various plants in the field. In spite of the fact that much has been said about the necessity of adequate oxygen for root growth and plant development, there is a lack of information on the exact oxygen requirements of various plants. It seems that most plants can grow well in soil with more than 10 percent and less than 21 percent oxygen (Geisler 1969, Kohnke 1968).

Symptoms of Deficiency of Oxygen Supply to Root System

Soil oxygen deficiency is difficult to recognize and perhaps has been overlooked in the past because the

symptoms of O_2 deficiency are often associated with symptoms of water and nutrient shortages.

In general, under poor aeration conditions, the leaves of the tree usually turn yellow progressively from the bottom, die and drop off. When poor aeration also causes a mineral deficiency, the leaves of the tree become mottled and anthocyanin is found, causing the leaves of the tree to turn red prematurely (Kramer 1950). If the trees are growing under very poor aeration, the twigs and branches may die also and, ultimately, the whole top may die. Sometimes, it is difficult to determine an oxygen deficiency from the symptoms of the top only, because some tree species can survive for two or more years after flooding and then die suddenly. Kramer (1950) reported that loblolly pine seedlings flooded for 10 months developed no visible top injury, but the roots were damaged badly.

The Important Roles of Soil Oxygen in Controlling the Root Growth and Development of Plants

In addition to the effects of soil oxygen on root growth (Patrick 1971, Patrick et al. 1969), it affects water uptake of roots, nutrient absorption and availability, soil processes, root morphology, auxin metabolism and disease incidences of most plants.

a. Soil oxygen and root growth. -- Attempts have been made to relate soil oxygen to root growth of various

plants. Leyton and Rousseau (1958) found that all spruce (*Picea* sp.) and pine seedlings used in their experiment required at least 10 percent oxygen for optimum growth. In the absence of oxygen, root growth of spruce and pine seedlings ceased and the roots died within two days.

Letey et al. (1962a, 1962b) reported that the roots of cotton, sunflower and beans ceased growing at low oxygen content and that low oxygen (less than 1%) is most detrimental during the early stages of growth. Root and top growth of barley and peas were also influenced by the concentration of soil oxygen. As the concentration of oxygen was reduced to very low levels, both root and top growth were decreased (Geisler 1967). Patrick et al. (1969) studied the development of root systems of sugar cane in relation to soil oxygen content. They found that oxygen content was often a limiting factor for optimum growth of sugar cane, especially in the first part of the growing season, in several soil series such as Mhoon, Sharkey, Baldwin and Iberia.

Root elongation is one of the plant functions that can be closely related to soil oxygen content. Stolzy et al. (1961) found that root elongation increased as the oxygen concentration increased up to 21 percent. That penetration of plant roots into soil is suppressed by low oxygen content in the soil also has been reported (Hopkins and Patrick 1969). Soil oxygen content as a limiting

factor influencing root growth of various plants has been investigated by Bergman (1920), Boynton (1940), Brown et al. (1965), Currie (1962), Erickson and Van Doren (1960), Gill and Miller (1956), Luxmore and Stolzy (1969), Poel (1961), Scott and Erickson (1964), and Vlamis and Davis (1944).

b. Soil oxygen and water uptake by root systems. -- Soil oxygen deficiency reduces water uptake of plants directly through its effect on absorption and indirectly by reducing root growth. Kramer (1949) stated that a decreased oxygen supply to the roots reduces their permeability to water, thus causing a decrease in water absorption. Childers and White (1942) found that the capability for water absorption of apple-tree seedlings was reduced when the seedlings were flooded. Parker (1950) observed that, when shade-tree seedlings were flooded, the water absorption of the seedlings decreased.

c. The effect of oxygen content on mineral absorption and nutrient availability. -- Mineral absorption by roots is one of the most important functions in plants that is affected by low soil oxygen content. Kramer (1950) reported that the absorption of phosphorus by pine trees was decreased to only 5 percent of the controls by displacing all oxygen with nitrogen. When oxygen content was lower than 3 percent, both K- and P-uptake were reduced (Hopkins et al. 1950). Iron deficiency of tomato plants

is frequently associated with nonaerated conditions, according to Guminski et al. (1965). Wallihan et al. (1961) reported that orange seedlings in calcareous soil developed strong iron chlorosis at a low oxygen level (3.5%) and that the concentration of iron and manganese in the leaf was reduced greatly due to low O_2 content.

Harris and Van Bavel (1957b) experimented with tobacco plants and found that nutrient absorption remained relatively constant until the oxygen content was reduced below 10 percent. The order of sensitivity of the nutrients to oxygen concentration seems to be K>N>P>Mg>Ca.

Nutrient uptake of plants limited by oxygen deficiency has also been demonstrated by others for a wide variety of crop plants (Brouwer 1965, Cline and Erickson 1959, Lawton 1945, Letey et al. 1962b, Stolzy and Letey 1964a) and for several bottomland tree seedlings (Hosner and Leaf 1962). The availability of some mineral nutrients is also influenced indirectly by oxygen deficiency because it limits the activities of certain soil microorganisms, especially those concerned with the processes of nitrification (Kramer 1969).

d. Soil processes as affected by soil oxygen. -- One of the most important ways in which soil oxygen indirectly influences plant growth and development is through its effect on the biological processes of the soil. In the absence of oxygen, anaerobic reactions predominate and the

reduced forms of nitrogen and sulfur may accumulate and be toxic to plants. The amount of soluble iron and manganese are also influenced by the amount of soil oxygen. Under conditions of inadequate soil oxygen, some microbiological processes may be harmful to plant growth; for example, N_2 or CH_4 is evolved, organic inhibitors appear, and sulfide, ferrous, and manganous ions accumulate during periods of O_2 deficiencies (Alexander 1961).

e. Soil oxygen and root morphology. -- The roots of plants grown under conditions of adequate aeration are quite different from those grown under poor aeration conditions. The influence of soil oxygen on root structure has been studied by Loehwing (1937), Weaver and Himmel (1930), Daubenmire (1959), and others. Under a good supply of oxygen, roots usually are long and light-colored, with an abundance of root hairs. In contrast, under conditions of oxygen deficiency, roots are shorter, thicker, darker, and have less numerous root hairs. Aquatic plants and those indigenous to poorly drained soils generally form specialized root structures. For example, the knees of baldcypress trees (*Taxodium distichum* (L.) Rich.) may serve to supply oxygen for normal root growth and development (Bergman 1920, Clements 1921, Dean 1933, Sifton 1945). However, the recent research has shown that the knees of cypress trees do not play an important role as aerating structures (Kramer et al. 1952).

Andrews and Beal (1919) reported that the cortical cells of aerated roots were uniform in size with no conspicuous air cavities, while the cortical cells of the nonaerated roots contained larger air cavities. The root anatomy of various plants grown under oxygen deficiency was also studied by Armstrong (1964), Luxmore and Stolzy (1969), Kramer (1951), and Yu et al. (1969).

f. Soil oxygen content and auxin metabolism. -- Recent evidence indicates that soil oxygen directly or indirectly affects the production, transport, or activity of auxin in plants. Kramer (1951) showed that oxygen deficiency causes downward curvature of plant leaves and initiation of new roots. Low oxygen content inhibits cyclosis (protoplasmic streaming) and increases the viscosity of protoplasm (Seifriz 1945) which influences transport and diffusion of auxin within the plant tissues (Grable 1966).

g. Soil oxygen and plant diseases. -- In addition to the above effects, soil oxygen content also influences growth and production of plants through its effect on plant diseases (Bergman 1959, Zentmyer 1966). When aeration is poor, the fungus *Phytophthora cinnamomi* becomes so abundant that it causes serious injury to avocado root systems (Zentmyer and Klotz 1948). The same fungus causes "little-leaf" disease in loblolly pine and shortleaf pine (Mustanoja and Leaf 1965).

Factors Affecting Oxygen Content in the Soil

Under natural conditions, the oxygen supply to the root system is controlled by the rate of oxygen diffusion through the soil (Cline and Erickson 1959, Stolzy et al. 1961). It is generally agreed that the oxygen diffusion rate should be at least 30 x 10^{-8}g/cm^{2}/min. for satisfactory plant growth (Bertrand and Kohnke 1957, Stolzy and Letey 1964a) and that the rate of oxygen diffusion depends largely on such soil properties as soil moisture content (Taylor 1949) and soil texture and structure (Currie 1962).

Soil moisture affects soil oxygen content. -- Taylor (1949) has reported that the oxygen diffusion rate is strongly influenced by the soil moisture content. An increase in soil moisture content will decrease oxygen content in the soil. During the winter months, the oxygen in a silt loam soil may vary from 0.15 to 0.25 percent, but as the soil dries out after April, the oxygen content increases rapidly (Boynton and Reuther 1939). Epstein and Kohnke (1957) also reported that high moisture content decreased oxygen content at the 8-inch depth in silt loam soil.

Soil oxygen content affected by soil texture and structure. -- Soil texture and structure play very important roles in controlling the soil oxygen content. The

oxygen supply is usually adequate in sandy soils, but it is often a limiting factor in fine-textured soils, particularly in those with less than 10 or 12 percent of noncapillary pore space (Robinson 1964, Vomocil and Flocker 1961). Lemon and Erickson (1952) have shown conclusively that oxygen diffusion in the soil is a linear function of water-free porosity. The oxygen content at field capacity in Amarillo fine sandy loam is optimum for normal root growth but is not optimum in Miller clay, according to Wiegand and Lemon (1958). Boynton and Reuther (1939) found that the oxygen content was only 0.19 percent at the 6-foot depth of a silty clay soil. Leonard (1945) also reported that the oxygen content under cotton in a field of Houston clay ranged to zero, while the lowest content in Sarpy fine sandy loam was 8 percent.

<u>Soil organic matter and oxygen content</u>. -- There is close relationship between organic matter content and soil oxygen content. Adding additional organic matter to the soil will increase the activities of soil microorganisms and results in decreased oxygen content in the soil (Epstein and Kohnke 1957). Kohnke (1968) reported that the lower the oxygen content in the soil, the higher its organic matter content will be, because high soil oxygen will cause organic matter to be oxidized quickly in the field.

Soil compaction influences oxygen content in the soil. -- Soil compaction usually reduces soil oxygen content (Epstein and Kohnke 1957, Patrick 1971, Rickman et al. 1965 and 1966, Rosenberg 1964, Tackett and Pearson 1964), but in the field it is difficult to separate the effect of low oxygen content from the mechanical effect of compaction on root growth (Hopkins and Patrick 1969).

Summary of Review of Literature

The importance of soil oxygen to root growth and tree development is obvious. The deficiency of soil oxygen influences root growth, water uptake by roots, nutrient absorption and availability, root morphology, disease incidence, and auxin metabolism of various plants. In order to have optimum root growth and development, trees must have adequate soil oxygen. The soil oxygen requirement for good growth varies with species and age of the plants. However, most plants require at least 10 percent of soil oxygen for their optimum growth.

The content of soil oxygen varies with season and soil depth. Soil oxygen content is usually low in winter and early spring and increases as the season progresses, and the content of soil oxygen decreases with increases in soil depth.

Under natural conditions, the soil oxygen content is controlled chiefly by the rate of oxygen diffusion through

the soil. The rate of oxygen diffusion depends largely on such soil properties as texture, structure, moisture content, organic matter content, and soil compaction.

METHODS AND PROCEDURES

Location and Description of Study Area

Twenty circular quarter-acre plots (numbered from 1 to 20) were established under Louisiana Agricultural Experiment Station Project 1276 in 1967 at different locations and on different soil types on the University's Lee Memorial Forest near Franklinton in Washington Parish, Louisiana. The main objective of Project 1276 is to study the rooting depth of mature southern pine trees and to determine soil properties which limit deeper penetration of roots within the soil profile. Related to this objective is the study of variations in soil oxygen, which is the subject of this report.

Only nine of the 20 plots (Number 1, 4, 5, 7, 9, 10, 17, 18, and 20) were used for the study of soil oxygen. These plots are located in even-aged loblolly pine stands ranging in density from 65 to 127 ft^2 of basal area per acre, and the trees on the plots average from 39 to 48 years old. The stand characteristics, soils and depths at which oxygen was measured in each plot are listed in Table 1.

The soils on the nine study plots are representative of the uplands and minor stream bottoms of the Coastal Plain. The soils are loamy in texture and range from the poorly drained Bibb (a Typic Haplaquent) and Myatt (Typic

Table 1. Stand characteristics, soils, and depths at which soil oxygen content was measured in each plot

Plot Number	Basal area	Average tree age	Site index[a]	Soil classification	Measurement depths
	Ft^2 per acre	Years			Feet
1	65	42	98	Stough vfsl (Aquic Fragiudult)	1,2,3,4
4	101	41	98	Bowie fsl (Plinthic Paleudult)	1,2,3,4
5	113	48	107	Bibb sil (Typic Haplaquent)	1,2,3,4
7	127	42	100	Lexington sil (Ultic Paleudalf)	1,3,5,7
9	118	39	100	Ruston sl (Typic Paleudult)	1,2,3,4,5,6,7
10	98	39	98	Ruston sl (Typic Paleudult)	1,2,4,6
17	109	43	115	Bowie l (Plinthic Paleudult)	1,2,3,4

Table 1 (Continued)

Plot Number	Basal area	Average tree age	Site index[a]	Soil classification	Measurement depths
	Ft^3 per acre	Years			Feet
18	114	39	113	Myatt vfsl (Typic Ochraquult)	1,2,3,4
20	115	42	118	Stough vfsl (Aquic Fragiudult)	1,2,3,4

[a] Based on mean height (in feet) of dominant and codominant trees at age 50.

[b] Letters after soil series name represent soil texture: sil - silt loam, sl - sandy loam, fsl - fine sand loam, vfsl - very find sandy loam, l - loam. The descriptions of these soils may be found in Appendix A.

Ochraquult) to the well drained Ruston (Typic Paleudult). The depths at which the soil oxygen content was measured in each plot were determined on the basis of previously measured soil moisture changes; oxygen measurements were made at those depths where appreciable changes in soil moisture had occurred during the previous two years.

So far as is known, none of the study plots had ever been in cultivation. The original forest stand - probably pure longleaf pine (Pinus palustris Mill.) on the uplands and loblolly pine mixed with hardwoods on the wetter sites - was clearcut in the early 1920's. Subsequently, much of the University Forest became reestablished to loblolly pine with the typical hardwood component. When the plots were established in 1967, the hardwood trees were cut or injected with a herbicide after which the hardwood sprouts were controlled by periodic herbicide application with a mist blower. An aluminum access tube for soil moisture measurements was installed to a depth of 20 feet in each of the plots when they were first established. A view of one of the study plots is shown in Plate 1.

Soil Oxygen Measurement in the Field

The method used to measure the soil oxygen content in this study was similar to the method used by Patrick et al. (1969) for sampling and analyzing the oxygen content

Plate 1. Overall view of one of the plots used for oxygen measurements.

in soil profiles in the sugarcane area. This method involved the establishment of a permanent air reservoir in the soil profile at each depth selected for oxygen measurements. These reservoirs were sealed off from the atmosphere and the air in the reservoir was allowed to come to equilibrium with the soil air. Samples of soil air (12 to 20 cc) were drawn into an oxygen analyzer cell and the oxygen content was read directly on an oxygen meter.

Air reservoirs - one at each sampling depth - were established about 1 foot apart and at least 3 feet from the soil moisture access tube, and three replications were used for each soil depth in each plot (Plate 2). The physical location of the three replications varied among the plots due to the distribution of trees on the plots in relation to the soil moisture access tube (Figure 1).

The materials used in constructing the soil-air reservoirs are shown in Plate 3 and the sampling system as established in the soil profile is illustrated in Figure 2. A sampling tube 3/4-inch in diameter was used to cut into the soil to a depth 2 inches greater than the desired sampling depth. A No. 4 rubber stopper was slipped on the end of a section of copper tubing of 1/8-inch O.D. and was stabilized with epoxy. After the epoxy had hardened, the copper tubing with the attached stopper was forced into the hole far enough so that an opening 4

Plate 2. Close view of Plot No. 9 to illustrate measurement points for oxygen readings (white points) in relation to the soil moisture access tube.

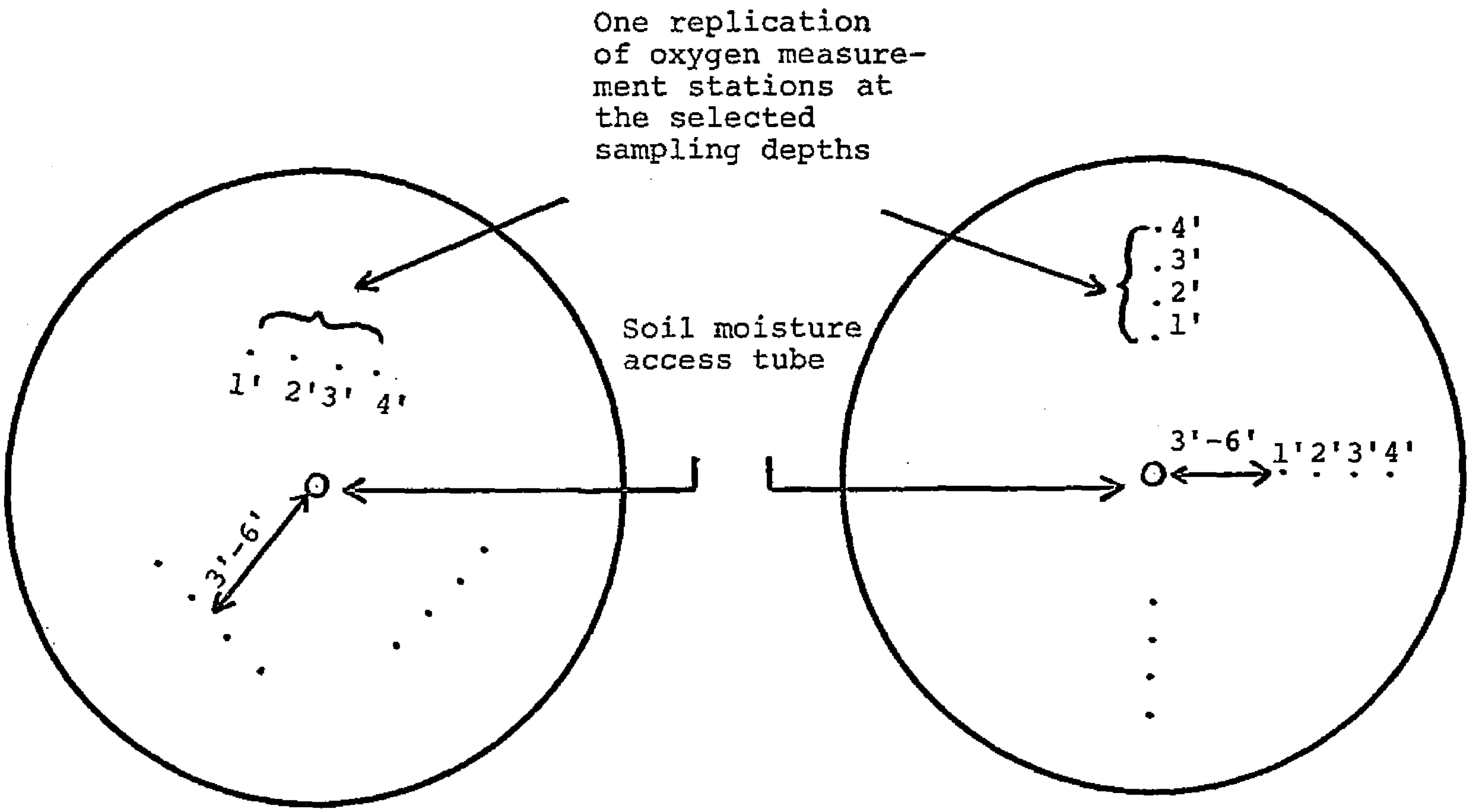

Figure 1. Schematic diagram of oxygen sampling points as established in the study plots.

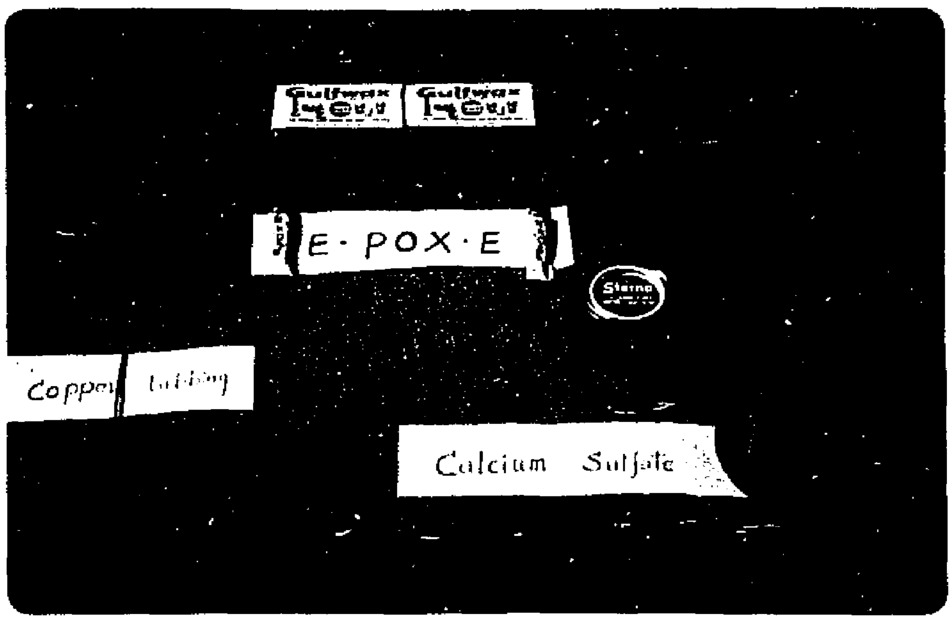

Plate 3. The components used in constructing the soil air reservoir for oxygen measurement.

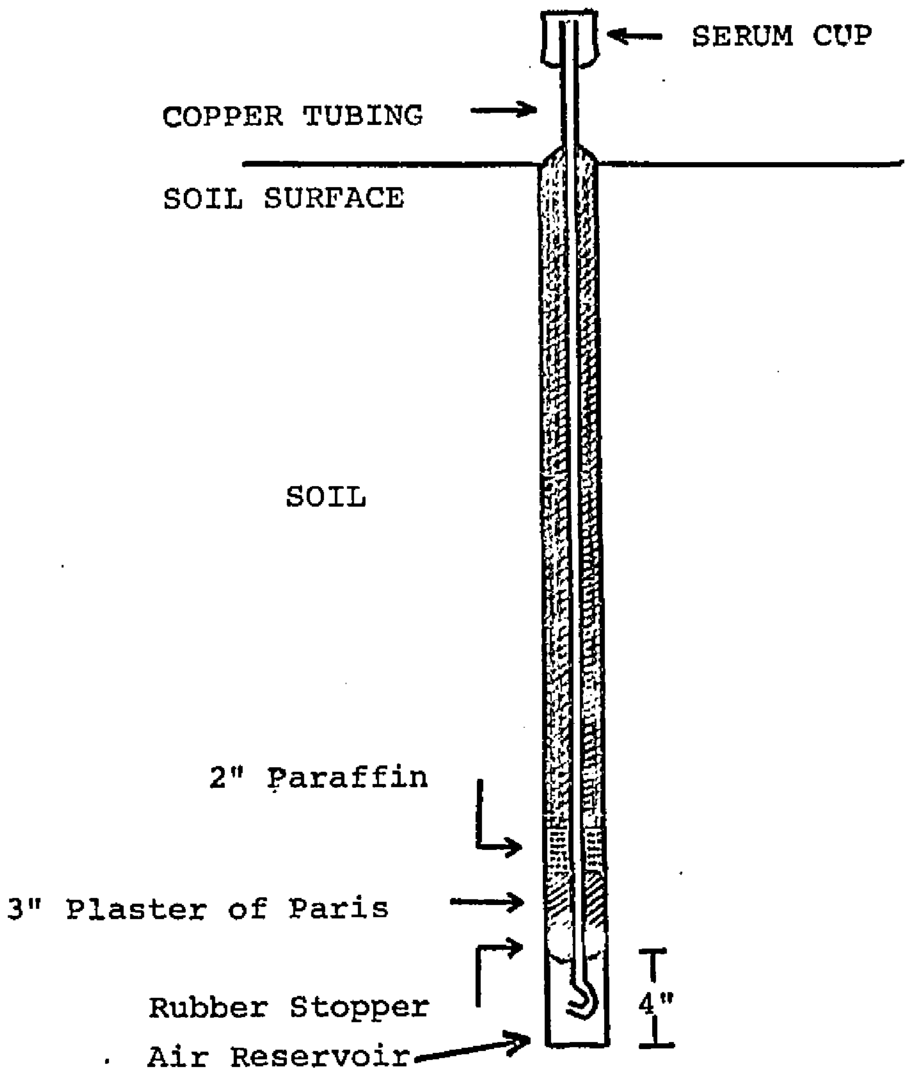

Figure 2. System used for establishing air reservoirs in the soil (adapted from Patrick et al. 1969).

inches long was left below the stopper. In this way the reservoir was large enough to permit exchange of gases between the soil and the reservoir.

In order to prevent contamination with atmospheric oxygen, a 3-inch layer of plaster of paris and a 2-inch layer of melted paraffin were poured into the hole, and the remainder of the hole was filled with soil. The portion of the copper tubing above the soil surface was covered with a small serum cap.

Samples of soil air were drawn into a specially designed cell connected to an oxygen analyzer (Yellow Springs Instrument Company Model 51 as shown in Plate 4). The percent oxygen in the air sample was then read on the meter and recorded.

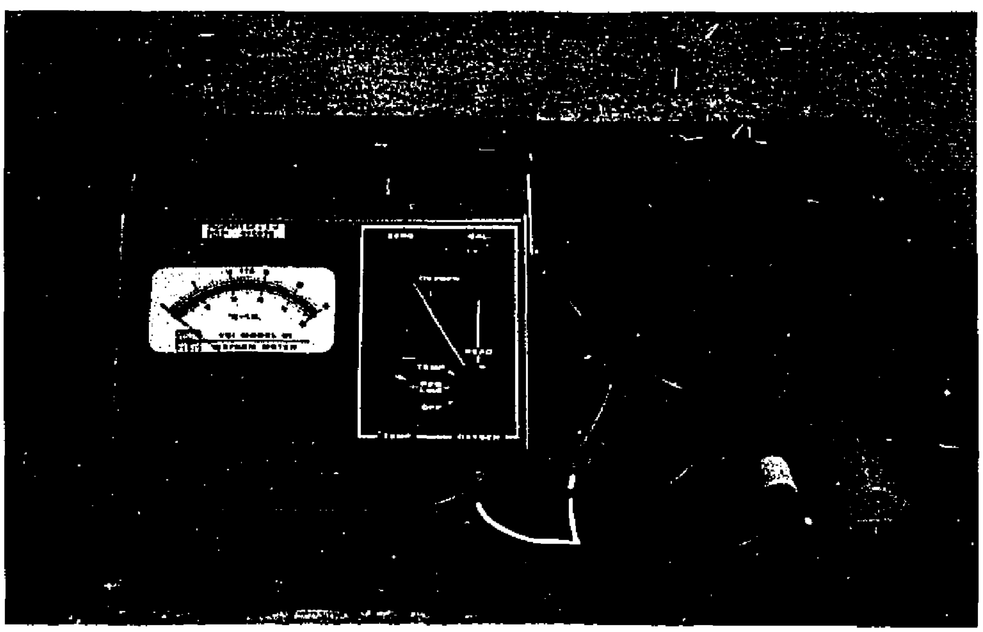

Plate 4. The meter and sampling system used for measuring soil oxygen in the field.

The soil oxygen content was measured at two-week intervals at each soil depth. Measurements were started on April 4, 1970, and continued for a year (until April 20, 1971) to determine the seasonal pattern of soil oxygen changes under the mature loblolly pine trees.

Soil Moisture Measurement in the Field

Soil moisture contents were measured weekly with a neutron moisture probe and portable scaler (Plate 5).

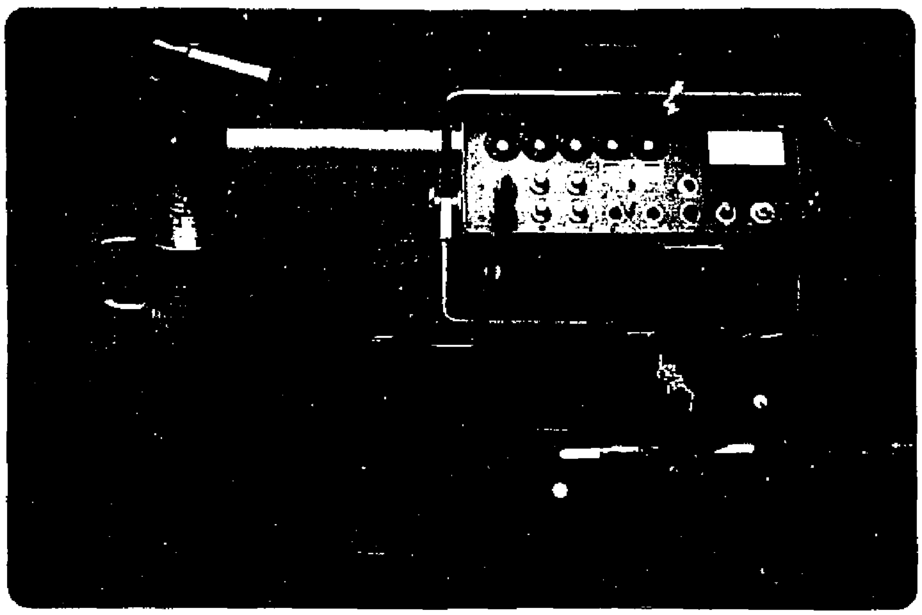

Plate 5. The instruments (neutron moisture probe and scaler) used for soil moisture measurements.

The soil moisture measurements collected from the same depths and on about the same dates as the oxygen measurements were used to determine the correlation between oxygen content and moisture content in the soil.

Measurement of Water Table

Sections of drain-pipe 5 feet long and 4 inches I.D. were installed in the soil in six of the nine plots (1, 4, 5, 17, 18 and 20) to measure fluctuations in the water table. These pipes were inserted to a depth of 4½ feet in October 1970. The tops were covered with plastic to prevent direct entrance of rain into the pipes.

Depth to the water table was measured with a tape at two-week intervals in each plot to relate the presence of free water to the oxygen content in the soil profile.

Collection and Analyses of Soil Samples

Two soil samples were collected from each soil depth in each plot in November 1970. In order to determine the bulk density and porosity of the soil, cores of undisturbed soil approximately 2 inches in diameter and 3 inches thick with a volume of 200 cm^3 were collected with a soil core-sampler similar to that developed by Jamison, Weaver, and Reed (1950).

The sample cores were saturated in a water bath and then transferred rapidly to a tension table similar to that

developed by Leamer and Shaw (1941) and described by Hoover, Olson and Metz (1954).

The soil-sample cores were drained on the tension table at 0 and 60 cm of water tension and were weighed after about 8 hours at each tension. In order to get the oven-dry weight of the soil samples, the sample cores were put in the oven at 105°C for more than 24 hours.

The bulk density (volume weight) of each core sample was calculated by the procedures described by Baver (1956). The total porosity of each sample core was determined from the following equation:

$$\text{Total Porosity (\%)} = \frac{\text{Saturated weight-Oven-dry weight}}{\text{Volume of core}} \times 100$$

The noncapillary porosity was considered equal to the volume of water drawn from the cores by 60 cm of water tension. The difference between total and noncapillary porosity is the capillary porosity.

The Bouyoucos method as modified by Patrick (1958) was used for the mechanical analysis of soil samples. The texture of soil was determined from the calculated sand, silt and clay percentages by using the standard texture triangle (Soil Survey Staff 1951).

Statistical Analysis of Data

An analysis of variance was used to test the effect

of changes in season and soil depth on soil oxygen content. The relationships between soil oxygen content and soil moisture, texture, porosity, and bulk density were evaluated using linear correlations.

The oxygen content in the free water table present in some of the study plots was found to range from 4 to 8 ppm. Kennedy (1969) reported oxygen concentrations of 3.7 to 6.0 ppm in the surface water of flooded plots. Thus, in those cases where the water table was encountered at the sampling depths, the oxygen content was represented by 0.90 percent in the statistical analyses.

RESULTS AND DISCUSSION

Basic plot data on biweekly measurements of soil oxygen content during the period of April 5, 1970, through April 20, 1971, are presented in Tables 8 through 16 in Appendix B. The significant results drawn from these basic data are summarized and discussed in the following sections.

Seasonal Variations in Oxygen Content

The biweekly changes in oxygen content of the forest soils under the mature loblolly pine trees in four of the nine plots are illustrated in Figures 3, 4, 5 and 6. The contents of soil oxygen in these plots are representative of those measured in the other plots. It is apparent from these figures that the oxygen content in these forest soils was normally lower in winter and in early spring (December to March) and was higher during the summer and in the first part of autumn (June to October), and that the soil oxygen content increased gradually as the growing season progressed. Similar results were reported for other soils by Boynton and Reuther (1938, 1939), Franken (1968) Russell (1952), Patrick et al. (1969), and Unger and Danielson (1965).

The results of the analysis of variance testing the effect of measurement dates on oxygen content in these forest soils under mature loblolly pine stands are presented

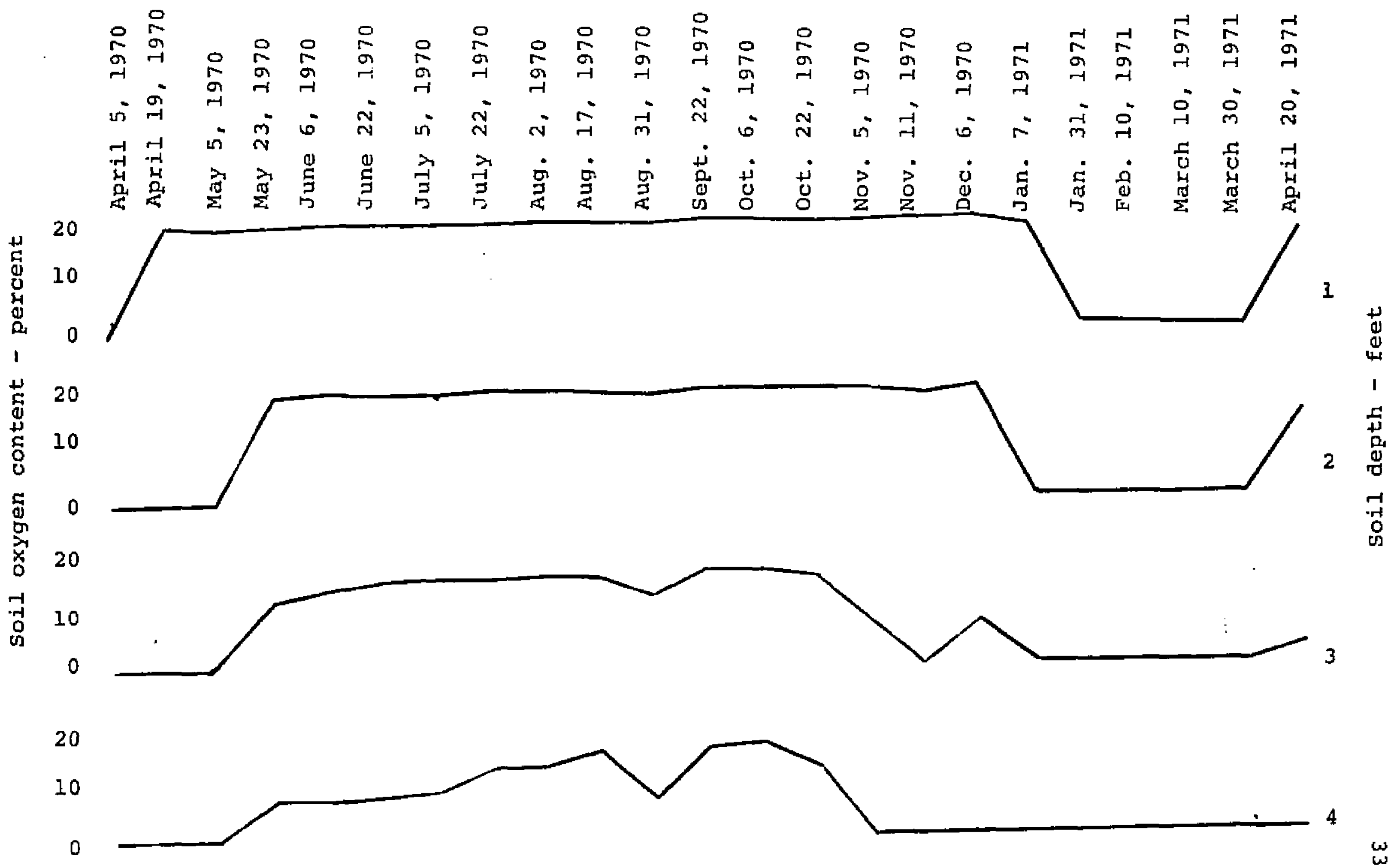

Figure 3. Biweekly changes in soil oxygen content in Plot No. 1.

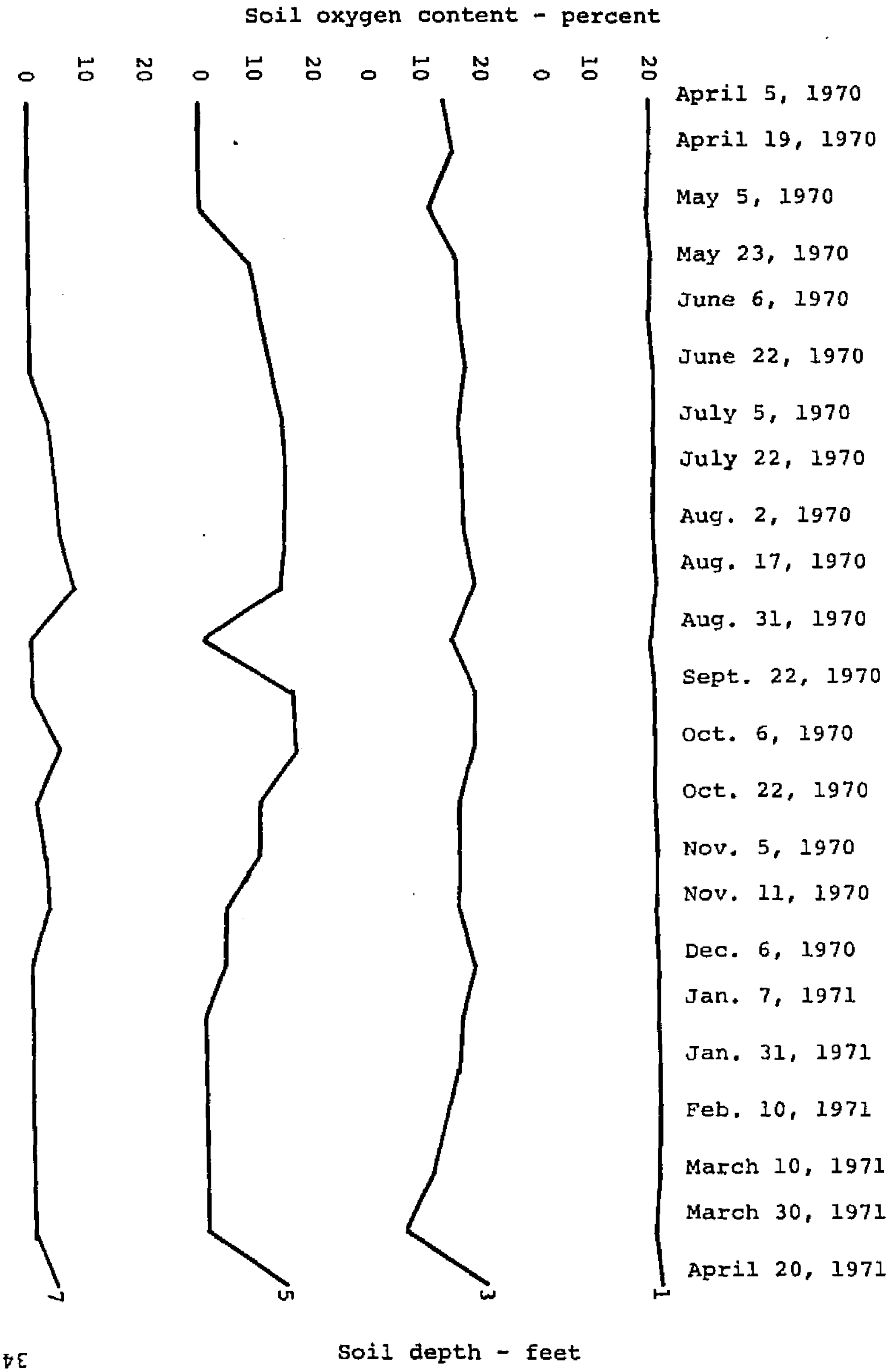

Figure 4. Biweekly changes in soil oxygen content in Plot No. 7.

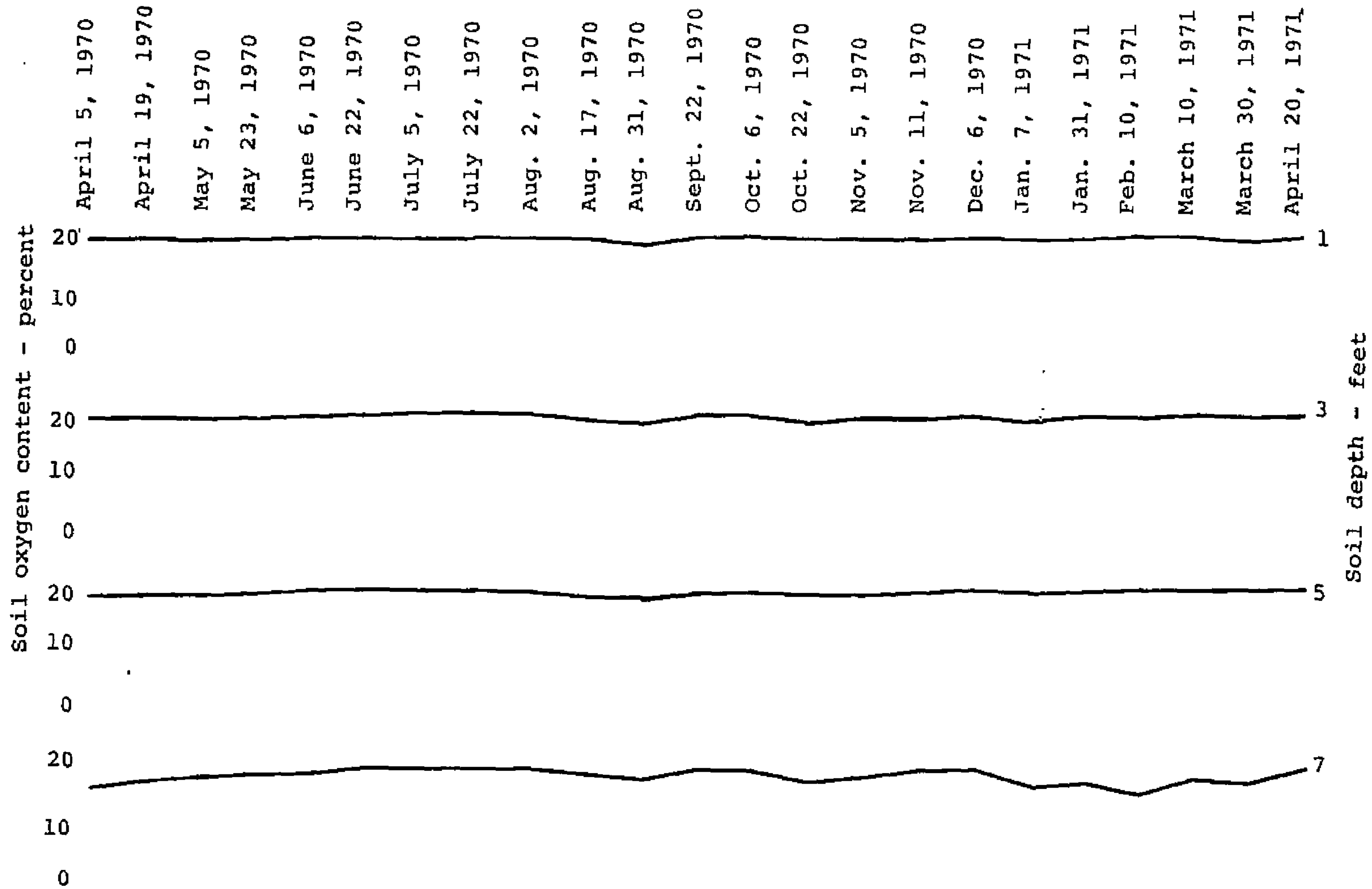

Figure 5. Biweekly changes in soil oxygen content in Plot No. 9.

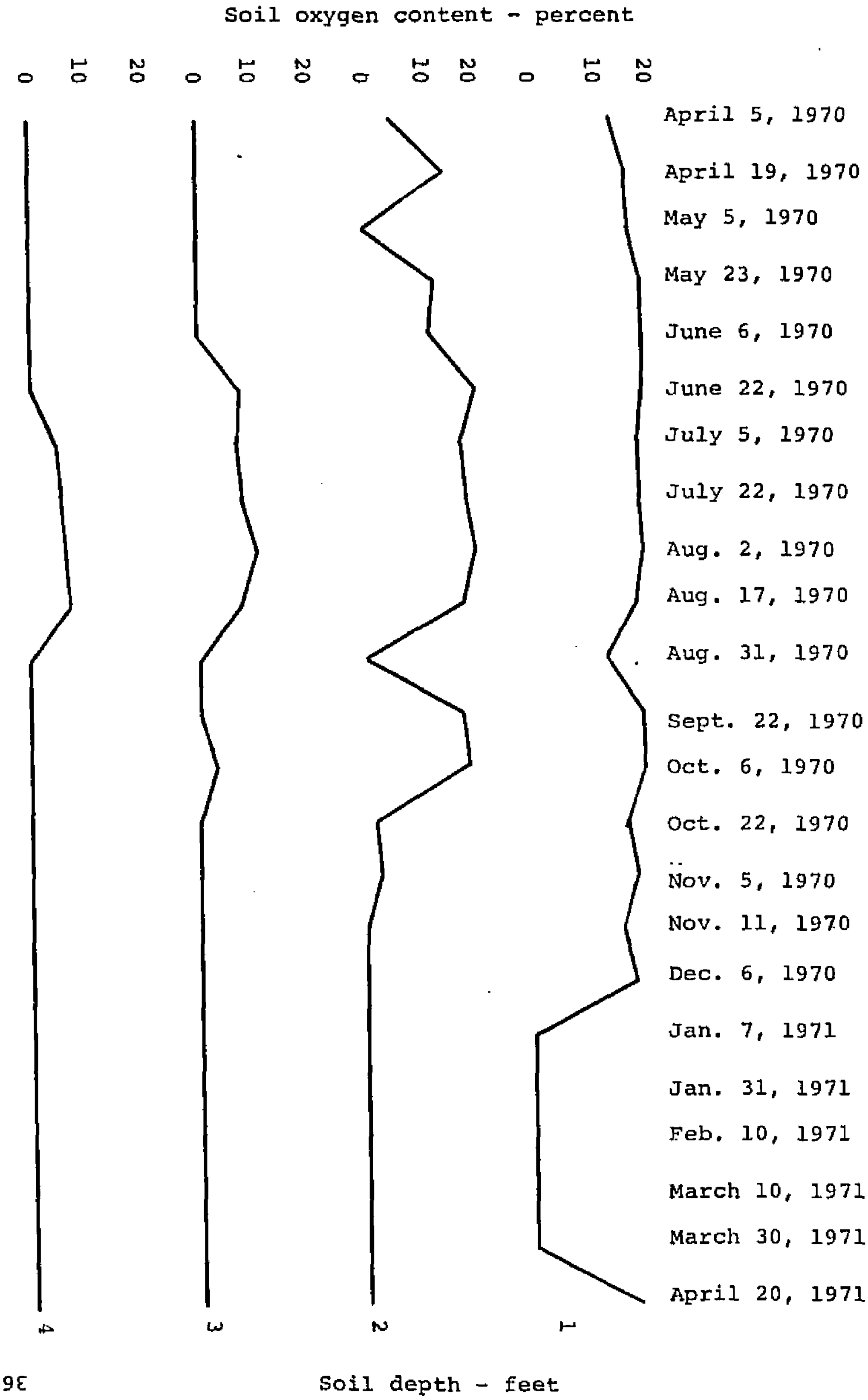

Figure 6. Biweekly changes in soil oxygen content in Plot No. 18.

in the following table:

Table 2. Analysis of variance for the effect of sampling date on soil oxygen content

Plot No.	D.F.	Sum of Squares	Mean Squares	F
1	22	3973.170	180.599	10.11**
4	22	3158.345	143.563	9.04**
5	22	1838.082	83.549	6.17**
7	22	591.559	26.889	2.91**
9	22	34.573	1.571	7.75**
10B[a]	22	25.297	1.150	1.11
10M	22	21.488	0.977	2.61**
10U	22	6.039	0.275	5.33**
17B	22	311.704	14.168	1.41
17M	22	518.349	23.561	2.11*
17U	22	932.981	42.408	1.90*
18	22	1734.367	78.835	3.78**
20	22	3736.256	169.830	10.46**

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

[a] Letters denote position on the slope: B = Bottom of the slope, M = Middle of slope, U = Upper slope.

As indicated in Table 2, the biweekly variations in soil oxygen contents are statistically significant in every plot except in the case of the bottom slope positions in Plots 10 and 17. This may be explained by the presence of a high water table in these two plots so that the bottom of the slope was saturated with free water most of the year. The oxygen content of free water, either in or on the surface of the soil, is very low, ranging from 4 to 8 ppm in the water tables encountered in this study and from 3.7 ppm to 6.0 ppm in case of surface water (Kennedy 1969). Thus, the oxygen content in free water is much less than 1 percent and therefore was represented by 0.9 percent oxygen in the statistical analyses. Because the soils at the bottom of the slope in both Plot No. 10 and 17 were saturated by free water most of the year, the results of the statistical analysis of biweekly variations should be nonsignificant.

The curves in Figures 3, 4, 5 and 6 also indicate that the oxygen content began to increase in April and reached their highest values during the summer and then declined again until they reached their lowest values during the winter months. This may be explained by changes in soil moisture and temperature. Trees begin very active transpiration in April. As a result, water tables decline and soil moisture also begins to be decreased. As soil moisture decreases in April, the air space for gaseous

exchange increases which will in turn cause an increase of oxygen in the soil. Air and soil temperature changes and the initiation of growth processes of trees in April also will speed up the rate of oxygen diffusion, thereby contributing to the increase of oxygen in the soil profile. All the factors that influence the seasonal variation of soil oxygen will have their maximum effects during the summer. As the end of the growing season approaches, transpirational losses become less, soil moisture increases, and temperatures decrease. The end result is a decline in oxygen levels in the soil.

The seasonal variations of soil oxygen were more marked at the lower depths (subsoils) and in low sites such as Plot Nos. 1, 4, 5, 17, 18 and 20. This may be due to greater variations of soil moisture in the subsoils and in low sites as a result of fluctuations in the water table levels.

Variations in Oxygen Content with Soil Depth

As would be expected, the oxygen content in these forest soils normally decreased with soil depth. The soil oxygen content changed with soil depth as is illustrated in Figures 7, 8, and 9. Data for the other plots followed a similar pattern (as shown in Tables 9,10, 11, 13, 14 and 16 in Appendix B). In these figures, it is clearly demonstrated that there was a decrease in oxygen content

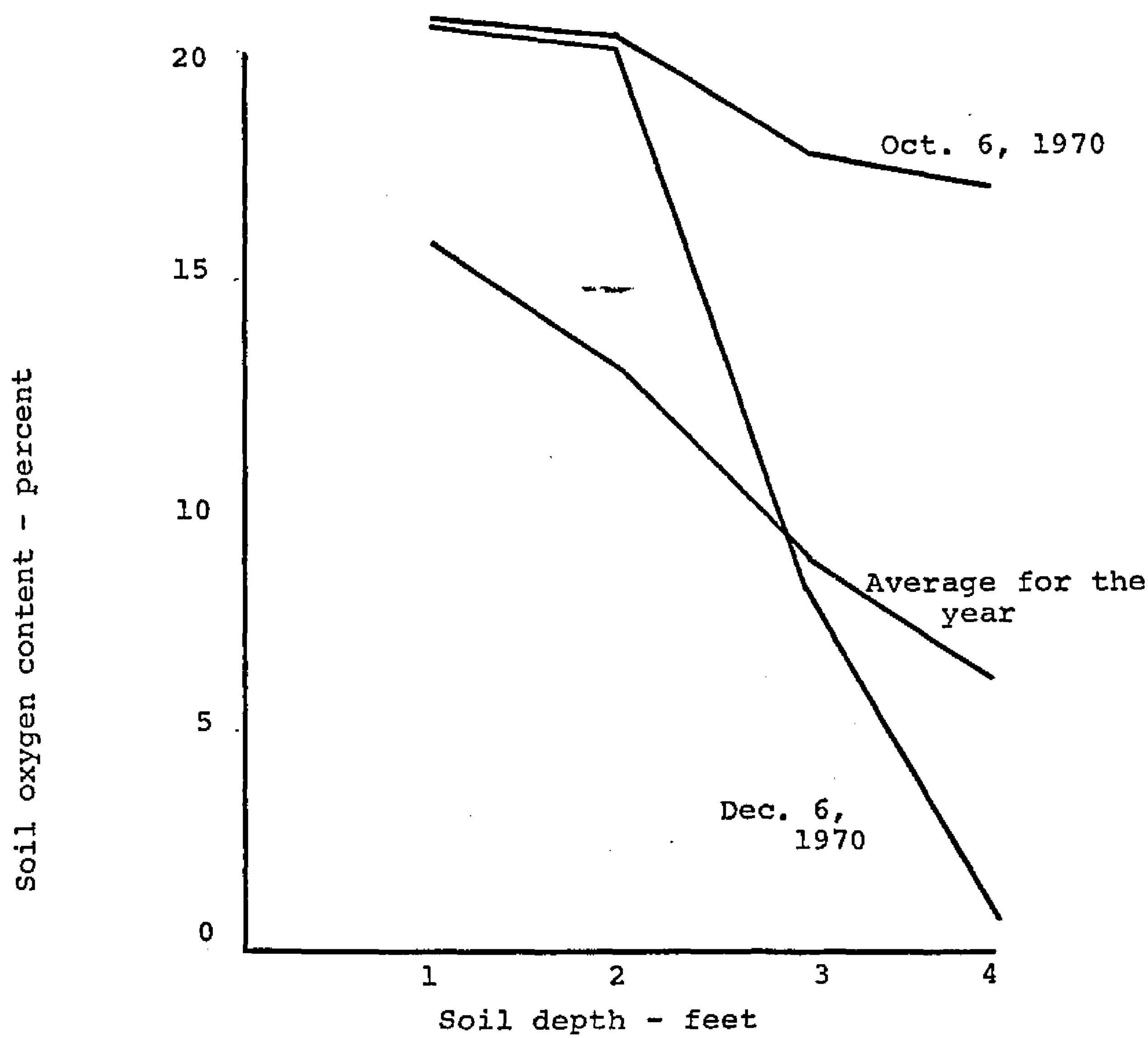

Figure 7. Changes in soil oxygen content with soil depth in Plot No. 1.

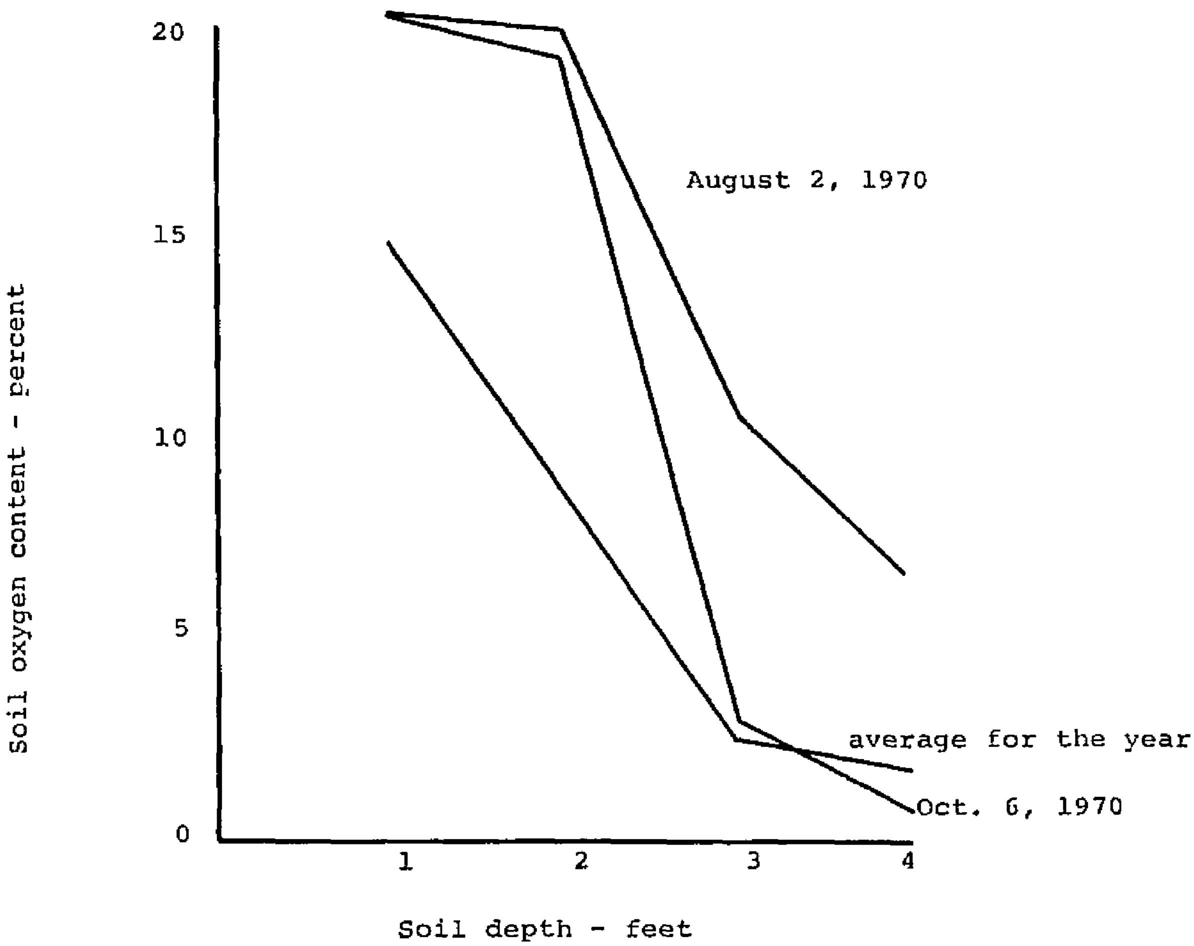

Figure 8. Changes in soil oxygen content with soil depth in Plot No. 18.

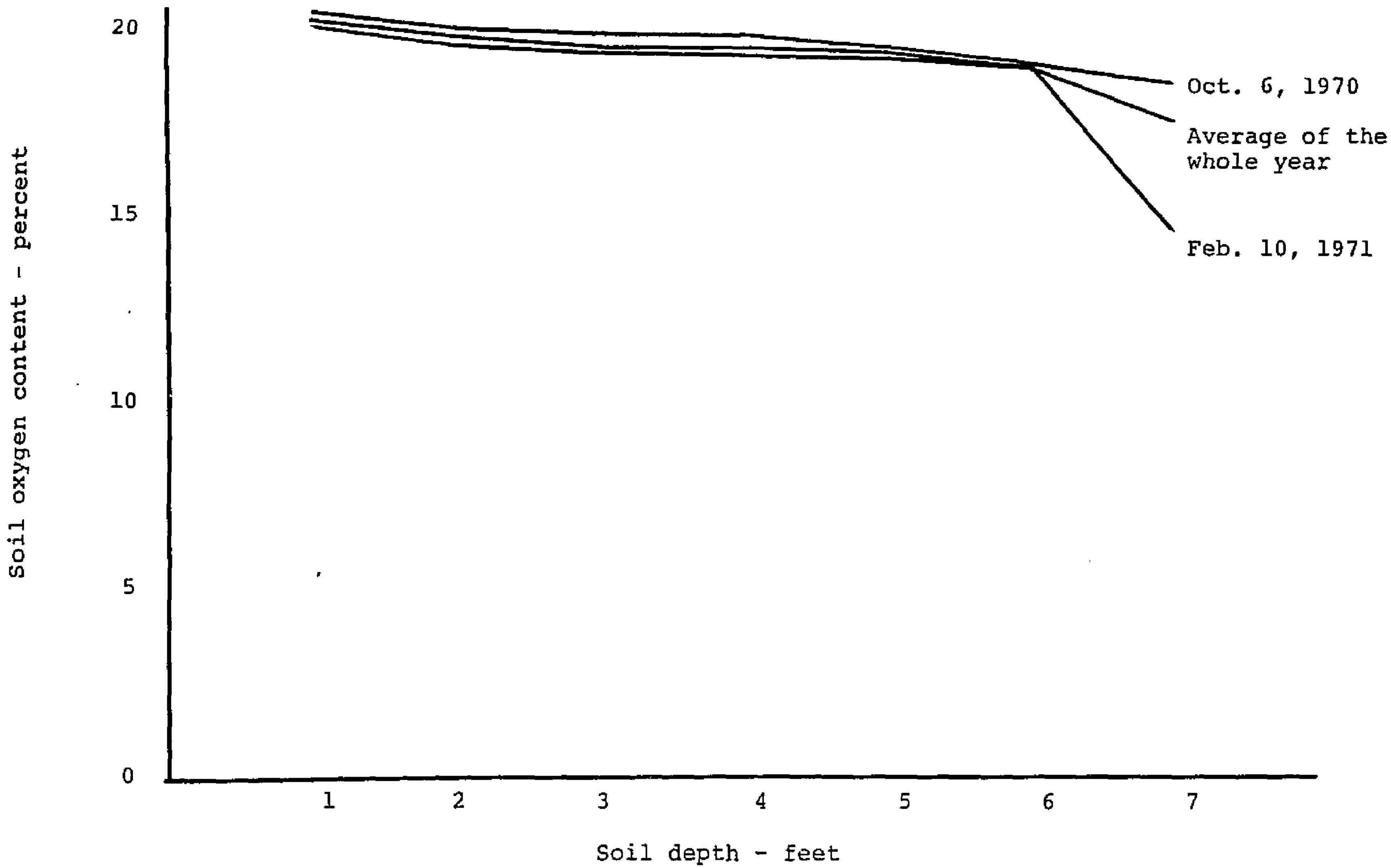

Figure 9. Changes in soil oxygen content with soil depth in Plot No. 9.

in these soils with depth throughout the whole year in every plot, as well as a marked decline in soil oxygen content with soil depth during the winter and early spring months. Those figures also indicate that the oxygen content changed only slightly with depth in a dry soil such as in Plot No. 9 (Figure 9), but changed greatly in the low-site plots such as are depicted in Figures 7 and 8. This is in general agreement with all the early reports (Boynton and Reuther 1938 and 1939, Franken 1968, Patrick et al. 1969, Russell 1952, Unger and Danielson 1965, and others).

In every plot, changes in oxygen content with soil depth were shown to be highly significant by analysis of variance (Table 3).

Table 3. Analysis of variance for the effect of soil depth on oxygen content

Plot No.	D.F.	Sum of Squares	Mean Squares	F
1	3	1305.103	435.034	24.34**
4	3	1021.243	340.414	21.44**
5	3	2597.314	865.771	63.96**
7	3	4374.131	1458.044	157.56**
9	6	94.350	15.725	77.52**
10B[a]	3	5968.672	1989.557	1918.49**
10M	3	129.193	43.064	115.09**
10U	3	15.663	5.221	101.46**
17B	3	6449.027	2149.676	214.43**
17M	3	5147.423	1715.808	153.82**
17U	3	2752.173	917.391	41.16**
18	3	2503.939	834.646	39.98**
20	3	1153.936	384.645	23.68**

** Significant at the .01 level of probability.

[a] Letters denote position on the slope: B = Bottom of the slope, M = Middle of slope, U = Upper slope.

As might be expected, topsoils are usually higher in oxygen content than are subsoils. The noncapillary porosity in topsoils is normally higher than in subsoils and the bulk density in topsoils is usually lower than in subsoils. The high moisture content in subsoils as a result of a high water table also contribute to the reduction of oxygen content in the subsoils.

Rainfall and Its Effect on Soil Oxygen Content

The oxygen contents in the soils on every plot dropped sharply from the normal several times during the year of measurements. These sharp reductions of soil oxygen content were likely due to relatively large amounts of rainfall received one day or several days before the oxygen readings were taken. The effect of rainfall on soil oxygen content is shown in Figure 10. The dates and amounts of rainfall received on the Lee Memorial Forest are presented in Table 17 (Appendix C).

As shown in Figure 10, the first reduction of soil oxygen occurred on May 5, 1970, which resulted from 3.28 inches of rainfall on May 2-3, 1970. On August 31, 1970, marked reductions in the oxygen content at all depths and in all plots were recorded. These sharp decreases in soil oxygen were probably caused by high soil moisture resulting from 4.47 inches of rain which fell between the August 17 and August 31 samplings. Other reductions of soil oxygen

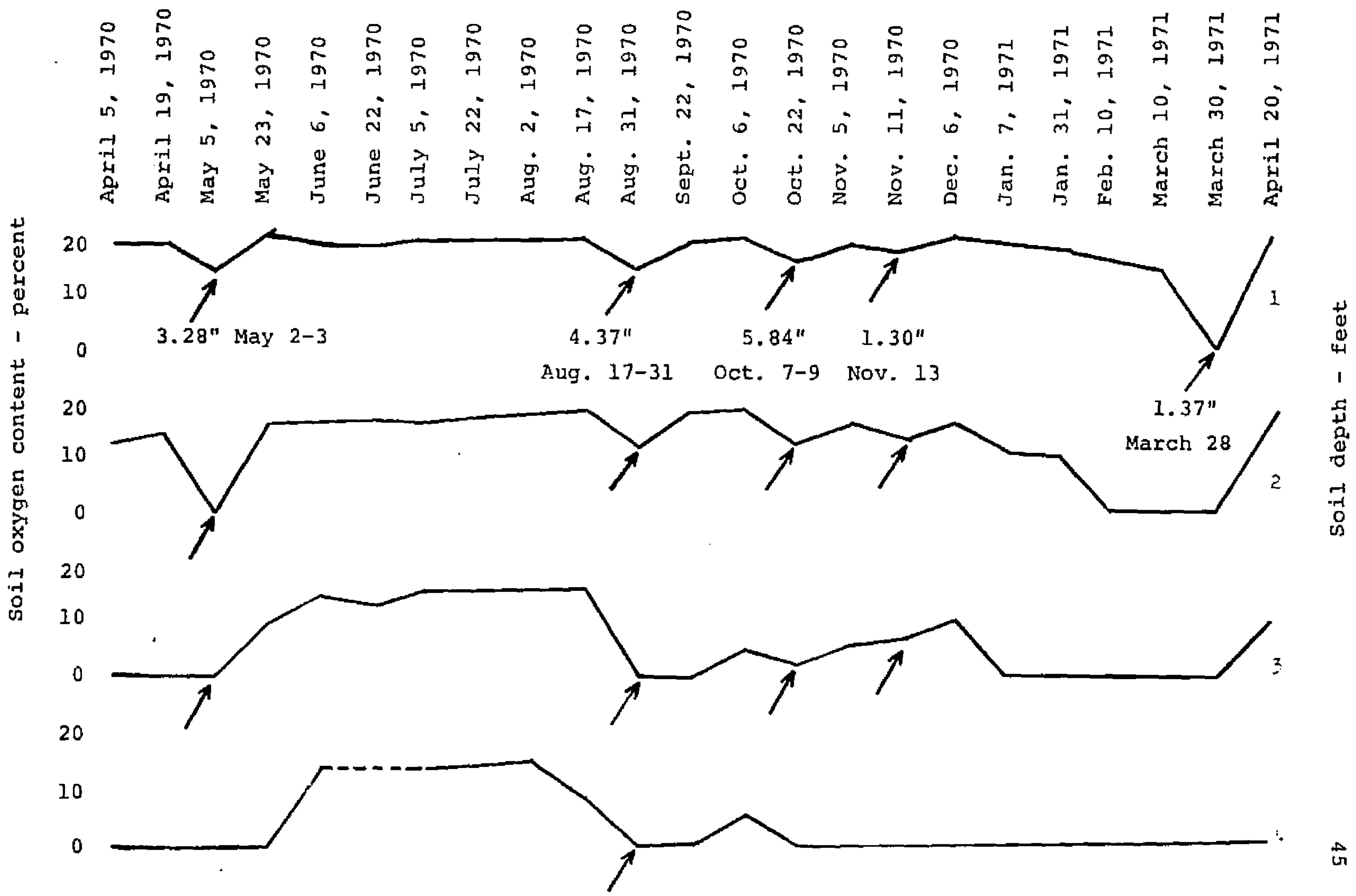

Figure 10. The effect of rainfall on soil oxygen content in Plot No. 5. Arrow indicates the sharp reduction of oxygen content resulting from rainfall.

content occurred on October 22 and November 18, 1970, and on March 30, 1971. Those reductions of soil oxygen content are also likely due to rains which occurred on October 7-8-9 (5.84 inches), November 13 (1.30 inches), and March 28, 1971 (1.37 inches).

Furr and Aldrich (1943) experienced similar results and reported that marked decreases in soil oxygen contents occurred following rains and irrigation in a very fine sandy loam soil. Patrick and his associates (1969) also noted that a heavy rain can add additional moisture to the soil which in turn will cause the reduction of oxygen content in the soil. However, low amounts of rainfall (less than 0.25 inches) had very little or no measurable effect on soil oxygen content because they did little to recharge soil moisture.

Soil Moisture and Its Relation to Soil Oxygen Content

Data on the soil moisture content at each soil depth for all nine plots are presented in Tables 18-26 in Appendix D. However, only six (Plot Nos. 1, 5, 7, 9, 10, and 20) of the nine plots were used to test the relationship between moisture and soil oxygen by linear correlation analyses. The moisture readings for the three other plots were very high below 4 feet due to the high water table. The correlation coefficients for the six plots as a group are presented in the following table:

Table 4. The correlation coefficients for soil oxygen with soil moisture in the statistical analysis

Soil Depth	Number of observations	Correlation Coefficients
Feet		
1	96	-0.5686**
2	84	-0.8219**
3	60	-0.8357**
4	83	-0.7094**
5	24	-0.8552**
6	48	-0.7016**
7	24	-0.9350**

** Significant at 0.01 level of probability.

The results clearly prove that the relationship between soil oxygen content and soil moisture content is highly significant at every soil depth for the plots as a whole. However, the correlation analyses by depths in individual plots resulted in non-significant correlation coefficients in the following cases:

Soil depth	Plot number
1 foot	1 and 5
2 feet	10
4 feet	10
5 feet	9
6 feet	9 and 10
7 feet	7 and 9

In each of the above cases, sample size is small -- only 12 observations per plot at the indicated sampling depths. But when the data for all six plots were combined in the analysis, the relationship between soil oxygen and soil moisture content was found to be highly significant at every soil depth. As the soil moisture increased the oxygen content decreased; as the soil moisture decreased, the oxygen content in the soil increased.

This finding is in general agreement with other reports (Kohnke 1968, Taylor 1949 and others). Taylor (1949) reported that oxygen diffusion is strongly influenced by soil moisture. Under natural conditions, an excess of moisture in the soil is one of the situations which may result in poor aeration (Buckman and Brady 1957). Furr and Aldrich (1943) also reported that as the soil moisture content decreased, the oxygen content in the soil increased. Under field conditions, soil moisture is the most profound factor that influences soil oxygen content.

Water Table Influences on Soil Oxygen Content

During the period of study, a high water table was present on six of the nine plots and often prevented the extraction of air samples, especially from the lower depths and during the winter months. In a few plots, notably Nos. 4, 5, 7, 18 and 20, the water receded below

the deepest sampling depth only during July and August (Table 9, 10, 11, 15, and 16 in Appendix B). Water table measurements were not begun until November 5, 1970, after the installation of drain-pipes for this purpose. Subsequent measurements on depth to the water table and the corresponding soil oxygen contents in these plots are presented in Table 5. The water table in every plot was so high that oxygen-sampling reservoirs at the 3- and 4-foot depths were flooded by free water most of the time, so that no soil air could be extracted for oxygen measurements. Only the oxygen content in the soil air above the free water could be measured by the oxygen meter. It is obvious from Table 5 that the oxygen content in the soil profile was definitely influenced by fluctuations in the water table and that the oxygen content in the soil just above the water table was quite low, no doubt resulting from a very high soil moisture content in the capillary zone above the surface of the water table.

Young (1969) conducted an experiment on two wetland forest soils, a heavy soil (Bayboro clay loam) and a sandy soil (Plummer loamy sand) and found a similar relationship between soil oxygen and the water table. He reported that as fluctuating water table levels dropped, the oxygen diffusion rates increased in both soils, particularly in the heavy loam soil. Patrick and his associates (1969) had difficulty with their oxygen samplings due to the high

Table 5. The water table and the corresponding soil oxygen contents in several low plots on the L.S.U. Lee Memorial Forest

Plot No.	Date	Depth of water table below the ground surface	Soil oxygen content by depth			
			1 foot	2 feet	3 feet	4 feet
		Feet	Percent			
1	Nov. 5, 1970	3.2	20.0	19.5	7.7	H_2O
	Nov. 19, 1970	3.0	20.0	18.5	H_2O	H_2O
	Dec. 6, 1970	4.1	20.5	20.0	8.0	H_2O
	Jan. 7, 1971	1.7	18.7	H_2O	H_2O	H_2O
	Jan. 31, 1971	1.0	H_2O	H_2O	H_2O	H_2O
	Feb. 10, 1971	0.3	H_2O	H_2O	H_2O	H_2O
	March 10, 1971	0.2	H_2O	H_2O	H_2O	H_2O
	March 30, 1971	0.1	H_2O	H_2O	H_2O	H_2O
	April 20, 1971	3.1	18.0	15.7	3.1	H_2O
4	Nov. 5, 1970	2.8	19.6	9.0	H_2O	H_2O
	Nov. 19, 1970	2.1	11.1	H_2O	H_2O	H_2O
	Dec. 6, 1970	2.9	20.1	12.3	H_2O	H_2O
	Jan. 7, 1971	1.1	H_2O	H_2O	H_2O	H_2O
	Jan. 31, 1971	0.9	H_2O	H_2O	H_2O	H_2O
	Feb. 10, 1971	0.9	H_2O	H_2O	H_2O	H_2O
	March 10, 1971	0.2	H_2O	H_2O	H_2O	H_2O
	March 30, 1971	0.6	H_2O	H_2O	H_2O	H_2O
	April 20, 1971	3.0	19.1	5.5	H_2O	H_2O

Table 5 (Continued)

Plot No.	Date	Depth of water table below the ground surface	Soil oxygen content by depth			
			1 foot	2 feet	3 feet	4 feet
		Feet	- - - - - - - -	Percent	- - - - - - - -	
	Nov. 5, 1970	4.1	19.5	16.5	6.6	H_2O
	Nov. 19, 1970	3.9	17.9	13.8	7.3	H_2O
	Dec. 6, 1970	3.2	20.3	17.0	11.0	H_2O
	Jan. 7, 1971	2.5	19.0	11.7	H_2O	H_2O
5	Jan. 31, 1971	2.2	18.4	10.9	H_2O	H_2O
	Feb. 10, 1971	1.7	15.9	H_2O	H_2O	H_2O
	March 10, 1971	1.6	13.8	H_2O	H_2O	H_2O
	March 30, 1971	1.0	H_2O	H_2O	H_2O	H_2O
	April 20, 1971	3.7	20.2	16.8	10.3	H_2O
	Nov. 5, 1970	3.3	20.1	19.6	6.2	H_2O
	Nov. 19, 1970	3.2	20.1	19.7	6.3	H_2O
	Dec. 6, 1970	3.6	20.4	19.9	6.7	H_2O
	Jan. 7, 1971	3.2	20.4	20.0	6.2	H_2O
17	Jan. 31, 1971	3.4	20.1	19.7	10.6	H_2O
	Feb. 10, 1971	2.6	20.2	19.7	H_2O	H_2O
	March 10, 1971	2.3	20.0	19.5	H_2O	H_2O
	March 30, 1971	4.0	20.4	20.0	6.0	H_2O
	April 20, 1971	3.9	20.1	19.9	8.5	H_2O

Table 5 (Continued)

Plot No.	Date	Depth of water table below the ground surface	Soil oxygen content by depth			
			1 foot	2 feet	3 feet	4 feet
		Feet	- - - - - - - -	Percent	- - - - - - - -	
	Nov. 5, 1970	1.2	19.3	3.0	H_2O	H_2O
	Nov. 19, 1970	1.4	16.4	H_2O	H_2O	H_2O
	Dec. 6, 1970	1.3	18.6	H_2O	H_2O	H_2O
	Jan. 7, 1970	0.8	H_2O	H_2O	H_2O	H_2O
18	Jan. 31, 1971	1.0	H_2O	H_2O	H_2O	H_2O
	Feb. 10, 1971	0.8	H_2O	H_2O	H_2O	H_2O
	March 10, 1971	0.9	H_2O	H_2O	H_2O	H_2O
	March 30, 1971	0.9	H_2O	H_2O	H_2O	H_2O
	April 20, 1971	2.1	19.2	H_2O	H_2O	H_2O
	Nov. 5, 1970	1.8	19.9	H_2O	H_2O	H_2O
	Nov. 19, 1970	0.2	15.8	H_2O	H_2O	H_2O
	Dec. 6, 1970	2.6	20.2	7.3	H_2O	H_2O
	Jan. 7, 1971	0.9	H_2O	H_2O	H_2O	H_2O
20	Jan. 31, 1971	0.9	H_2O	H_2O	H_2O	H_2O
	Feb. 10, 1971	0.75	H_2O	H_2O	H_2O	H_2O
	March 10, 1971	0.9	H_2O	H_2O	H_2O	H_2O
	March 30, 1971	1.0	H_2O	H_2O	H_2O	H_2O
	April 20, 1971	2.8	19.5	8.2	H_2O	H_2O

water table during the first part of the growing season. Generally, soils with low water tables and of coarse texture have high air capacities (Kohnke 1968) and in turn can have high contents of oxygen for plant growth.

The Effect of Slope on Soil Oxygen Content

Two of the study plots -- No. 10 and No. 17 -- are located on slopes of 17 and 6 percent, respectively. The effect of these slopes on oxygen content is shown in Figure 11. The oxygen content in the soil at the top of the slope was generally higher than on the middle-slope position, which in turn was higher in oxygen content than at the bottom of the slope. However, this was true only below the 2-foot depths; at the upper soil depths the oxygen content was rather uniform across the slope positions.

The effect of slope on soil oxygen content in Plot No. 10 may be explained by soil moisture differences across the slope. The soil moisture at the top of the slope was normally lower than on the middle-slope position, which in turn was lower in soil moisture content than at the bottom of the slope (Appendix Table 23). Through the study period, soil moisture at 4 feet averaged 6.20, 12.56 and 14.95 percent in the upper, middle, and lower slope positions, respectively. Likewise at 6 feet, soil moisture averaged 6.85, 14.58 and 17.14 percent, respectively, from

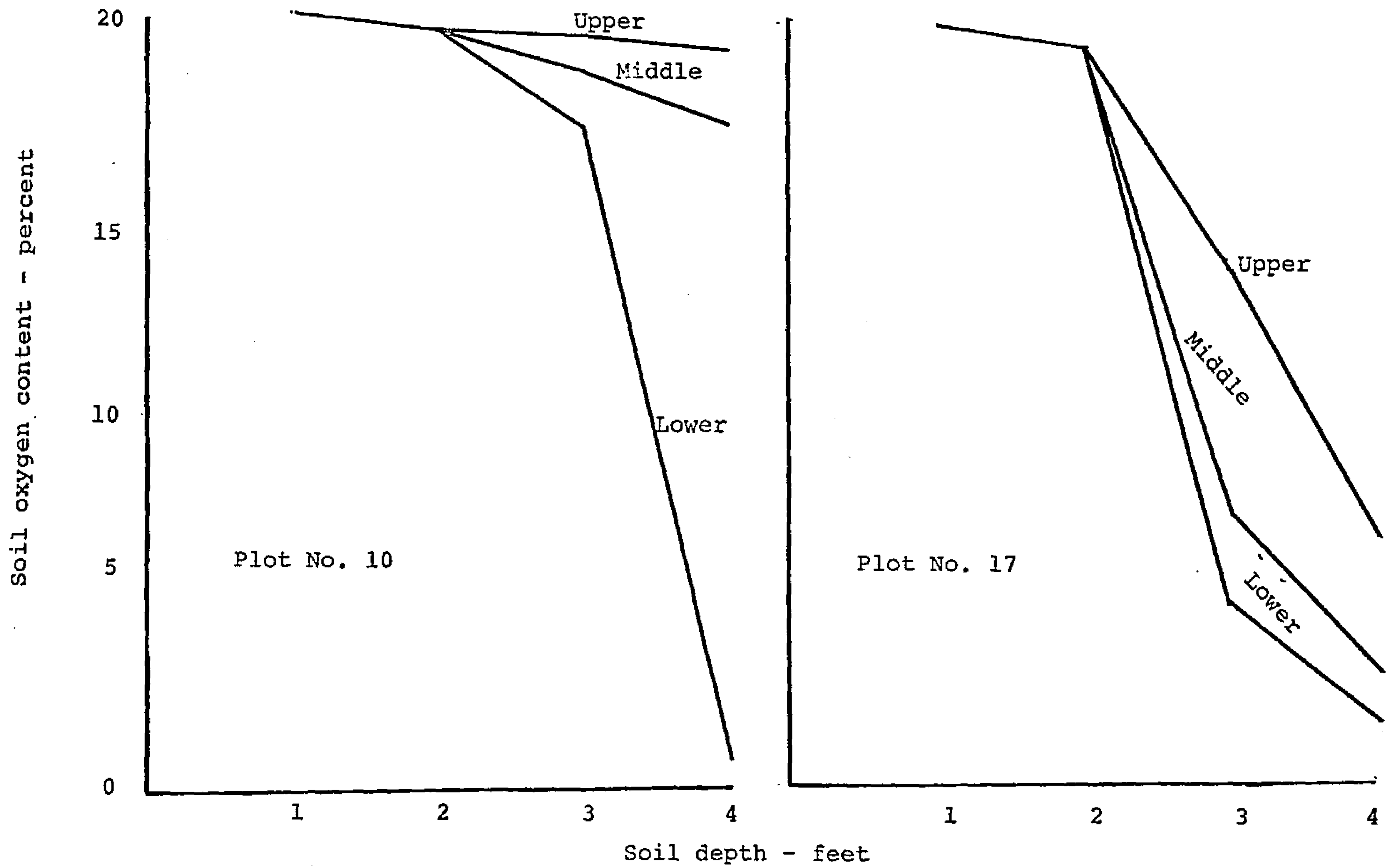

Figure 11. Soil oxygen content changes with slope.

top to the bottom of the slope.

There is only one access tube for soil moisture measurements in Plot No. 17, so that soil moisture data across the slope are not available for comparison. However, the influence of slope on soil oxygen content in Plot 17 is probably also caused by differences in soil moisture across the slope.

Soil Oxygen Content as Related to Other Physical Properties of the Soil

A correlation analysis was used to test the relationship of soil oxygen content to other physical properties of the soil: percent of sand, silt, and clay; capillary, noncapillary, and total porosity; and bulk density. The calculated correlation coefficients were then tested for significance by the F-test. The soil oxygen data used in the correlation analyses were the average soil oxygen contents for the whole year (average of the 23 biweekly readings) at each soil depth.

The physical properties (texture, porosity, and bulk density) of the soils in each plot are presented in Table 6. The results of the statistical analysis are shown in Table 7.

The relationship between soil oxygen content and noncapillary porosity proved to be highly significant (Table 7). The positive coefficient indicates that the

Table 6. Average plot values[a] for the physical properties of the soil

Plot no.	Soil depth	Mechanical Analysis				Porosity			Bulk density
		Sand	Silt	Clay	Texture	Noncapillary	Capillary	Total	
	Feet	- - - Percent - - -				- - - - - Percent - - - -			g/cc
	1	58.8	34.9	6.3	Sandy loam	4.46	26.20	30.66	1.79
1	2	56.8	35.0	8.2	Sandy loam	5.42	22.49	27.91	1.91
	3	55.0	26.8	18.2	Sandy loam	3.59	25.73	29.32	1.81
	4[b]	--	--	--		--	--	--	--
	1	57.5	33.6	8.9	Sandy loam	11.59	30.63	42.22	1.47
4	2	54.6	29.0	16.4	Sandy loam	5.72	39.39	45.11	1.46
	3	54.4	27.7	17.9	Sandy loam	5.26	33.68	38.94	1.63
	4	75.8	11.0	12.5	Sandy loam	7.47	28.97	36.44	1.71
	1	42.5	47.5	10.0	Loam	4.10	30.76	34.86	1.69
5	2	54.5	36.2	9.4	Sandy loam	3.49	29.30	32.79	1.77
	3	65.6	25.7	8.7	Sandy loam	3.59	28.37	31.96	1.77
	4[b]	--	--	--		--	--	--	--
	1	44.3	44.4	11.3	Loam	17.63	31.82	49.45	1.23
7	3	48.8	33.7	17.5	Sandy loam	7.73	31.60	39.33	1.58
	5	66.3	24.7	9.0	Sandy loam	5.21	25.58	30.79	1.87
	7[b]	--	--	--		--	--	--	--

Table 6 (Continued)

Plot no.	Soil depth	Mechanical analysis				Porosity			Bulk density
		Sand	Silt	Clay	Texture	Noncapillary	Capillary	Total	
	Feet	- - - Percent- -				- - - -Percent- - - - - -			g/cc
	1	55.1	30.5	14.4	Sandy loam	11.63	24.13	35.76	1.56
	2	48.6	34.0	17.4	Loam	9.48	28.48	37.96	1.57
	3	58.8	24.9	16.3	Sandy loam	9.23	25.01	34.24	1.72
9	4	70.3	19.7	10.0	Sandy loam	14.81	20.65	35.46	1.69
	5	75.6	14.6	9.8	Sandy loam	13.87	16.74	30.61	1.75
	6	72.5	11.8	15.7	Sandy loam	10.20	20.24	30.44	1.76
	7	71.8	13.2	15.0	Sandy loam	12.23	20.70	32.93	1.78
	1	69.4	22.5	8.1	Sandy loam	18.87	21.37	40.24	1.49
10	2	66.3	11.8	21.9	Sandy Clay Loam	10.70	28.73	29.43	1.59
	4	72.5	5.0	22.5	Sandy Clay Loam	10.80	24.93	35.73	1.71
	6	70.0	5.0	25.0	Sandy Clay Loam	6.51	30.42	36.93	1.75
	1	42.3	39.2	18.5	Loam	8.97	29.96	38.93	1.57
17	2	44.8	41.2	14.0	Loam	5.52	30.87	36.39	1.69
	3	47.0	38.8	14.2	Loam	4.88	30.09	34.97	1.75
	4[b]	--	--	--		--	--	--	--
	1	73.1	20.5	6.4	Sandy loam	5.99	24.50	30.49	1.76
18	2	74.4	18.4	7.2	Sandy loam	7.39	27.89	35.28	1.70
	3	71.8	18.8	9.4	Sandy loam	5.92	30.04	35.96	1.73
	4[b]	--	--	--		--	--	--	

Table 6 (Continued)

Plot no.	Soil depth	Mechanical Analysis				Porosity			Bulk density
		Sand	Silt	Clay	Texture	Noncapillary	Capillary	Total	
	Feet	- - - Percent - -				- - - Percent - - - - - -			g/cc
20	1	53.8	29.3	16.9	Sandy loam	5.94	29.57	35.51	1.67
	2	63.7	23.1	13.2	Sandy loam	6.36	28.89	35.25	1.70
	3	57.5	27.6	14.9	Sandy loam	4.48	31.25	35.73	1.71
	4	54.2	30.2	15.6	Sandy loam	3.95	33.82	37.77	1.66

[a]Average of two soil samples.

[b]Data are not available because of high water table when soil samples were collected.

Table 7. The correlation coefficients for soil oxygen content with texture, porosity, and bulk density

Property	Number of observations	Correlation coefficients
sand	34	-0.1189
silt	34	0.0374
clay	34	0.1924
noncapillary porosity	34	0.6056**
capillary porosity	34	-0.4117*
total porosity	34	0.0969
bulk density	34	-0.2765

*Significant at 0.05 probability level.

**Significant at 0.01 probability level.

oxygen content in the soil profile increased as noncapillary porosity increased also. This is in general agreement with other findings (Robinson 1964, Vomocil and Flocker 1961, and Kohnke 1968). A soil is considered well-aerated for crop plants if the noncapillary porosity is 10 percent or more of the total volume, unless there is a high water table (Kohnke 1968). In Plot 9, the noncapillary porosity of the soil profile down to 7 feet exceeds or is very close to 10 percent (Table 6). The oxygen contents also were not critical at any time during year in this plot (Appendix

Table 12). Likewise, the noncapillary porosity and therefore the oxygen contents in Plot No. 10 are also adequate for tree growth at all depths, except perhaps at 6 feet where there is only 6.51 percent noncapillary porosity. But in the low sites, such as Plot No. 1, 4, 5, 18 and 20, the noncapillary porosities at all depths are less than 10 percent. The oxygen contents below 1 foot are not considered as adequate for optimum tree growth.

The relationship between capillary porosity and soil oxygen content is also significant. However, their correlation coefficient is negative which means that as the capillary porosity increased the oxygen content in the soil profile decreased. Since capillary porosity is responsible for soil moisture retention, this finding is also in general agreement with other early reports. Lemon and Erickson (1952) reported that the diffusion of oxygen is a linear function of water-free porosity.

The relationship between total porosity and soil oxygen content was not statistically significant. Since there are positive and negative relationships between soil oxygen content and noncapillary and capillary porosity, respectively, the effect of total porosity is probably canceled out in this particular case.

No significant relationship was found between soil oxygen content and percentages of sand, silt and clay. This does not agree with the findings of other workers

(Epstein and Kohnke 1957, Kohnke 1968, Patrick 1971, Rickman et al. 1965 and 1966, and others) who have reported that texture and bulk density do affect the soil oxygen content. Soil texture and bulk density are the prime factors in determining porosity; thus, direct measurement of porosity is probably a better indicator of aeration than either texture or bulk density alone.

Soil Oxygen Content and Loblolly Pine Tree Growth

It was earlier reported (Kramer 1950) that the root systems of loblolly pine seedlings were severely damaged under conditions of soil oxygen deficiency without visible symptoms of injury to the tops of the seedlings. There is also evidence that tolerance to oxygen deficiency increases with the age of the tree (Grable 1966, Leyton and Rousseau 1958). Since most of the plots in the present study were characterized by low soil oxygen levels during the winter and early spring, it would seem reasonable to assume that the root systems of the loblolly pine trees growing on the study plots might be adversely affected by these low soil oxygen levels as they grow to maturity. Soil oxygen levels were found to be particularly low on sample plots located on wet sites and at lower depths in the subsoils on some of the drier plots.

The site index values for loblolly pine trees on the nine study plots ranged from 98 to 118 (Table 1). These

values indicate that the trees are growing well on all of the plots and that, in general, loblolly pine trees are rather tolerant to the low soil oxygen contents in the winter and early spring. In fact, of the nine study plots the three wet plots (Nos. 17, 18, and 20) had the highest site index values (115, 113, and 118, respectively). Furthermore, if a soil oxygen content of 10 percent or more throughout the year is considered necessary for normal root activity and rapid growth, then only one of the study plots (Plot 9) did not reach the critical levels of the soil oxygen at any measured depth throughout the year. The lowest soil oxygen content recorded on this plot was 14.6 percent at 7 feet on February 10, 1971. The site index on Plot 9 is only 100, a much lower index value than those for Plots 17, 18, and 20, despite the fact that soil oxygen contents on these latter plots were less than 10 percent during much of the year, especially at depths greater than 4 feet.

Most loblolly pine trees have roots which not only extend beyond the spread of the branches but also penetrate deeply into the soil profile. The rooting depth of trees varies from several inches to several feet depending on soil characteristics such as aeration and drainage (Kramer 1960). Ninty percent of the small roots were distributed within 5 inches in the topsoils in forests of North Carolina

(Coile 1937). The heavy distribution of roots near the surface of the soil is probably related to poorer aeration at the greater depths (Kramer 1960). The oxygen contents in some of the study plots were usually low in subsoils (below 4 feet) during the growing season, therefore, the oxygen-absorbing root systems of these loblolly pine trees may be limited to the upper 4 feet of the soil profile.

Apparently, low soil oxygen content during the winter and early spring does not limit the growth of the mature loblolly pine trees even on wet sites. Soil oxygen content reaches adequate levels on these sites after the initiation of growth and active transpiration. A comparison of Plot 9 (site index 100, soil oxygen contents greater than 10 percent at all measured depths throughout the year) and Plots 17, 18, and 20 (site index 115, 113, and 118, respectively, low soil oxygen contents in the winter and early spring) suggests that the presence of readily available water early in the growing season may be more important for the growth of loblolly pine trees than is an adequate soil oxygen level at this time. Tree growth on Plot 9, a Ruston sandy loam soil located on a hilltop, may be limited by the insufficient soil moisture in the early spring despite adequate soil oxygen at this time.

Obviously, both sufficient soil moisture and adequate soil oxygen are necessary for good growth of loblolly pine

trees. Optimum growth of loblolly pine trees is probably dependent upon a proper balance of both factors throughout the growing season.

The results of this study suggest that low soil oxygen content in the winter and early spring is not detrimental to the growth of mature loblolly pine trees if levels of soil oxygen content rise to more than 6 percent above four feet later in the growing season. Further, comparisons of site index values between the various sample plots indicate that under the above conditions, a high level of soil moisture during part of the growing season, even at the expense of adequate soil oxygen, may be more beneficial to rapid growth of loblolly pine trees than the opposite condition, i.e. soil oxygen content greater than 10 percent but soil moisture limited.

SUMMARY AND CONCLUSIONS

Soil oxygen content is very essential to normal root activity and growth of trees. Deficiency of soil oxygen affects root growth, water uptake by roots, nutrient absorption and availability, root morphology, disease incidence, and auxin metabolism of various plants. In order to have optimum root growth and development, trees must have adequate soil oxygen. But the requirement of soil oxygen for optimum growth varies with species and the age of the plants. Most plants require at least 10 percent of soil oxygen for good growth.

The main purpose of this study was to measure the soil oxygen content under mature loblolly pine trees and to find out how it changes with season and with depth. An attempt was also made to relate the soil oxygen content to such soil factors as moisture content, texture, porosity, bulk density and depth to the water table.

Nine circular quarter-acre plots were selected for this study at different locations and on different soil types on the University's Lee Memorial Forest near Franklinton in Washington Parish, Louisiana. The plots were located in even-aged loblolly pine stands and the hardwood trees and brush in all plots were eliminated by cutting or injection and periodic spray applications of herbicide. Samples of soil air were drawn from air

reservoirs established at various depths in each plot with three replicated installations per plot. The measurements were made with an oxygen meter and cell at two-week intervals at each soil depth. The oxygen measurements were started on April 4, 1970, and were continued for a year to determine the seasonal pattern of soil oxygen changes under these mature loblolly pine stands.

Weekly soil moisture measurements were made with a neutron soil moisture probe in access tubes previously installed in the center of each plot. In plots where a free water table was present, a drain-pipe was installed and depth to the water table was measured biweekly.

Soil samples were collected from each soil depth in each plot for the determination of bulk density, texture, and porosity in the laboratory. The relationship of these soil physical properties to soil oxygen content was then determined by correlation analysis.

An analysis of variance was used to determine the effect of seasonal changes and soil depth on oxygen content in the soil profile. The influence of soil moisture on soil oxygen content was determined by a correlation analysis and the significance of the correlation coefficients determined by the F-test.

The following conclusions may be reached from the results of this study:

1. The oxygen content in the forest soils under these

mature loblolly pine stands varied throughout the year. Usually, it was lower in winter and in early spring and increased as the growing season progressed, especially in subsoils and on low sites.

2. The oxygen content also changed with soil depth throughout the whole year. In general, the oxygen content in the soil profile decreased with depth. Seasonally, the greatest decrease of soil oxygen content with depth occurred during the winter and in early spring. This reduction of soil oxygen content with depth was also greater in wet sites than in drier sites.

3. The oxygen content in the forest soils was definitely influenced by soil moisture content. As the soil moisture content increased, the oxygen content in the soil profile decreased. A high moisture content in the soil profile caused by a heavy rain also reduced the oxygen content in the soil because of blockage of soil pore space, thus resulting in curtailing the natural gas exchange between the soil and the atmosphere.

4. The oxygen content in these forest soils under mature loblolly pine stands was greatly influenced by the fluctuating water table. As the water table became higher, the oxygen content in the soil strata immediately above the water table was sharply reduced.

5. There seemed to be a relationship also between soil oxygen and slope. The oxygen content at the top of

slope was normally higher than at the middle of the slope which in turn was higher than at the bottom of the slop at the same soil depth. This may be related to differences in soil moisture content across the slope.

6. A significant relationship was found between soil oxygen content and capillary and noncapillary porosity. However, the correlation coefficient for capillary porosity was negative and for noncapillary porosity positive. As the capillary porosity increased, the oxygen content in the soil profile decreased, whereas as the noncapillary porosity increased, the oxygen content in the soil increased also.

7. No significant relationship was established between soil oxygen content and either soil texture or bulk density in this study.

8. Mature loblolly pine trees are probably rather tolerant to low soil oxygen content. Low soil oxygen content in the winter and early spring or in subsoils (below 4 feet) apparently was not detrimental to the growth of these loblolly pine trees. Optimum growth of loblolly pine trees perhaps depends more on the proper balance of soil oxygen and soil moisture content throughout the growing season rather than on a minimum level of oxygen alone.

This study should be continued to find out the effect of low soil oxygen content on root systems of

loblolly pine trees and to determine the exact requirement of the species for soil oxygen for optimum root growth. It is also necessary to study further the relationships of slope and the water table to soil oxygen content in order to find out how and why they influence oxygen content in the soil profile. Another good study would be one designed to determine the effect of seasonal variation and changes with depth on soil oxygen content under other species of mature southern pine trees for the purpose of comparing the growth conditions and for a better understanding of natural soil productivity for pine tree growth.

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APPENDIX A

DESCRIPTIONS OF THE SOILS

The following descriptions of the Bibb, Myatt, Ruston and Stough soils on the study plots are excerpts taken from the descriptive legend for the soil survey of the J. G. Lee, Sr., Memorial Forest as prepared by the Soil Conservation Service, U.S. Department of Agriculture, October 1970. Descriptions of the Bowie and Lexington soils are excerpts from the National Cooperative Soil Survey's Established Series descriptions available from most Soil Conservation Service offices.

BIBB SERIES

The soils of the Bibb series are in the coarse-loamy, siliceous, acid, thermic family of Typic Haplaquents. They are grey, poorly drained and moderately permeable soils located on the floodplains of the local streams. They have formed in loamy alluvium from the Coastal Plains. They are associated with the Bruno, Myatt, Stough and Mashulaville soils. They are more poorly drained than the Bruno and Stough soils, coarser textured than Myatt, Stough and Mashulaville soils, and lack the fragipan found in the Mashulaville and Stough soils.

Bibb soils have dark gray surface layers about 11 inches thick. Texture is silt loam to find sandy loam. The subsoils are gray fine sandy loam. Permeability is moderate and runoff is slow. Available water capacity is moderate. The reaction is medium acid to strongly acid in the surface and is strongly acid in the underlying layers. Wetness and frequent flooding are problems on these soils.

A representative profile of Bibb fine sandy loam, frequently flooded, was described on the Forest by soil scientists of the Soil Conservation Service, U.S. Department of Agriculture, as follows:

A_1 -- 0-7". Dark gray (10YR 4/1) find sandy loam; weak coarse subangular blocky structure which breaks into weak fine granular; friable; common pores; few small thin patches of bleached silt grains; medium acid; clear smooth foundary.

A_{12} -- 7-11". Dark gray (10YR 4/1) silt loam with common medium faint dark brown (10YR 4/3) mottles; massive, friable; strongly acid; clear wavy boundary.

B_2 -- 11-24". Gray (10YR 5/1) very find sandy loam with many coarse distinct strong brown (7.5YR 5/6) mottles; weak very coarse subangular blocky structure; firm; slightly brittle; common pores; thin clay films in some root channels; strong brown is mostly confined to root channels and structural faces; about 15-17 percent clay; strongly acid; clear smooth boundary.

B_3 -- 24-35". Gray (10YR 6/1) fine sandy loam with few fine distinct yellowish brown (10YR 5/6) mottles; massive; firm; few pores; strongly acid; clear smooth boundary.

IIC_1 -- 35-50". Gray (10YR 5/1) fine sandy loam with thin strata light gray (10YR 7/1) loamy fine sand; massive; very friable; few pores in root channels; strongly acid; gradual wavy boundary.

$IIIC_2$ -- 50-60". Dark grayish brown (10YR 4/2) loamy sand with pockets of light gray and gray loamy sand; single grain structure; very friable; strongly acid.

Range in Characteristics: The A_1 horizon ranges from very dark gray (10YR 3/1) to grayish brown (10YR 5/2). Texture is fine sandy loam to silt loam. Thickness ranges from 4 to 12 inches, but very dark gray layers are less than 8 inches thick. The B and C horizons are gray fine sandy loam or very fine sandy loam. Reaction is medium acid to strongly acid in the A horizon and strongly acid in the B and C horizons.

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BOWIE SERIES

The Bowie series is a member of the fine-loamy, siliceous, thermic family of Plinthic Paleudults. These soils have fine sandy loam A horizons, yellowish brown sandy clay loam upper Bt horizons, and mottled yellowish brown, red, and gray lower Bt horizons that contain about 25 percent nonindurated plinthite.

The Bowie soils are on uplands of the Coastal Plain. Slopes generally are 1 to 5 percent but they range from 0 to 12 percent. The regolith consists of thick beds of unconsolidated sandy clay loam, sandy loam, and sandy clay. Bowie soils are moderately well to well drained, and internal drainage is medium. Permeability is moderate in the upper part of the Bt horizon and Bowie soils are associated with the Lakeland, Ruston, Shubuta, and Susquehanna soils. Lakeland soils are sandy to depths of more than 72 inches. Ruston soils lack plinthite and their Bt horizons have hue redder than 7.5YR. Both Shubuta and Susquehanna soils have Bt horizons that contain more than 35 percent clay. In addition, the Bt horizons of Shubuta soils lack plinthite and are more than 60 inches thick, and the upper parts of the Bt horizons of the Susquehanna soils have chroma of 2 or less.

A typifying pedon of Bowie fine sandy loam (pasture) is described in the National Cooperative Soil Survey as follows:

A_p -- 0-6". Dark grayish brown (10YR 4/2) fine sandy loam, grayish brown (10YR 5/2) dry; structureless; soft, very friable; many roots; few worm casts; slightly acid; clear smooth boundary. (2 to 8 inches thick.)

A_2 -- 6-12". Pale brown (10YR 6/3) fine sandy loam, very pale brown (10YR 7/3) dry; structureless; soft, very friable; many roots; common fine pores; few worm casts; slightly acid; clear wavy boundary. (4 to 12 inches thick.)

$B_{21}t$ -- 12-30". Yellowish brown (10YR 5/6) sandy clay loam, brownish yellow (10YR 6/6) dry; few fine and medium distinct strong brown and reddish yellow mottles; weak medium subangular blocky structure;

hard, friable; common roots; common fine pores; thin patchy clay films on ped faces and in pores; few worm casts; few fine strongly cemented pitted brown iron oxide concretions; strongly acid; gradual wavy boundary. (6 to 25 inches thick.)

B_{22t} -- 30-42". Yellowish brown (10YR 5/6) sandy clay loam, brownish yellow (10YR 6/6) dry; common medium prominent red and yellowish red mottles; weak medium subangular blocky structure; very hard, friable; few roots; common fine pores; thin patchy clay films on ped faces and in pores; 2 percent by volume of nonindurated plinthite; few fine strongly cemented pitted brown iron oxide concretions; few weakly cemented iron oxide concretions; strongly acid; diffuse wavy boundary. (6 to 20 inches thick.)

B_{23t} -- 42-60". Prominently mottled yellowish brown (10YR 5/6), red (2.5YR 4/8) and gray (10YR 6/1) sandy clay loam; weak medium subangular blocky and blocky structure; very hard, friable; few roots in gray mottles; thin patchy gray clay films; 25 percent by volume red mottles of brittle nonindurated plinthite; very strongly acid; diffuse irregular boundary. (15 to 40 inches thick.)

B_{24t} -- 60-78". Prominently mottled light gray, red, and strong brown sandy clay loam; weak coarse blocky structure; very hard, friable; few roots; few pores; red mottles are brittle nonindurated plinthite; few clay films; very strongly acid.

Range in Characteristics: The solum ranges from 60 to more than 100 inches in thickness. Depth to horizons that contain more than 5 percent nonindurated plinthite ranges from 30 to 60 inches. Strongly cemented to indurated iron oxide concreations less than ½ inch in diameter range from less than 1 to 5 percent by volume in the upper part of the Bt horizon, but they are lacking in some pedons. The texture of the A horizon ranges from light loam to loamy fine sand. Texture of the Bt horizon ranges from heavy fine

sandy loam to medium clay loam. The upper 20 inches of the Bt horizon contains 18 to 35 percent clay, 20 to 40 percent silt, and more than 15 percent sand coarser than very fine sand. The structure of the Bt horizon ranges from weak to moderate subangular blocky to blocky. The B23t and B24t horizons contain between 10 and 35 percent by volume of nonindurated plinthite.

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LEXINGTON SERIES

The Lexington series is a member of the fine-silty, mixed, thermic family of Ultic Paleudalfs. These soils have brown silt loam A horizons, and reddish brown silty clay loam Bt horizons underlain by sandy loam. There is evidence of clay eluviation and secondary clay accumulations below the zone of maximum accumulation.

Lexington soils are on nearly level to sloping topography, with slope gradients of 2 to 15 percent most common. These soils are formed in a silty mantle (commonly loess) about 2 to 3 feet thick overlying sandy Coastal Plain material. Lexington soils are well drained and moderately permeable. They are associated with the Memphis, Ruston, and Providence soils. Memphis soils have a solum thickness of 48 inches or more with less than 5 percent sand throughout. Ruston soils have more than 15 percent sand, and Providence soils have fragipans.

A typifying pedon of Lexington silt loam (cultivated) is described in the National Cooperative Soil Survey as follows:

A_p -- 0-7". Brown (10YR 4/3) silt loam, weak fine granular structure; very friable; many fine roots; strongly acid; abrupt smooth boundary. (5 to 9 inches thick).

B_{21t} -- 7-12". Reddish brown (5YR 5/4) silty clay loam; crushed color strong brown (7.5 YR 5/6); moderate medium subangular blocky structure; friable; thin clay films on vertical and horizontal ped faces; common fine roots; strongly acid; clear smooth boundary. (10 to 18 inches thick).

B_{22t} -- 22-34". Reddish brown(5YR 5/4) silt loam, crushed color strong brown (7.5YR 5/6); moderate medium and coarse subangular blocky structure; friable; patchy clay films; strongly acid; clear smooth boundary. (8 to 16 inches thick).

B_{23t} -- 34-38". Dark brown (7.5YR 4/4) silt loam with noticeable amount of sand (approximately 15 to 25 percent); weak medium and coarse subangular blocky structure; very friable; thin patchy clay films; strongly acid; clear smooth boundary. (4 to 12 inches thick, this layer begins from about 27 to 40 inches below the surface).

IIB_{24t} & IIB_3 -- 38-50". Dark brown (7.5YR 4/4) sandy loam; approximately 15 percent clay; weak medium and coarse subangular blocky structure; very friable; few thin patchy clay films; strongly acid; clear smooth boundary. (6 to 30 inches thick).

IIA'_2 & IIB'_{2t} -- 50-85". Alternating layers of yellow (10YR 7/6) loamy sand 1 to 3 inches thick and reddish brown (5YR 4/4) sandy loam ¼ to 1 inch thick. The yellow loamy sand is loose, single grain, and sand grains are uncoated. The bands of reddish brown sandy loam are very friable or loose and have very weak blocky structure that with slight pressure breaks to weak fine granular structure; some sand grains are coated; there are very few patchy clay films; this brown sandy loam layer has pockets (about 10 percent) of yellow loamy sand or sand. This 35-inch thick horizon consists of about 75 percent yellow loamy sand layers (IIA'2) and the remainder is reddish brown sandy loam (IIB'2t).

From 85 to 112 inches, the yellow loamy sand layers and the dark brown sandy loam layers are about the same thickness, about 2 inches each.

<u>Range in Characteristics</u>: Reaction for the whole profile ranges from medium to strongly acid. Texture of the A horizon is silt loam. Texture of the Bt horizon is silt loam or silty clay loam. Sand content increases with depth. The IIA horizons are loamy sand and sand. The IIB horizons are sandy loam and loam.

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MYATT SERIES

The soils of the Myatt series are in the fine-loamy, siliceous, thermic family of Typic Ochraquults. They are gray, poorly drained and slowly permeable soils situated on the smooth local stream terraces. They have formed from old acid alluvium washed from the Coastal Plains. They are associated with the Mashulaville, Stough, Kalmia and Bibb soils. Kalmia and Stough soils are better drained than Myatt, the Bibb soils are coarser textured and less developed than Myatt, and the Stough and Mashulaville have fragipans.

Permeability of Myatt soils is low and surface runoff is slow. The available water capacity is moderate. Reaction is medium to strongly acid in the surface ranging to very strongly acid in the subsoil. Wetness is a problem.

A representative profile of Myatt very fine sandy loam was described on the Forest by soil scientists of the Soil Conservation Service, U.S. Department of Agriculture, as follows:

A_1 -- 0-6". Dark gray (10YR 4/1) moist, light gray (10YR 7/1) dry, very fine sandy loam; weak, very fine granular structure; slightly hard; many roots; strongly acid; abrupt smooth boundary.

A_{21g} -- 6-12". Gray (10YR 5/1) very fine sandy loam with few fine distinct yellowish brown (10YR 5/6) mottles; weak, medium subangular blocky structure; friable; many roots; strongly acid; abrupt smooth boundary.

A_{22g} -- 12-18". Gray (10YR 6/1) very fine sandy loam with many medium distinct yellowish brown (10YR 5/6) mottles; weak medium subangular blocky structure; firm; few thin patchy clay films in pores; roots and root channels are common; few pin holes; very strongly acid; diffuse wavy boundary.

B_{tg} -- 18-48". Gray (10YR 6/1) sandy clay loam with many medium distinct yellowish brown (10YR 5/6) mottles; moderate medium subangular blocky structure; thin patchy clay films; slightly plastic; few roots and pin holes present; very strongly acid.

Range in Characteristics: The A horizon is gray fine sandy loam or very fine sandy loam 12 to 22 inches thick. The B horizon is gray (10YR 5/1, 6/1) or light brownish gray (10YR 6/2). Texture of the B horizon varies from very fine sandy loam to loam, clay loam, or sandy clay loam. Thickness ranges from 25 to 40 inches. Mottles are dominantly yellowish brown. The reaction is strongly acid to very strongly acid.

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RUSTON SERIES

The Ruston series is in the fine-loamy, siliceous, thermic family of Typic Paleudults. Ruston soils are well drained and moderately permeable. Available water capacity is moderate. They have a brown surface and a yellowish red subsoil. Ruston soils occur on moderate to steep slopes and ridgetops. They have developed in loamy Coastal Plains sediments.

A representative profile of Ruston fine sandy loam, 3 to 8 percent slope, was described on the Lee Memorial Forest by the Soil Conservation Service, U.S. Department of Agriculture, as follows:

A_1	--	0-8".	Dark grayish brown (10YR 4/2) fine sandy loam with common medium faint yellowish brown (10YR 5/6) mottles; massive; friable; medium acid; clear wavy boundary.
B & A	--	8-10".	60% yellowish red (5YR 4/6) sandy clay loam and 40% yellowish brown (10YR 5/4) fine sandy loam; weak coarse subangular blocky structure; friable; few clay films in pores; strongly acid; clear smooth boundary.
B_{21t}	--	10-18".	Yellowish red (5YR 4/6) clay loam with few fine faint yellowish brown mottles; moderate medium subangular blocky structure; friable; many thin clay films; very strongly acid; gradual smooth boundary.
B_{22t}	--	18-28".	Yellowish red (5YR 4/6) sandy clay loam; weak medium subangular blocky structure; friable; few patchy clay films; very strongly acid; clear smooth boundary.
A'_2	--	28-36".	Strong brown (7.5YR 5/6) fine sandy loam with common medium distinct yellowish red (5YR 5/6) mottles; weak coarse subangular blocky structure; friable; slightly brittle; thin pale brown ped coats; very strongly acid; clear wavy boundary.

B'_{21t} -- 36-56". Red (2.5YR 4/6) sandy clay loam with few fine distinct yellowish brown (10YR 5/6) mottles; weak medium subangular blocky structure; friable; many thin discontinuous clay films; very strongly acid; gradual smooth boundary.

B'_{22t} -- 56-72". Yellowish red (5YR 5/8) fine sandy loam; weak medium subangular blocky structure; friable; few clay films; very strongly acid.

Range in Characteristics: The A1 horizon ranges from very dark grayish brown (10YR 3/2) to brown (10YR 5/3). The A2 horizon ranges from brown (10YR 5/3) to light yellowish brown (10YR 6/4). The B horizons range from yellowish red (5YR 5/6) to red (2.5YR 4/8). Texture is sandy clay loam, clay loam or loam. Reaction is medium acid to strongly acid in the surface layers and very strongly acid in the subsoil.

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STOUGH SERIES

The Stough series is in the coarse-loamy, siliceous, thermic family of Aquic Fragiudults. The soils of the Stough series are brown with gray mottles and have compact lower subsoil layers. They are somewhat poorly drained and moderately slowly permeable. Surface runoff is slow and available water capacity is moderate. The soil is strongly acid to very strongly acid throughout. Wetness and low fertility are the main problems.

Stough soils are on the flat to gently sloping local stream terraces. They have developed in alluvium from Coastal Plain uplands. They are associated with the Myatt, Mashulaville and Kalmia soils. Stough soils are better drained than the Myatt and Mashulaville soils and more poorly drained than the Kalmia soils. In addition, Myatt and Kalmia lack fragipans.

A representative profile of Stough very fine sandy loam, 0 to 1 percent slope, was described on the Lee Memorial Forest by the Soil Conservation Service, U.S. Department of Agriculture, as follows:

A_1 -- 0-4". Dark grayish brown (10YR 4/2) moist, light brownish gray (10YR 6/2) dry, very fine sandy loam; weak, very fine granular structure; slightly hard when dry; many roots; strongly acid; abrupt smooth boundary.

A_2 -- 4-10". Brown (10YR 5/3) very fine sandy loam with common medium distinct yellowish brown (10YR 5/6) mottles and red (2.5YR 4/8) stains on cleavages and in root channels; weak, very fine granular to medium subangular blocky structure; friable; many roots; strongly acid; abrupt wavy boundary.

B_{2t} -- 10-14". Brownish yellow (10YR 6/6) light sandy clay loam with common, medium distinct pale brown (10YR 6/3) mottles; weak medium subangular blocky structure; friable; few soft brown concretions and pin holes present; few patchy clay films; few roots; very strongly acid; gradual wavy boundary.

B_{x1} -- 14-18". Yellowish brown (10YR 5/6) very fine sandy loam with common, medium, distinct gray (10YR 6/1) mottles; weak, medium platy structure; firm; few soft brown concretions and pin holes present; very strongly acid; abrupt, smooth boundary.

B_{x2} -- 18-30". Gray (10YR 6/1) fine sandy loam with common, medium distinct yellowish brown (10YR 5/6) mottles; weak medium to coarse platy structure; firm; slightly brittle; few pin holes present; very strongly acid; abrupt, smooth boundary.

B_{x3} -- 30-48". Yellowish brown (10YR 5/6) fine sandy loam with common, medium, distinct gray (10YR 6/1) mottles; weak medium subangular blocky structure; firm; slightly brittle; patchy clay films on ped faces; very strongly acid.

Range in Characteristics: The A horizon is dark grayish brown to brown very fine sandy loam, fine sandy loam or silt loam 5 to 10 inches thick. The B_{2t} horizons range from yellowish brown (10YR 5/4) to brownish yellow (10YR 6/6). Mottles of gray or light brownish gray are dominant. Texture is fine sandy loam, loam or light sandy clay loam. The B_x horizons are yellowish brown and gray fine sandy loam to light sandy clay loam. Depth to compact and brittle layers range from 14 to 27 inches.

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APPENDIX B

BASIC PLOT DATA ON OXYGEN MEASUREMENTS

Table 8. The soil oxygen contents in Plot No. 1 by measurement dates and soil depth

Date	Soil oxygen content			
Month-Day-Year	1 foot	2 feet	3 feet	4 feet
	- - - - - - - - - - - Percent - - - - - - - - - -			
4-5-70	H[a]	H	H	H
4-19-70	19.7	H	H	H
5-5-70	19.0	H	H	H
5-23-70	19.9	19.2	12.5	7.3
6-6-70	20.5	19.8	14.6	7.4
6-22-70	20.2	19.8	16.0	7.9
7-5-70	20.0	19.5	16.7	9.0
7-22-70	20.1	20.0	16.3	12.8
8-2-70	20.3	20.1	16.8	13.1
8-17-70	20.0	19.7	16.3	15.8
8-31-70	19.6	19.0	13.0	7.0
9-22-70	20.5	20.1	17.5	16.1
10-6-70	20.6	20.2	17.6	16.9
10-22-70	19.8	19.0	16.1	12.8
11-5-70	20.0	19.5	7.7	H
11-19-70	20.0	18.5	H	H
12-6-70	20.5	20.0	8.0	H
1-7-71	18.7	H	H	H
1-31-71	H	H	H	H
2-10-71	H	H	H	H
3-10-71	H	H	H	H
3-30-71	H	H	H	H
4-20-71	18.0	15.7	3.1	H

a H in this and subsequent tables indicates free water which was represented by 0.9 percent of oxygen in the statistical analyses.

Table 9. The soil oxygen contents in Plot No. 4 by measurement dates and soil depth

Date	Soil oxygen content			
Month-Day-Year	1 foot	2 feet	3 feet	4 feet
	Percent			
4-5-70	H	H	H	H
4-19-70	H	H	H	H
5-5-70	H	H	H	H
5-23-70	20.0	16.5	8.9	H
6-6-70	19.6	16.0	9.0	H
6-22-70	20.5	17.5	16.0	H
7-7-70	19.0	17.0	16.5	5.0
7-22-70	19.3	15.0	12.5	7.0
8-2-70	19.3	16.6	12.6	7.3
8-17-70	19.1	15.5	11.0	7.0
8-31-70	H	H	H	H
9-22-70	19.9	15.8	15.0	9.8
10-6-70	20.5	18.4	17.9	12.5
10-22-70	17.6	7.1	2.9	H
11-5-70	19.6	9.0	H	H
11-19-70	11.1	H	H	H
12-6-70	20.1	12.3	H	H
1-7-71	H	H	H	H
1-31-71	H	H	H	H
2-10-71	H	H	H	H
3-10-71	H	H	H	H
3-30-71	H	H	H	H
4-20-71	19.1	5.5	H	H

Table 10. The soil oxygen contents in Plot No. 5 by measurement dates and soil depth

Date	Soil oxygen content			
Month-Day-Year	1 foot	2 feet	3 feet	4 feet
	- - - - - - - - - - - Percent - - - - - - - - - -			
4-5-70	19.0	13.0	H	H
4-19-70	19.2	15.0	H	H
5-5-70	14.5	H	H	H
5-23-70	20.3	16.5	10.5	H
6-6-70	19.2	17.0	15.5	14.0
6-22-70	18.9	17.2	13.7	-
7-7-70	20.0	17.0	16.3	14.0
7-22-70	20.1	17.9	16.5	14.3
8-2-70	20.0	18.7	16.8	15.4
8-17-70	20.1	19.2	11.7	8.8
8-31-70	14.6	12.5	H	H
9-22-70	19.6	18.9	H	H
10-6-70	20.3	19.7	6.3	6.1
10-22-70	16.5	13.1	2.8	H
11-5-70	19.5	16.5	6.6	H
11-19-70	17.9	13.8	7.3	H
12-6-70	20.3	17.0	11.0	H
1-7-71	19.0	11.7	H	H
1-31-71	18.4	10.9	H	H
2-10-71	15.9	H	H	H
3-10-71	13.8	H	H	H
3-30-71	H	H	H	H
4-20-71	20.2	16.8	10.3	H

Table 11. The soil oxygen contents in Plot No. 7 by measurement dates and soil depth

Date	Soil oxygen content			
Month-Day-Year	1 foot	3 feet	5 feet	7 feet
	- - - - - - - - - Percent - - - - - - - - -			
4-5-70	20.0	13.3	H	H
4-19-70	20.1	15.0	H	H
5-5-70	19.8	11.0	H	H
5-23-70	20.2	15.5	9.0	H
6-6-70	19.9	15.8	10.5	H
6-22-70	20.6	17.1	13.0	H
7-5-70	20.3	16.0	14.7	4.0
7-22-70	20.3	16.7	15.1	4.9
8-2-70	20.0	16.3	15.0	5.2
8-11-70	20.2	18.3	14.1	7.7
8-31-70	19.3	14.3	H	H
9-22-70	20.3	18.6	16.0	H
10-6-70	20.6	18.5	17.2	5.1
10-22-70	20.0	15.8	10.5	1.3
11-5-70	20.2	15.7	10.0	3.1
11-19-70	20.2	15.0	4.5	3.0
12-6-70	20.5	17.9	4.0	H
1-7-71	20.4	16.0	H	H
1-31-71	20.5	15.0	H	H
2-10-71	20.5	12.9	H	H
3-10-71	20.2	10.5	H	H
3-30-71	20.0	5.5	H	H
4-20-71	20.5	20.0	14.6	4.5

Table 12. The soil oxygen contents in Plot No. 9 by measurement dates and soil depth

Date	Soil oxygen content						
Month-Day-Year	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet
				-Percent-			
4-5-70	20.0	19.5	19.1	18.7	18.6	18.5	15.4
4-19-70	20.3	19.6	19.3	18.9	18.9	18.9	16.6
5-5-70	19.8	19.1	18.9	18.8	18.7	18.7	17.6
5-23-70	20.o	19.8	19.5	19.6	19.3	19.0	17.8
6-6-70	20.2	19.9	19.8	19.6	19.5	19.2	17.9
6-22-70	20.5	20.1	20.1	20.0	19.6	19.5	19.1
7-7-70	20.4	20.2	20.1	20.0	19.7	19.6	18.8
7-22-70	20.4	20.1	20.1	19.9	19.7	19.6	18.9
8-2-70	20.2	19.8	19.8	19.8	19.6	19.4	18.7
8-17-70	20.0	19.0	18.8	18.5	18.4	18.2	17.9
8-31-70	19.0	18.4	18.3	18.5	18.5	18.4	17.0
9-22-70	20.4	19.5	19.4	19.2	19.1	18.8	18.4
10-6-70	20.5	20.0	19.9	19.8	19.5	19.0	18.5
10-22-70	20.0	19.0	18.6	18.5	18.4	18.0	16.8
11-5-70	20.0	19.3	19.2	19.1	18.8	18.7	17.5
11-19-70	20.0	19.2	19.1	19.1	19.0	18.8	18.4
12-6-70	20.2	20.0	19.9	19.9	19.9	19.7	18.6
1-7-71	19.9	19.1	19.0	18.9	18.7	18.5	15.8
1-31-71	20.2	19.8	19.5	19.3	19.0	18.4	16.0
2-10-71	20.3	19.8	19.5	19.5	19.4	19.1	14.6
3-10-71	20.3	20.0	19.9	19.6	19.4	19.2	17.0
3-30-71	19.8	19.5	19.4	19.4	19.3	19.2	16.2
4-20-71	20.2	19.9	19.7	19.6	19.5	19.3	18.3

Table 13. The soil oxygen contents in Plot No. 10 by measurement dates and soil depth

Date Month-Day-Year	Soil oxygen content 1 foot	2 feet	4 feet			6 feet		
	BMU[a]	BMU	B	M	U	B	M	U
	Percent							
4-5-70	20.3	20.1	12.0	20.0	20.0	H	18.0	19.8
4-19-70	20.6	20.1	13.5	19.0	20.0	H	18.5	19.5
5-5-70	20.4	19.5	17.0	18.1	19.4	H	17.5	19.1
5-23-70	20.7	20.0	18.5	19.0	19.9	H	17.5	19.8
6-6-70	20.4	20.1	19.2	19.8	19.8	H	18.0	19.0
6-22-70	20.8	20.3	19.2	19.5	20.0	H	18.0	19.0
7-7-70	20.3	20.2	19.3	19.6	20.0	H	18.1	19.2
7-22-70	20.1	19.8	18.4	19.6	19.7	H	19.0	19.3
8-2-70	20.5	19.9	18.8	18.9	19.8	H	16.5	19.5
8-17-70	20.4	19.7	18.0	18.9	19.0	H	15.5	18.9
8-31-70	20.5	19.6	15.9	16.0	19.2	H	15.0	18.5
9-22-70	20.5	20.0	16.0	16.5	19.1	H	16.5	18.5
10-6-70	20.8	20.2	-	19.0	19.9	H	16.9	19.8
10-22-70	20.4	20.0	16.2	17.8	19.5	H	16.0	19.0
11-5-70	20.5	19.9	18.8	19.6	19.8	H	17.1	19.5
11-19-70	20.3	20.0	17.9	19.5	19.8	H	16.8	19.5
12-6-70	20.8	20.2	18.0	19.8	20.4	H	18.1	20.0
1-7-71	20.6	19.7	14.0	-	19.8	H	-	19.5
1-31-71	20.7	20.2	18.0	18.5	19.7	H	17.8	19.7
2-10-71	20.7	20.3	15.5	18.5	19.9	H	17.5	19.6
3-10-71	20.7	20.4	19.4	19.4	20.4	H	18.5	20.3
3-30-70	20.7	20.4	18.5	19.0	19.8	H	18.0	19.4
4-20-70	20.7	20.2	19.0	19.1	20.0	H	18.0	19.9

[a]B=readings at bottom of the slope; M=readings at middle of the slope; U=readings on upper slope. The first and second column of soil oxygen contents are the average of three replications across the slope.

Table 14. The soil oxygen contents in Plot No. 17 by measurement dates and soil depth

Date	Soil oxygen content							
Month-Day-Year	1 foot	2 feet	3 feet			4 feet		
	BMU[a]	BMU	B	M	U	B	M	U
	Percent							
4-5-70	20.0	19.3	H	H	H	H	H	H
4-19-70	20.0	19.5	H	H	H	H	H	H
5-5-70	19.5	18.5	H	H	H	H	H	H
5-23-70	20.3	19.5	H	7.5	13.0	H	H	6.0
6-6-70	19.9	19.4	H	8.0	18.0	H	7.2	16.5
6-22-70	20.0	19.8	17.0	18.0	19.7	H	8.5	18.0
7-5-70	19.5	18.4	14.0	17.0	17.5	H	8.0	16.0
7-22-70	20.1	19.4	17.0	18.7	19.0	8.0	11.0	17.0
8-2-70	20.2	19.4	13.0	16.0	18.0	6.0	10.5	17.5
8-17-70	19.5	19.1	7.0	11.0	18.5	4.6	5.0	13.5
8-31-70	19.7	18.4	H	H	8.0	H	H	H
9-22-70	20.2	19.5	H	9.0	18.5	H	H	14.5
10-6-70	20.4	19.9	18.4	18.6	19.1	H	5.0	18.0
10-22-70	19.8	18.8	H	9.5	14.0	H	H	H
11-5-70	20.1	19.6	H	H	18.5	H	H	H
11-19-70	20.1	19.7	H	5.8	13.2	H	H	H
12-6-70	20.4	19.9	H	H	20.2	H	H	H
1-7-71	20.4	20.0	H	H	16.5	H	H	H
1-31-71	20.1	19.7	7.0	8.0	17.0	H	H	H
2-10-71	20.2	19.7	H	H	H	H	H	H
3-10-71	20.0	19.5	H	H	H	H	H	H
3-30-71	20.4	20.0	H	H	16.0	H	H	H
4-20-71	20.1	19.9	H	6.5	19.0	H	H	H

[a]B=O_2 readings at bottom of the slope, M=O_2 readings at middle of the slope, U_2=O_2 readings on upper of the slope. The first and second column of soil oxygen readings are the average of three replications across the slope.

Table 15. The soil oxygen contents in Plot No. 18 by measurement dates and soil depth

Date	Soil oxygen content			
Month-Day-Year	1 foot	2 feet	3 feet	4 feet
	- - - - - - - - - Percent - - - - - - - - -			
4-5-70	15.0	5.5	H	H
4-19-70	17.7	16.1	H	H
5-5-70	18.2	H	H	H
5-23-70	20.0	13.0	H	H
6-6-70	20.2	12.3	H	H
6-22-70	20.3	20.0	7.5	H
7-5-70	19.6	17.9	7.6	5.0
7-22-70	20.0	18.5	8.0	6.3
8-2-70	20.5	20.0	10.5	6.4
8-11-70	19.6	17.8	8.0	7.1
8-31-70	13.7	H	H	H
9-22-70	20.0	18.0	H	H
10-6-70	20.4	19.3	3.0	H
10-22-70	17.3	2.0	H	H
11-5-70	19.3	3.0	H	H
11-19-70	16.4	H	H	H
12-6-70	18.6	H	H	H
1-7-71	H	H	H	H
1-31-71	H	H	H	H
2-10-71	H	H	H	H
3-10-71	H	H	H	H
3-30-71	H	H	H	H
4-20-71	19.2	H	H	H

Table 16. The soil oxygen contents in Plot No. 20 by measurement dates and soil depth

Date	Soil oxygen content			
Month-Day-Year	1 foot	2 feet	3 feet	4 feet
	Percent			
4-5-70	9.8	H	H	H
4-19-70	17.3	H	H	H
5-5-70	17.0	H	H	H
5-23-70	20.0	17.0	12.0	H
6-6-70	19.5	17.5	14.2	9.0
6-22-70	19.9	18.0	15.5	14.0
7-7-70	19.0	18.0	14.9	14.5
7-22-70	19.5	18.3	15.0	14.6
8-2-70	19.5	18.3	16.3	16.1
8-17-70	19.3	17.9	14.5	13.1
8-31-70	13.8	13.0	H	H
9-22-70	20.0	19.0	15.8	11.2
10-6-70	20.3	19.4	17.8	16.2
10-22-70	18.0	17.2	H	H
11-5-70	19.9	H	H	H
11-19-70	15.8	H	H	H
12-6-70	20.2	7.3	H	H
1-7-71	H	H	H	H
1-31-71	H	H	H	H
2-10-71	H	H	H	H
3-10-71	H	H	H	H
3-30-71	H	H	H	H
4-20-71	19.5	8.2	H	H

APPENDIX C

RAINFALL DATA DURING THE STUDY PERIOD

Table 17. Rainfall data from April 1970 to April 1971 on the L.S.U. Forest

Date	Rainfall	Date	Rainfall
	Inches		Inches
April 1, 70	0.54	Oct. 7-8-9, 70	5.84
10, 70	0.86	23, 70	0.27
15, 70	0.43	27, 70	0.59
19, 70	0.56	28, 70	0.14
May 2-3, 70	3.28	Nov. 9, 70	0.83
16	0.62	13, 70	1.30
June 1-2, 70	1.80	Dec. 14-15, 70	3.69
24, 70	1.12	23, 70	0.29
27-28, 70	1.28	26, 70	1.07
		30-31, 70	2.00
July 4, 70	0.18		
9, 70	4.00	Jan. 8, 71	0.66
17, 70	0.32		
24, 70	1.18	Feb. 4-5, 71	2.00
		10-11, 71	1.79
August 5, 70	2.41	18-19-20, 71	1.37
8-9, 70	0.25	26, 71	0.81
18, 70	0.80		
21, 70	0.94	March 1-2, 71	3.21
27, 70	2.73	6, 71	0.27
		9-10, 71	0.60
Sept. 16, 70	0.30	15, 71	0.10
25, 70	0.22	28, 71	1.37
		April 1, 71	0.31

APPENDIX D

SOIL MOISTURE CONTENTS ON THE STUDY PLOTS

Table 18. The soil moisture contents in Plot No. 1 by measurement dates and soil depth

Date	Soil moisture content			
Month-Day-Year	1 foot	2 feet	3 feet	4 feet
	Percent			
4-4-70	15.67	16.11	15.59	15.37
4-18-70	14.95	16.54	15.95	15.69
5-6-70	14.56	15.39	15.42	15.21
5-23-70	11.19	12.50	13.68	14.42
6-6-70	4.37	12.48	13.36	14.33
6-20-70	8.16	11.30	12.96	14.32
7-30-70	9.28	11.10	12.42	13.49
8-18-70	11.71	12.65	13.01	13.86
9-2-70	11.73	12.41	13.15	14.30
10-4-70	5.54	9.51	11.75	12.42
10-23-70	11.41	12.80	13.04	13.67
11-20-70	11.29	12.72	13.38	13.40

Table 19. The soil moisture contents in plot No. 4 by measurement dates and soil depth

Date	Soil moisture content			
Month-Day-Year	1 foot	2 feet	3 feet	4 feet
	- - - - - - - - - - Percent - - - - - - - - - -			
4-4-70	16.43	18.41	16.96	15.74
4-18-70	15.76	18.48	17.01	15.87
5-6-70	15.61	17.69	16.68	15.70
5-23-70	11.99	14.04	16.22	15.65
6-6-70	11.81	13.09	14.86	15.34
6-20-70	8.76	12.75	14.44	15.51
7-30-70	12.39	13.76	15.65	15.45
8-18-70	13.53	14.64	16.30	15.87
9-2-70	15.39	17.56	16.68	15.64
10-4-70	8.28	11.87	13.87	14.95
10-23-70	13.00	14.01	14.99	14.29
11-20-70	13.11	15.51	14.73	13.77

Table 20. The soil moisture contents in Plot No. 5 by measurement dates and soil depth

Date	Soil moisture content			
Month-Day-Year	1 foot	2 feet	3 feet	4 feet
	Percent			
4-4-70	14.47	14.55	15.57	17.94
4-18-70	13.89	14.17	15.83	17.98
5-6-70	14.54	14.69	15.75	18.10
5-23-70	11.58	13.00	14.04	15.31
6-6-70	12.42	12.92	13.43	14.84
6-20-70	10.04	13.25	14.05	15.12
7-30-70	12.92	13.22	13.93	14.63
8-18-70	12.62	12.91	13.71	14.83
9-2-70	13.99	13.76	15.28	17.40
10-4-70	9.29	12.58	13.50	14.56
10-23-70	12.06	12.62	13.58	15.74
11-20-70	12.12	12.21	13.47	19.99

Table 21. The soil moisture contents in Plot No. 7 by measurement dates and soil depth

Date	Soil moisture content			
Month-Day-Year	1 foot	3 feet	5 feet	7 feet
	- - - - - - - - - - -Percent- - - - - - - - -			
4-4-70	12.27	14.57	14.68	16.50
4-18-70	11.47	12.96	14.33	16.36
5-6-70	11.56	14.56	14.06	16.07
5-23-70	9.94	11.78	12.38	15.54
6-6-70	9.47	11.43	10.39	15.23
6-20-70	8.84	10.97	10.04	15.76
7-30-70	10.47	11.40	10.49	14.72
8-18-70	9.77	11.54	11.91	14.84
9-2-70	11.60	14.14	13.59	16.67
10-4-70	8.44	11.70	9.36	15.09
10-23-70	10.19	12.84	12.85	14.62
11-20-70	9.68	11.00	11.84	14.08

Table 22. The soil moisture contents in plot No. 9 by measurement dates and soil depth

Date	Soil moisture content						
Month-Day-Year	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet
	Percent						
4-4-70	11.50	13.23	8.90	6.47	11.11	13.51	13.32
4-18-70	11.17	13.12	8.43	6.12	10.54	13.42	13.31
5-6-70	11.24	13.37	8.98	6.29	10.74	12.77	12.74
5-23-70	8.40	11.48	7.55	5.44	10.27	12.70	12.26
6-6-70	8.91	11.73	7.45	5.26	9.91	12.80	12.30
6-20-70	5.92	10.85	7.06	5.25	10.18	12.94	12.54
7-30-70	10.48	11.36	6.84	4.98	10.17	12.73	11.97
8-18-70	10.50	12.14	8.58	5.66	10.23	12.84	12.20
9-2-70	11.05	13.18	9.12	6.95	11.55	13.59	13.27
10-4-70	6.01	10.89	7.18	5.36	8.33	12.56	12.11
10-23-70	9.67	11.90	8.20	6.04	9.38	11.96	11.94
11-20-70	9.85	11.60	7.84	5.23	8.10	11.29	11.09

Table 23. The soil moisture contents in Plot No. 10 by measurement dates and soil depth

Date	Soil moisture content							
Month-Day-Year	1 foot	2 feet	4 feet			6 feet		
	BMU	BMU	B	M	U	B	M	U
	Percent							
4-4-70	10.3	11.7	16.28	13.77	6.60	18.64	15.26	8.11
4-18-70	9.7	11.3	15.73	13.35	6.56	18.42	15.16	7.11
5-6-70	9.8	12.1	16.19	14.04	6.44	18.38	14.58	7.00
5-23-70	6.8	10.1	14.78	12.91	5.80	16.78	14.67	6.81
6-6-70	8.2	10.0	14.75	12.36	5.59	16.61	14.35	6.67
6-20-70	5.7	9.4	14.69	12.46	5.32	16.94	14.28	6.67
7-30-70	9.3	10.8	14.56	13.03	5.75	15.84	13.92	6.55
8-18-70	8.4	10.7	14.50	13.18	6.29	16.41	14.35	7.21
9-2-70	9.9	9.9	15.88	13.97	7.31	18.01	15.07	9.18
10-4-70	5.3	9.1	13.80	12.18	5.66	16.17	14.20	5.54
10-23-70	8.1	10.3	14.79	11.82	6.60	16.62	14.23	5.89
11-20-70	8.4	10.2	13.46	7.62	6.44	16.80	12.91	5.49

[a] B = O_2 readings at bottom of the slope; M = O_2 readings at middle of the slope; U = O_2 readings on upper slope. The first and second column of soil moisture contents are the average of three replications across the slope.

Table 24. The soil moisture contents in Plot No. 17 by measurement dates and soil depth

Date	Soil moisture content			
Month-Day-Year	1 foot	2 feet	3 feet	4 feet
	Percent			
4-4-70	12.77	14.36	19.52	16.84
4-18-70	12.65	13.55	19.87	16.98
5-6-70	12.67	14.43	19.19	16.74
5-23-70	11.14	12.31	14.60	16.69
6-6-70	11.35	12.30	14.25	16.15
6-20-70	10.30	11.86	14.91	17.16
7-30-70	11.33	11.74	14.86	16.72
8-18-70	11.87	12.31	15.04	16.61
9-2-70	12.32	13.76	18.89	16.67
10-4-70	10.46	11.00	14.44	16.60
10-23-70	11.17	11.90	17.44	15.33
11-20-70	10.96	11.70	17.50	15.09

Table 25. The soil moisture contents in Plot No. 18 by measurement dates and soil depth

Date	Soil moisture content			
Month-Day-Year	1 foot	2 feet	3 feet	4 feet
	- - - - - - - - - - Percent - - - - - - - - - -			
4-4-70	15.97	17.78	17.01	16.87
4-18-70	16.03	17.43	17.10	16.84
5-6-70	15.35	17.63	16.74	16.50
5-23-70	12.31	16.37	16.35	16.09
6-6-70	12.10	16.20	16.64	16.47
6-20-70	9.27	13.60	15.99	16.67
7-30-70	10.47	14.00	16.09	16.43
8-18-70	12.04	15.73	16.53	16.39
9-2-70	15.03	17.26	16.81	16.93
10-4-70	9.87	14.09	16.63	16.63
10-23-70	13.88	15.45	16.02	15.41
11-20-70	13.56	15.00	15.14	14.93

Table 26. The soil moisture contents in Plot No. 20 by measurement dates and soil depth

Date	Soil moisture content			
Month-Day-Year	1 foot	2 feet	3 feet	4 feet
	- - - - - - - - - -Percent- - - - - - - - - -			
4-4-70	15.01	18.07	19.39	19.04
4-18-70	13.64	17.43	17.10	16.84
5-6-70	14.21	17.84	19.14	18.64
5-23-70	9.24	12.96	14.00	15.13
6-6-70	20.03	12.11	12.84	14.57
6-20-70	7.07	11.52	12.55	14.36
7-30-70	8.21	11.77	12.19	13.96
8-18-70	8.66	11.84	12.69	16.78
9-2-70	13.20	16.35	18.72	18.59
10-4-70	7.04	11.50	12.35	14.22
10-23-70	11.29	13.90	17.23	16.63
11-20-70	12.00	15.63	17.15	16.42

VITA

Shih-chang Hu was born in the rural community of Shan-cheng, Honan Province, China, on February 25, 1934. He is the oldest son of Mr. and Mrs. C. L. Hu.

He received his early education at Shan-cheng Elementary School, Nan-su Middle School, Taipei City High School and Subordinate High School of Taiwan Normal University. After passing the entrance examination, he entered Taiwan Provincial Chung-Hsing University, Taichung, Taiwan, China, in 1953. During his college work, he was an honor student and held a four-year scholarship. He completed his college work and was awarded the degree of Bachelor of Science in Forestry at the same university in July 1957.

After graduation from the university, Hu served in the army until his release from active duty in 1959. Then he was employed as a research forester at the Taiwan Forestry Research Institute for five years. He resigned his position in March 1964 and entered the Graduate School at Utah State University, Logan, in 1965. After the completion of the requirements for the degree of Master of Science in Forestry at Utah State, Hu entered the Graduate School at Louisiana State University in 1967. He is currently seeking the Doctor of Philosophy degree in the School of Forestry and Wildlife Management.

On August 14, 1965, Hu married the former Pai-cha Chow and they are the parents of two young sons, Bennie and Ben-Wha.

Hu is a member of Xi Sigma Pi.

EXAMINATION AND THESIS REPORT

Candidate: Shih-Chang Hu

Major Field: Forestry

Title of Thesis: Seasonal and Profile Variations in Oxygen Content of Forest Soils Under Mature Loblolly Pine (*Pinus taeda* L.) Stands.

Approved:

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:

July 16, 1971