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AN EXPERIMENT ON THE EFFECT OF ROOT PRUNING AND TWO DIFFERENT PLANTING METHODS ON CONIFEROUS STOCK
and
A STUDY OF NATURAL HARDWOOD REPRODUCTION IN STINCHFIELD WOODS

by
IVOR N. JENKINS

PART A

AN EXPERIMENT ON THE EFFECT OF ROOT PRUNING AND TWO DIFFERENT PLANTING METHODS ON CONIFEROUS STOCK

and

PART B

A STUDY OF NATURAL HARDWOOD REPRODUCTION IN STINCHFIELD WOODS

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By IVOR N. JENKINS

JUNE 1946

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N. L. M.

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IN PREPARING THIS REPORT

PART A

AN EXPERIMENT

ON

THE EFFECT OF ROOT PRUNING

AND

TWO DIFFERENT PLANTING METHODS

ON

CONIFEROUS STOCK

FORWARD

These two reports, the one on the effect of root pruning and the effect of two different planting methods on coniferous stock, and the other on the natural reproduction of hardwoods in Stinchfield Woods, are submitted as partial requirements for a Degree of Master of Forestry from the University of Michigan. The work was done under the direction of Leigh J. Young, Professor of Silviculture of the School of Forestry and Conservation, to whom I am indebted for the suggestion of the problem and for advice in gathering data.

I am also indebted to J. H. Stoeckeler, who is the Silviculturist at the Lake States Forest Experiment Station, for published and unpublished experimental findings of the Station.

May 1946

Ivor N. Jenkins

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INTRODUCTION

This is a continuation of the experimental report written in the spring of 1937 by Mr. C. F. Coffman, Jr., concerning a planting made on part of Lot 8, Stinchfield Woods. (See Map 1) That paper was added to by Mr. William E. Towell in 1938, Mr. Robert L. Metz in 1939, Mr. Robert E. Leeson in 1940, and Mr. G. David Bauch in 1942. (The originals of these reports are to be found in the Forestry School Library.)

The experiment was established, as stated by Mr. Coffman (A), in order to have a periodic check to determine:

1. The effect of various degrees of root pruning on survival and growth of both roots and tops of 2-0 Western yellow pine stock.
2. The same for 2-2 Austrian pine stock. (Only one type of pruning was done on this species.)
3. The effect of slit planting as opposed to center hole planting on survival and growth.

According to Towell (B), the objects of the experiment were also to "include a study of subsequent development of the root systems as affected by planting coniferous stock with the roots in one vertical plane, as is done in slit or dibble planting."

There have not yet been any comprehensive planting experiments in this region or in this country, as far as the writer is aware, sufficiently old to indicate the full effects of the various methods of planting. With favorable and normal soil, almost any system which gets the tree roots in the ground will give reasonably good early survivals. However, according to Rudolf[58], there are several European investigations which indicate that full effects of planting methods may not show up for ten to thirty years. When some crisis arises, suchas extreme climatic conditions or the severe competition for moisture and mineral nutrients which occurs when the tree crowns close in, the poor root distribution resulting from a system of planting such as the slit method may result in heavy losses. Among other deficiencies of such root systems is a failure to make the trees wind-firm due to the prevention of anchorage in certain directions.

An effect similar to that of slit planting occurs when the roots are confined to the upper strata of soil by the removal of the tap root, which usually fails to re-form. Thus the question arises as to whether, when an exceptionally dry year (or series of years) comes and the upper surface layers dry out, the tree will be able to exist with no contact with the moister layer below. Also, how can the tree be as wind-firm when the roots are confined to the upper layers?

The results of this experiment should help to fill the need[44] for the establishment of comprehensive forest planting studies that will cover a wide range of factors, such as soil types, species, age of stock, methods of planting, ground preparation, and mixtures. It is only through such studies, performed by horticulturists, physiologists and silviculturalists that more inexpensive and more sure methods will be found for successfully propagating superior trees and uniform stock for experimental purposes, and for producing disease-resistant clones.

The first examination in this experiment, made one year after planting (B) by Mr. Towell, showed that pruning the Western yellow pine to four inches was too severe (See Table III). This effect was produced in spite of the exceptionally moist planting year (See Graph 1). High mortality would probably have resulted even from the six-inch pruning if the precipitation during the planting year had compared with the extremely dry year of 1946, which had only one-half inch of rainfall in April.

A comparison (E) showed that the most thriving tree in the four-inch pruned plot, plot #5, was not as tall as the poorest tree in plot #7, where the trees were unpruned and planted by the center hole method.

The second examination, the second year after planting (C) showed the unpruned stock to have a better average height than the pruned stock (See Table V), and showed the trees planted by the center hole method to have a larger growth average than those planted by the slit method.

The third examination, the third year after planting (D), continued the same trend as noted in the second check (See Table V).

The fourth examination, the fifth year after planting (E), (See Table V) showed the same trend with the Austrian pine, and with the Western yellow pine the unpruned, center hole method still led the other methods; however, in the latter type of tree, the average heights of the trees pruned to four inches and planted by the slit method were higher than the other slit methods, even that of the unpruned trees. Furthermore, the trees pruned to six inches and planted by the slit method showed a better average growth than the unpruned stock.

The fifth examination, made by the author, after nine growing seasons (Table V) showed the unpruned, center hole method still had the highest growth averages for the Austrian pine, while trees pruned to six inches and planted by the slit method had a higher average than the six-inch pruned trees planted by the center-hole method. For the Western yellow pine, also, the unpruned, center-hole still showed the greatest growth, with the plot pruned to four inches and planted by the slit method showing a much smaller average height, though one which was still higher than the six-inch pruned or unpruned slit-planted trees. This year the unpruned slit planted plot showed a slight height advantage over the six-inch pruned plot.

A perfectly controlled experiment is almost an impossibility, if it is possible at all. It is difficult because, as Wahlenberg[73] states, a perfectly controlled experiment is one from which the action of all undertermined influences capable of affecting the results has been included. The one thing for which the test was installed remains as a variable so that the effects can be measured. However, perfect control is impossible to obtain under field conditions. Uniformity of site is always sought after in the field planting tests, but is never found. Often it becomes necessary to compensate for the lack of perfect control by multiplying the number of observations used as a basis for conclusions. This usually necessitates an increase in the number of trees planted. Within wide limits the effects of many of these troublesome extraneous factors can become compensating.

In recent years there has been considerable discussion about including check or control plots and the tendency[47], with the adoption of newer designs and the analysis of variance, is to have fewer plots as checks.

In agronomic investigations in former years the general practice was to have a separate experiment for each question to be answered. With the more recent designs and methods of analysis, it is possible to answer these questions better with a single experiment.

Thus it is possible to have a split-plot design in which the large plots can be divided and these subdivided. Thus, the largest plots are used to compare the factor of least importance, or which may be expected to give the larger differences, and the smaller plots are used to measure the factor of greatest importance, or the one from which the smallest differences are expected.

One caution that should be used, is judging the results obtained from one set of environmental conditions and then generalizing as to their having the same effect on all conditions.

Another important point to keep in mind is whether the difference as found is of sufficient practical importance to make it worth while to make recommendations for changes in agricultural practices based on the difference.

Too often experimenters, in their hurry to get their findings before the public, do not give their experiments sufficient time to develop really conclusive results, and so publish their reports at the end of a year. It is difficult to analyze the results of a single year and draw definite conclusions, and where the experiment can be carried on over a long period the results will give the seasonal variation of the individual trees and so be much more reliable.

These are some of the things that were considered when the original experiment was planned, and, as will be shown later in this paper, this is one of the very few long term experiments attempted on the problem of Root Pruning in conjunction with different planting methods on the survival percent and the effect of the treatments on trees.

DISCUSSION AND REVIEW OF LITERATURE

To have a thorough understanding of why root pruning is done and why various methods are used, there must first be a knowledge of what is meant by the various terminologies used; just what constitutes the different systems; what the relative cost of each is; what amount of equipment and labor is needed for each; and what soil and climatic factors affect each.

The first thing to be considered is the difference between seedlings, transplants, and root-pruned stock. In forest planting, two classes of planting stock are commonly used, seedlings, and transplants. Seedlings are trees one to three years of age, grown from seed in a seed-bed. According to Olson[54], a yellow pine seedling will have a twenty-two inch root in one year, while according to Westvelt[81], coniferous seedlings two years old usually average two to six inches in height, with the roots of a three-year-old seedling from three to ten inches long. (The photograph in Coffman's report (A) showed Western yellow pine roots of at least ten inches, and probably much longer.)

Because of the long, straggling root system of seedlings, it is not unusual to have from one-fourth to one-third of the root cut off when the tree is removed from the seed-bed[46]; it is the fine feeding roots that are removed[67], thus putting the seedlings at a disadvantage in field planting, since the tree has to manufacture more feed-roots before it can obtain food enough to really compete with the conditions of the field.

If a tree is left undisturbed in the nursery, it soon becomes no better than wild stock; and the longer it is left in place, the more extensive the rooting system becomes. Consequently, when the tree is removed, these far-spreading roots which comprise the greater portion of the root system can only be removed with painstaking care. Since it would be an expensive job to take the care necessary, only a small portion of the root is removed with the seedling[54].

The top of the tree grows in equal proportion to the root, and its size is in no way reduced as the roots are when the plant is taken up; thus the tree becomes top-heavy. It is for this reason that wild stock is difficult to transplant successfully, and that young trees are said to withstand the shock of transplanting better than older trees[87]. Plantable seedlings are those which have attained in the nursery such height, stem diameter, and root development as to give adequate promise of survival and early growth when planted in the field[39].

If the seedling were to be put in a field with ideal conditions of soil constituents, moisture, and lack of competition with other plants, then seedlings of two-year-old stock would have very little difficulty in establishing themselves, if handled properly. However, that is almost never the case. In the forests and abandoned farm areas which are usually planted, the adverse conditions generally result in little if any survival.

If all of the ideal planting conditions are produced for the seedling when it is transplanted, as is done in nurseries, then the shock of having its extensive system of food and moisture-securing roots removed is greatly mitigated. Trees that are re-set in a nursery under these conditions are called transplants, and, for forest-planting purposes, they remain in their beds from one to three years[81].

These transplants are set farther apart than seedlings, and so the root growth that is confined to the stem can grow into a compact, bushy system[54]. This gives the transplant a size and quality advantage over seedlings of the same age[81].

Small seedlings cannot stand as much competition for soil moisture and light as transplants. For this reason, on sites bearing heavy sod, tall weeds, or brush, the latter class of stock is the better choice. Grass or weeds not only compete for soil moisture and light in summer, but they form a smothering mulch in the winter. Therefore, unless the competing vegetation can be removed, small seedlings should not be used on such a site.

When trees are transplanted, the top growth slows down as a result of the drop in food and water supply made available for them. So it is that transplants tend to have better balance than seedlings, since the tops are relatively small in proportion to the length of the roots[49]. This ratio of the effective transpiring surface of the top to the effective absorbing surface of the root, or a ratio of stored food content, is an excellent parallel to plant behavior.[82] Such a top-root ratio is used either undefined, or on a fresh-weight (green-weight) or dry-weight basis. Plant vigor may seem to be an arbitrary criterion of good planting stock, but it may be closely approximated on the basis of such factors as the total size, root-top ratio, form of the roots and crown, stem thickness, and the color of foliage[24]; and about the most important way is to determine the root-top ratio.

Age classes are merely convenient expressions of size classes for a particular region. 1-0, 2-0, and 3-0 stock are seedlings one, two, and three years old consecutively, while transplants are 1-1, 1-2, and 1-3: one year in seed-bed and one, two or three years consecutively in the transplant bed. Transplants may be in any combination; for instance, a 2-2 has spent two years in the seed-bed and two years in the transplant bed. These age classes denote the years required in seed-beds and transplant beds to produce the greatest number of uniformly good plants of a certain size for certain areas or regions. It is futile, according to Olsen[54], to apply age-class studies of one nursery to that of another nursery operating under different climatic conditions. This is especially true in the western United States where site conditions are usually more severe than in the East[69].

Forest nursery stock, whether it be seedling or transplant, should be judged by the condition of the root system and the balance between the root and the top. Unlike ornamental stock, these trees are out-planted in the forests, waste areas, and abandoned farms where no care is given to them after planting. The change from deep soil and a well-watered condition to a permanent, hot, dry and exposed position usually holds the trees at a standstill for the first year. Only the most successful ones can make the adjustment[54]. There is the added disadvantage of roots of heavy grass and weeds that compete for the available moisture. A 3-0 is usually used in place of a 2-0 here, even though it is more expensive, because the larger top gives an advantage over weeds and grass both in aiding summer growth and in preventing burial in winter and consequent loss.

The object of all good nurserymen is to produce high class nursery stock in quantities adequate to the problem in hand. This stock should be produced at a price within the reach of every land owner, since much of the land being reforested is owned by private owners. The price per thousand at which nursery stock is sold has a decided effect upon the number of trees planted and upon the character of the land reforested[34].

Transplants, though costing more than seedlings, are sometimes a better investment in terms of the number of trees that actually live; for instance, in difficult planting sites some loss will usually take place. An eighty percent seedling survival and a ninety-five percent transplant survival is considered highly successful planting[81].

Although transplanting and certain other nursery treatments produce sturdier and better-balanced stock, such measures greatly increase the cost of stock, and so there is a great tendency for some foresters to use the poorer stock[58]. Tests carried on by the Lake States Forest Experiment Station[54] on the Huron National Forest have shown a regular increase in survival and height growth from 1-0 to 2-1 stock, the results differing enough to mean, under certain conditions, the difference between replanting and not replanting, between two years of release or five years of release, etc.

In addition to the commoner nursery practices of using seedlings and transplants, the nurseryman often uses more uncommon methods such as root pruning and the planting of cuttings. Pruning the roots stimulates the growth of new laterals[82] and of many fine rootlets or tips near the apex of the root system[49]. These tips of roots are the most active in the formation of root hairs, the vital parts that absorb the food and moisture[58]. The pruning may be done before the stock is transplanted, or it may be done by pruning it in place (underground root-pruning).

It has been said[8] that roots are pruned:

1. When the plant is transplanted:

A. To remove injured or diseased parts

B. To maintain a balance between the root and the top.

2. When the plant is established:

A. To keep the growth within bounds, particularly when it is desired that the plant be dwarf.

B. To concentrate or contract the area of the roots.

C. To make the plant more fruitful.

In forestry, the pruning is done to obtain the results mentioned above in Part 1, A and B, and Part 2-B. The question of maintaining a balance has already been discussed, as has that of concentrating and contracting the root area. The removal of injured or diseased parts will be taken up in the following section which covers the causes for death of plantation and forest stock.

The pruning of seedlings' roots when they are transplanted is usually termed trimming, and it is done with a knife, scissors, hatchet or other sharp instrument. The trimming helps facilitate transplanting operations by making it unnecessary to dig the trenches so deep to receive the seedlings[67]. In addition, it helps form the compact, well-developed root system desired in future field planting.

In 1942, with the advent of the war[64], there was the prospect of a considerable shrinkage in the supply of labor for forest nursery operation. So it was that nurserymen were faced with either adopting labor-saving methods or virtually abandoning the production of larger planting stock. This need gave an added impetus to the already increasing use of horse and tractor drawn mechanical diggers or underground root pruners.

Often, either due to lack of available manpower, need for cutting down the expense of transplanting, the particular management plan of the nursery or some other reason in the culture of evergreen plants, it is advisable not to move the plants every two years; therefore, underground root pruning is substituted[46]. This is done by cutting the lower part of the roots of seedlings without removing them from the beds[67]. The purpose is usually to force a more compact rooting system for young stock that normally expends much of its energy developing a pronounced tap root[39, 46].

The pruning is sometimes done by inserting the long blade of a spade or shovel along and under the beds[27]. This method is not too satisfactory[46] as a great deal of care and physical effort are required, and the roots are not uniformly pruned.

Underground root pruning can best be accomplished by passing a sharp draw knife beneath the bed[34,46]. The blade of the knife should be a little longer than the seed-bed is wide, should have vertical blades between the rows, and should be so constructed that it can be set for a certain depth at which it will remain while being drawn beneath the ground[8,34,39,46]. The root-shear, when in position and adjusted properly, is drawn lengthwise of the bed, pruning all of the roots at the depth required.

One type of pruning-shear[46], fitted with a U-shaped beam, is used to lift the trees partially as it cuts the roots, thus leaving the trees upright, but loose enough for a man to pull them out. This tree-digger greatly mitigates the labor of digging and root-pruning seedlings, and it may be obtained in various sizes, to be drawn by either horse or tractor.

The time of the year to do underground root pruning, and just the proper depths to which to prune are two important matters. According to Laurie[46], the time of year to root-prune evergreens is in the fall, about September, or in the spring; it should be done when the cut roots will heal quickly and when the plant will withstand a reduced water supply for a short period of time.

According to Tillotson[67], root pruning is sometimes practiced during the first season the plants are in the seed-bed; however, he recommends this being done at the beginning of the growing season of the second or third year, just at the time the growth is about to start. He claims that this gives the plants an ample chance to recover from the cutting during the moist part of the year.

As to the depth to which roots are to be pruned, it was found at the Savenac Nursery[54] that roots of 1-0 seedlings can be shortened to two and one-half inches below the ground line without risking high mortality in the stock; however, the pruning was usually varied from three to eight inches. According to Wahlenberg[73], three inches was too shallow and seven inches too deep for yellow and white pine stock two to three years old. Recommendations are made for pruning to four or five inches, if pruning is done at the close of the first growing season. Tests were used by Olson[54] and Wahlenberg[73] in the Idaho and Montana nurseries on transplants having their roots pruned from three to ten inches. It was found that a definite increase of initial survival is exemplified as the length of the root is increased. The longer root carries with it an improvement in balance that seems to be more than proportional to the root length. Thus it can be said that severity of pruning must be determined by the length and distribution of the roots desired in the stock when ready for field planting. When a fibrous root system deep in the ground is desired, the pruning is less severe, whereas a short, fibrous root system can be developed only by severe pruning[54].

The above differentiations are made after a thorough study has been made of the conditions found on the field to be planted, and a proper consideration is taken of the normal root development type of the species to be used.

<u>Heredity Root Tendencies</u>

The general characters of the root systems of species are often as marked and distinctive as are those of the aerial, vegetative parts; and although these may be modified when subjected to different environments, according to Weaver[76] they still retain the characteristic impress of the species in its usual habitat or site condition. Some species have tap-roots that develop rapidly and penetrate deeply, others branch near the soil surface, and the tap-root soon loses dominance. Still other species are characterized by a fibrous root that spreads widely.

In the case of the long-leafed pine, ninety per cent of the laterals occur in the surface foot of soil. However, it has a strong, deep tap-root[37]. Pinus lambertiana, the sugar pine, grows naturally in California where the summers dry the soil to a great depth. Consequently, it has developed a long tap-root which grows from twenty to thirty inches the first season. This species developed the same long tap-root when planted in the soil of Connecticut, which is moist the year round[37]. Red oak also develops a characteristic tap-root under any circumstances[68].

The red maple is a species that develops a short tap-root with quite a great extension of lateral roots. However, Weaver[77] says that the roots develop strictly in accordance with the amount of moisture in the soil, little moisture resulting in a long tap-root, much moisture in a more flat, pan-like extension of laterals.

The typical root system structure of white and yellow pine seedlings is obconical[54], that is, resembling an inverted cone. The tree has long lateral roots near the surface and successively shorter ones below. Consequently, the greater half of the absorbing surface is in the first four inches of the root system. In spite of this, the roots in the zone from four to eight inches below the ground line are more important to the trees because they can obtain moisture when the upper soil layers dry out in summer.

Pruning in Place on Trees

Since different species have individual root types, root-pruning in place will have a greater effect on some than on others. Huberman[39] gives these effects fairly well:

> "Pruning longleaf pine, a tap-rooted species, in June or August, significantly increases the plantable percentage, but many of the resulting forms are undesirable from the standpoint of ease of planting.
>
> Pruning slash and short-leafed pine, both fibrous and rooted species, had no significant effect on the plantable percentages."

Bailey[8] states that roots of tap-rooted species that have been pruned do not always develop a tap-root, as new roots do not grow from the callus and go directly downward. Keeble[40] says that wound substances are produced upon decapitation of roots which tend to prevent further growth in the immediate region. In addition, it is stated by Appleman[4] that the terminal bud secretes a substance antagonistic to the superapical or lateral buds, and that when this substance migrates to these buds, their growth is retarded. Thus, if the bud of the root tip is removed, the retarding substance is no longer sent to the lateral roots, which consequently increase in their growth.

Factors Not Hereditary Which Affect Growth

There are still many growth tendencies that cannot be explained by heredity, root enzymes, or prohibitants. The environmental influences or conditions under which the plant is grown may vary the structure, extent, weight, number and direction of the roots[10,41]. In other words, the general behavior of the roots in the soil is the result of the influence of many factors, the most important of which are moisture, nutrients, oxygen supply, temperature, physical texture of the soil, light and gravity[41].

At this time a discussion of light and gravity seems relatively unimportant, as almost every young tree needs and can stand a great deal of shading, while the effect of gravity is so constant as to seem of little consequence. According to Olson[54], the five soil factors that have the greatest influence on the behavior of roots are moisture, fertility, aeration, temperature and physical properties.

Moisture

One of the first things that is learned about environmental influences on plants is the need for sufficient moisture. Almost everyone is familiar with wilting, or loss of turgidity, and yet how little is really known about the influence and effect moisture has on a growing plant[14], especially on the development of lateral or tap-roots.

The root habit of a species is usually altered greatly when the plants are grown under distinctly different conditions. This is especially true in regard to moisture, as the distribution of roots conforms strikingly with the amount of soil moisture[79]. The amount of soil moisture available is so closely governed by the texture of the soil, in most cases, that it would be fruitless to try to discuss the one without considering the other. Nevertheless, this will be attempted whenever it is at all feasible.

Plants grown in fairly dry soil are forced to extend their roots in search of moisture[67], while a plant need develop only a comparatively small and compact root system to exist where there is plenty of available soil moisture[13,68,69]. The extension of the root system applies to both the lateral roots and the vertical roots. Miller and Bailey[8,49] state that the lateral extent of roots is greater when there is less moisture, and many authors[1,8,48,49,55,57] show that vertical roots will develop into lateral roots in order to obtain more moisture.

When a species ordinarily considered to be a shallow-rooted species (48 and 68, dealing with Jack Pine and Red Maple respectively) is observed, under certain soil and moisture conditions, to develop strong tap-roots in conjunction with many lateral roots whose ends turn downward[1,19,45,48,68,77], only one conclusion can be drawn--that the plant is seeking an available supply of moisture.

For example, Adams and Chapman[1] found strong vertical roots developing from lateral roots along with heavy tap-roots in a plantation of twenty-eight-year-old jack pine located on sandy soil in Vermont. MacAloney[48] found a similar situation on very fine sandy loam of Cass Lake, Minnesota. Here the stand of ten-year-old jack pine had vertically turned roots and tap-roots penetrating to a depth of nine feet.

Some of the most extensive studies seem to have been done by Vater on the Dresden heath sands back in 1927[71]. His investigations considered much older trees than those used by any other investigator. Vater used trees as old as one hundred and twenty years, while most of his investigations seemed to concentrate on sixty to one hundred-year-olds. In his use of pines, spruce, and beech, he uncovered the striking fact that at certain ages the downward growth of the tap-root is passed by the vertically turned descending lateral roots. In fact, many of these roots went almost two and one-half times as deep as the tap-root. Vater also indicated that the roots would probably have gone down deeper into the ground water if the aeration of the water had been better.

According to Anderson[2], the length of the tap-root is largely a hereditary factor and is used more for anchorage than for absorption. This might explain the findings of Vater, inasmuch as the lateral roots, whose business it is to obtain moisture and food[54], pass the tap-root in their search for these necessities.

The moisture content of the soil is largely governed by the fineness of the soil particles, the finer soil having a greater capacity to hold water than coarse soil[2,67,77,79]. Therefore, the lateral roots would be shorter in fine soil than in coarse soil, because they would not have to grow as far to obtain the same amount of moisture.[2]

Nutrients

Paralelling the effect moisture has on root growth is the influence that a soil high or low in nutrients has upon root growth. Some of the first to find that the total length of roots in good soil was less than that in poor soil were Ter-Aarkisov in 1882, Laitakari in 1927, and Savits and Tolski in 1913[63]. The difference in the root systems developed is shown well in an experiment by Haveler[35] who used alternate layers of chaved sand and fertile soil rich in humus. He found that whenever the roots passed through the fertile soil, a profuse branching of the several roots took place, but when the roots passed through the sand there was very little branching. One of the classic experiments of all time dealing with fertilizers was performed by Nobbe[53], using corn plants in infertile clay soils that had specific regions treated with nutrient salts. The fertilizers used were ammonium sulfate, calcium nitrate, and di-potassium phosphate. These were added only to specific regions of the clay soil in the containers. After the plants had grown for four months the roots were washed, and it was found that the general form of the roots remained normal and practically the same in all of the experiments. The only difference appeared in the local variation in the number of root branches. In the unfertilized portion of the soil the number of branches per unit both of primary and secondary roots remained small, while in the fertilized portions of the soil the number was strikingly large. In the cylinder where the fertilizer was distributed equally throughout the soil, the number of branches per unit length of both primary and secondary roots was the same in all parts of the vessel.

In general, it may be stated that the application of fertilizer increases the weight of roots per unit area. However, the weight of the tops usually increases more in proportion under such conditions than the roots[49], so the dry weight of the tops compared to the dry weight of the roots generally yields a higher ratio in fertile than in infertile soil.

<u>Aeration and Temperature</u>

The root growth is also governed by the aeration and temperature of the soil. The aeration of the soil affects the plants both directly and indirectly[49]. In an indirect way, it affects them because it is necessary to the proper functioning of the bacteria that transform the various materials of the soil into a form which the plant can utilize and absorb. In a direct way, the aeration of the soil benefits the plant by furnishing a supply of oxygen, which is essential to the proper functioning of the protoplasm of the root cells.

Here again it is hard to divorce the general texture of the soil from the consideration of aeration, since it is the texture of the soil which determines the amount of air circulation in the soil[32]. Many soils are so light and porous that a temporary deficiency of oxygen is not a limiting factor in them[49,67], and it is a well known fact that in many regions cultivation during the growing season is unnecessary for crop production, provided the surface soil is kept free from weeds and is not too compact to absorb rainfall. Weeds and grass can almost shut off aeration, and they can reduce the soil moisture enough to cause death or wilting injury to trees under normal growing conditions[45].

If the soil temperatures are high, there is a greater demand for energy and therefore for oxygen and moisture, due to the greater physiological activities. For this reason, the aeration of the soil must be good to meet the increased demand, or the growth of the plants will be seriously cut down[49].

Extremes of temperature, especially of high temperature, may have drastic effects on the survival of young trees. In some regions the high soil surface temperatures cause death from lesions or stem girdle. This can be almost eliminated by running the rows of the beds north and south, so having the trees shade each other[54].

Experimental findings[64a] have pointed out that small trees, such as the seedling stock commonly planted in the field, may be killed by exposure to temperatures of approximately one hundred and twenty-five degrees Farenheit. That soil surface temperature frequently exceeds this amount is indicated by measurements carried out in connection with a comprehensive experiment on the Huron National Forest. It is thus evident that small trees in plantations are frequently subjected to potentially lethal temperatures, and even though these exposures are often of short duration, the repetition of such conditions weakens the trees, and eventually causes the deaths of the least hardy.

In many American planting fields there are often long periods during the growing season when the soil temperature and soil moisture go below the minima. This is one aspect that explains much of the mortality and stagnation of some stands[43]. Kjeld made quite extensive studies on the effect that low temperatures have on root growth. He found that root growth started at a lower soil temperature than bud activity did at corresponding air temperatures, and that it increased rapidly at higher temperatures. Low soil moisture retarded root growth and the best growth occurred during moist periods of summer. Small plants and trees with flat root systems suffered most during periods of drought. The greatest stagnation attributed to temperatures was observed on wind and sun-exposed sites with clay soils. Root growth was relatively weak up to ten to fourteen degrees centigrade, and continuously more rapid until twenty-four to thirty-two degrees centigrade was reached, at which point it decreased abruptly.

In addition, Collison[21] showed that root elongation, and consequently absorption, assimilation and respiration took place in apple trees when the air temperature was below zero and the soil temperatures not far above freezing.

<u>Soil Texture</u>

Thus it can be said that a fertile soil with a sandy foundation, particularly a sandy loam, is better for planting operations than a soil with a clay or lime base. The latter dries out and warms up slowly in the spring, delaying the growth of plants; it freezes and heaves more decidedly than the former; it is more difficult to work in plowing and planting operations; the roots skin more when planted in it; it forms a hard surface and cracks upon drying; the fine lateral roots do not develop as well in it; and it is more difficult to control weed competition in it. On the other hand, a soil that is extremely light, sandy, or loose should be avoided, as it dries out quickly and promotes too extensive and unproductive a rooting system.

If the surface soil is a good, fairly moist, retentive, sandy loam, the deeper it is the better[67]. When it is deep there will be an abundant supply of fertility upon which to draw, the infertile sub-soil will not be disturbed when the ground is prepared or when the young trees are planted, and so will not be mixed with the other soil. A good combination is a porous surface soil, three to four feet in depth, and a more retentive subsoil. Such a surface soil is of sufficient depth to allow the necessary drainage. As moisture is needed it can be obtained by capillarity from the retentive subsoil. A subsoil of heavy clay should be avoided, as it does not allow good drainage, and the moisture retained may cause the soil to sour and to freeze and heave excessively.

This seems to be substantiated by the work of Haig[33] with red pines on the soils of Connecticut. He determined that the site index, and consequently the root growth and height growth, bear a definite relation to the colloidal contact of the upper layers of the soil. His curves indicate that it is lowest for sandy soils, higher for soils of clay, and highest for loam.

It is not easy to understand why roots grow longer on sandy soils; however, as has been shown, the investigators have considered the differences in plant development on soils as due to the amount of moisture available. In other words, the less moisture, the greater the root development. This accounts for the shortest roots being produced on loam, somewhat longer roots on clay, and the longest roots on sand. But it also implies that any decrease in moisture is accompanied by a corresponding increase in growth. If this theory is accepted, it does not explain the reduction of growth during the first part of the summer, just when the greatest amount should be expected. On the other hand, if the rest period is to be attributed to summer drought, some other explanation must be sought for the relation between root development and soil type. The factors to be considered in addition to soil moisture are soil temperature, the composition of the soil atmosphere, and the physical nature of the soil. As in so many biologic phenomena, the factors which regulate the rate of root growth are many and interacting.

Distortion--Natural and Otherwise

In addition to growth effects, there are also distortion or physical effects that must be considered in regard to root development. These consist of physical blocks to the root growth by rocks or a hard, compact soil. Toumey[68] placed large rocks a few inches below the surface and directly beneath acorns of red oak, a strong tap-rooting species. The long tap-root grew downward to this obstruction. Here it curved out along the surface of the rock and continued in this plane to the edge, where it again turned downward. This would seem to indicate that even if a plant of a species which grows a strong tap-root was placed in too shallow a hole, the downward growth of the root would not be prevented, providing the tip were not injured.

It has been thought that every time there is a bend in a root, it is a sign that the growing root tip has met an obstruction[76]. However, this does not apply in all cases, but rather, as Brown[15] has stated, it is apt to be due to physiological conditions which cause the cambium to be active on one side of the root and dormant on the other.

Nevertheless, evidence points so often to a physical block or lack of care in planting as the cause of mortality of young plants that this should not be overlooked. A hard, compact soil limits the extent of root systems to a marked degree, and in a compact soil the roots are more or less contorted or kinked, while branching decidedly less than in a soil of loose texture.[77] The greater degree of compactness of the soil, the more it confines the roots. Permanently compacted subsoils confine the rooting medium mainly to the superimposed rooting horizons[23]. In trees that have persistent tap-roots, such as hickory, black walnut, and long-leaf pine, nothing will break this tap-root up or change its form. If it strikes soft ground it goes straight down; if it strikes an impervious stratum, it curls up like a bed spring[19].

Roots of most plants are not able to penetrate a layer of dry soil in order to reach a supply of moist soil which may be underneath, since the water would be extracted from the roots in the dry soil and the roots would perish[49]. Using the premise that roots will not grow into dry soil, the conclusion can be drawn that only when water penetrates the clay or hardpan will the roots grow through it[79].

Soils very high in gravel content are rarely considered as being impervious[71] but are in reality the most impervious. This probably is because moisture is not retained well in gravel soils.

It has often been said that through the lack of care used by planters, many young trees have had their roots so badly bent that they did not recover, or if they did happen to live, their growth was retarded. In order to obtain facts on this question, Cheyney[20] performed an experiment in Minnesota. He used white pine, arbor vitae, and black spruce trees; the roots were rolled into compact balls and the planting was done with a spacing of six inches in rows two feet apart. The control plants were set in rows alternating with the test plants, and had their roots spread in planting in the most approved fashion.

After four years of growth the plants were dug and the roots inspected (See Table I). The balls into which the roots had been rolled on planting were still visible, but there was such an extensive growth of side roots that the root systems varied little from those of the controls.

Many people have stated a belief that a particular method of planting will give a permanent impress to the plant that may affect its later welfare. There are others who do not hold this belief, and both sides of the controversy have their own strong supporters. One of these "bad" methods is said to be the slit or wedge method. This is usually held in opposition to the deep hole method which is considered to be the method best for the plant's future. In the practice

Table I

RESULTS OF CHEYNEY'S PLANTING EXPERIMENTS

Species	Planting Method	Number of Trees	Height-Ground Line to Top (Max.)	(Min.)	(Ave.)
W. Pine	Roots balled	24	57"	32"	46.8"
	Roots spread	10	59"	41"	48.5"
Arbor Vitae	Roots balled	48	63"	20"	35.7"
	Roots spread	24	60"	23"	42.0"
Bl. Spruce	Roots balled	13	58"	22"	34.6"
	Roots spread	6	38"	24"	28.3"
Total	Roots balled	85			38.7"
	Roots spread	40			41.5"

of planting by the slit method, the soil on the sides of the hole into which the plant is inserted is relatively compact by the pressure of the planting bar. This makes two planes of compacted soil through which the roots of a tree have a difficult time penetrating, especially if the planting is being done in very heavy soil. This promotes a growth in one plane only.

Kroodsma[44] states that the slit method is not wholly good nor is it wholly bad. However, the method lends itself to cheap, mass-production planting. For this reason, and because the harmful effects are either unknown or ignored, the method has received widespread use. Therefore, some emphasis should be made on the possible detrimental effects of slit planting.

Only thirty percent of the trees planted to test the slit methods[44] were able to recover enough to develop root systems of good distribution in an experiment to test the various planting systems. This is because the slit method starts the trees out with their root systems cramped into a single plane, and those which were not able to overcome this initial defect to any great extent showed a decrease in survival and growth. The mortalities were of the heat and drought types.

So far as the individual cost is concerned, it cannot be gainsaid that slit planting is cheaper than any other method of planting so far devised. It can be said, without trying to detract from the importance of initial cost, that the final cost of establishing a plantation is of most importance, and that there still has not been any really conclusive demonstration that the slit method is more certain than the other more careful methods to produce plantations at the lowest final cost.

Kroodsma continues by saying that too much emphasis has been put on the hundreds of plantations planted by the slit method which have had good survival. He claims that these statistics do not mean too much, as few if any of these have reached maturity (essential for determining the success of any plantation), and he says further that hundreds of plantations planted by the slit method have suffered such severe mortality that they had either to be replanted or written off as losses.

Turner[70] is of the opinion that any distortion imparted to the roots at the time of planting is retained for an indefinite period, possibly for the life of the tree. He further states that the extension of the roots is probably controlled as much by the initial direction as by differences in soil texture.

Münch[51] tried extensive experiments in Germany to try to determine if oblique planting would have any effect on the permanent extension of roots. Instead of the vertical slit, he opened the ground on an angle sloping away from the worker by using a mattock. Thus the roots were headed in a direction quite opposed to the natural trend. Eighteen years after the planting was made, no apparent differences were found between the test trees and the control trees, either in root development or in the height growth. Pines of one and two years were used in the initial planting experiment.

Most of the plantings made in the Lake States Region, and in other regions, have been made by either the deep hole or by the slit method. In recent years, mostly because of lack of manpower and because of the cheapness of the operation, the slit method has been favored. Therefore, if there are any serious consequences due to the slit method of planting, they should be in great evidence in the future when the plantings reach maturity.

When plantings are made of older trees, or when there is a need to have as many of the roots saved as possible, the center-hole method is usually used. This method, if done properly, spreads the roots into their normal growing positions. The furrow method is very similar, save that the furrow is made by a plow, the hole by a spade.

Ground Preparation

The furrow method brings up the subject of pre-planting preparation of the ground and its effect on the survival of planted trees. Usually not enough attention is given to the proper preparation, and inadequate or improper soil preparation is probably responsible for as many losses in plantation trees as any other one cause[66]. Generally speaking, field planting without some ground preparation is just so much wasted effort and needless expense[58]. As a rule it is necessary to give planted trees two or three years grace to establish their own roots sufficiently to enable them to compete successfully with low vegetation. Furrowing and scalping (stripping of the sod) are commonly used for this purpose, and there is some promise that this can be accomplished in regions of comparatively heavy brush by the new heavy plows. According to Rudlof, furrows have generally given much more satisfactory results than hand-made scalps.

Stoeckeler[65], however, does not recommend furrowing highly, since the usual technique in this method is to turn the upper, most fertile layers aside and place the young tree in the lower, more sterile soil. Thus the nutrient-laden surface layers do not immediately benefit the tree. The Lake

States Forest Experiment Station[65] performed tests with black spruce and red pine planted on disked areas, or turned under soil, in comparison to trees planted in furrows. They discovered a fifty percent greater height growth two and three years after planting, in favor of the trees planted on the disked and turned over ground areas.

Too often only the surface layer of the soil is given any attention[81] and it will be found upon examination that the soil is made up of layers or horizons which differ from each other in texture, fertility, and color. Therefore, the planting site should be considered to a soil depth of at least four feet in order to determine the site adaptability and the species that would grow best on that site.

If the planting is to be done in the bottom of furrows, as Rudlof[58] recommends, or if the planting is done on areas where the surface soil has been removed in grading, terracing, or strip mining, the toxic effect of the exposed subsoil will stunt or prevent the growth of the trees.[14] This is especially true in the humid regions and in areas where there is a sharp distinction between the surface soil and the subsoil. It has been found by Breazeale to be particularly true that in the East the planting of such areas would net little growth. The plants usually make a stunted growth, but few, if any, feeding roots develop, so the plants are extremely susceptible to other agencies, which usually destroy them. He continues to say that the toxic condition of the subsoil may be observed for several years after exposure, until organic matter is incorporated into the soil or until atmospheric agencies so weather the soil that plants will grow in it. The same soil horizon that will support tap-root systems will not support feeding roots.

Baker[9] states that it is the physical character (the lightness) and the fertility of the soil which are the conditioning factors in growth where young Western yellow pine is concerned. He claims that only the weakening influence of a heavy soil or lack of fertility tends to permit factors like toxicity to enter the picture.

Other Factors Affecting Survival

Other things which affect the success of a planting are the care used in handling and in setting the young plants in the ground, the time of year the planting is made, rodent damage, climatic extremes, fungus and plant diseases.

On national forests it is often impossible to secure other than unskilled, careless and indifferent labor, which means the stock will be poorly planted[67]. Lack of care in planting causes death to a great amount of the stock, by roots stripped, bent, or cut too short, trees set too high or too low or in poor places, such as on rocks, by biotic injuries[73] and by the exposure of the roots to the wind and sun.

According to Baxter[12] careless lifting of trees causes skinning and possible entrance of fungus; he also states that if trees are jammed into the ground during planting, growth later increases this distortion of the root systems and leads to the condition known as "U" roots. Mortality of such trees is great, especially during a drought, even though the drought occurs several years after planting. According to Schopmeyer[60], in any recently planted area there will be found dead trees with their roots doubled up, others with part of the stem below the ground surface, others planted almost out of the ground, others with the roots skinned and still others in unpacked or over-packed soil. One of the greatest influences affecting the survival percentage is exposure. Some trees will die in a two to three minute root exposure on a hot or windy day[67]. Pinchot[56] recommends that a tree be transplanted with the least possible exposure of the roots. He states that the root hairs, or feeding cells, on the roots of a plant will shrivel and perish if exposed to the dry atmosphere for even a few minutes. The roots of conifers are particularly sensitive, so these require even more care in transplanting than broadleafed trees. The tops of conifers may remain green for a long time after the roots are dead, and so their appearance cannot be taken as a criterion of the stock's condition[60,67]. Thompson[66] recommends quality of work as much more important than quantity in transplanting, and Yerkes[84] even goes so far as to say that the planters should exercise judgment in determining the quality of the stock and should sort out and discard the weak or damaged plants, thus saving unnecessary labor and expense.

Large areas have been planted with excellent results in both fall and spring in some regions; however, there are some regions in which foresters have had especially good luck with the spring planting. Wahlenberg[73] reports for trees which he studied that season of planting had slight effect on survival in the average year. However, the cold nights and warm days of "Indian Summer" following fall planting seem detrimental. He continued to say that if such weather does not intervene between the time of planting and winter, there may be an advantage in fall planting over that of spring. Usually in the spring there is such a lack of time in nursery work to do all that should be done that more men can be made available to do planting in the fall, and so more care is used in the operation.

Schopmeyer[60] found in Region One that spring planting is better than fall planting if not done too late in the spring. If planting is done too late, the root development may not keep up with the decreasing level of available moisture as the summer drought progresses. Also, freezing air temperatures may injure the plants before they are put in the ground. Furthermore, the fall rains may not come soon enough to supply moisture after the summer drought. He found that between 1910 and 1937 the survivals of the spring-planted Western white pine and Ponderosa pine were seven to ten percent higher than those of the fall-planted trees of the same species. In the Lake States region it has been found[43a,46,64a,64] that the degree of success depends more upon the type of weather in the individual season than it does on any general difference between spring and fall. Spring plantations established when soil moisture and favorable planting weather follow the setting survive better than plantings made during a dry fall, but plantings established during a rainy fall are more satisfactory than those set out in a dry spring[43a]. Tillotson[67] says that when sufficient rainfall occurs during spring and early summer, and where winters are severe, spring is the logical time for planting. The soil is in good condition. Planting will not be hindered long by newly fallen snow, plants will be in no danger of frost-heaving or winter killing, and they will have time to become permanently established before hot, dry weather occurs.

One factor influencing young plantation success that is usually not considered is the damage and possible complete destruction that is caused by rodents and rabbits; the specific pest depends on the individual locality. Young[87] states, in speaking of the plantations at Saginaw Forest, on the basis of aggregate damage, mice have been the most destructive. He continues by stating that whenever a heavy sod was formed during the early years after planting, the areas became densely populated with field mice which fed on the bark of the young trees during the winter and early spring. Many of the young trees were girdled and died. Other trees were partially girdled, which gave decay-producing fungi a chance to become established in them.

Of the pests that beset the young English forest, the rabbit is the most widespread[3]. Most of the trouble in this instance has come from the natural reproduction of cut-over lands being destroyed.

In the western part of the Lake States[58] the snowshoe hare is the worst offender. During their population peaks, these animals practically preclude the possibility of succesful planting in bushy areas. Observations indicate that the hares seldom if ever eat the tips that they nip. According to Young[87], rabbits cause two forms of injury. The larger plantation trees are either partially or completely girdled, and the smaller trees usually have their tops bitten off.

Another cause of difficulty in plantation work is fungus infection. Forest plantations are biologic communities which have been established under more or less unnatural conditions, and all too often they are composed of species not native to the particular conditions of the site. These communities are subject to attack by various fungi, and sometimes a succession of diseases results from an ailment caused by a fungus or one particular adverse condition of the site. The young plantation, however, is often susceptible to a certain class of disease which is not necessarily similar to that of the mature forest. Frequently the maladies are of serious concern only during the early history of the stand. An example of this is Coleosporium Solidaginus[11].

Mention has been made previously in this report of the danger of root injury in planting. Both Frothingham[30] and Hepting[36] found a great deal of evidence that rot had entered the dead roots of trees. Baxter[12] states that if root-pruning is done by a clean cut there is no need to worry about the entrance of rot, as the root tissues will heal over the scar very quickly. However, if the cut is not cleanly made, but is torn, or if the root has been scraped, there is great danger of rot entering the weakened section.

After the plantations have reached the "heartwood" stage, many of the diseases found are totally different from those which previously affected the plantation. Two exceptions[11] to this should be mentioned: (1) Adverse site conditions will lengthen the period during which the plantation suffers from certain ills. (2) Even suitable soils and favorable climates will not prevent the destruction of forest plantations if a parasite specific to a given tree appears. If one species is planted in great blocks, the entire plantation may be greatly damaged or even completely wiped out. At present there is such an infestation of an insect which is attacking the terminal buds of the pines at Stinchfield Woods.

According to Baxter[11], pine is not a suitable tree to plant on "worn out" farm lands or in other areas in Southern Michigan where there is an impervious layer of clay approximately two feet or less below the surface. On such sites, pine is subject to a root rot caused by Polyporus schweinitzii when the stand reaches even the early age of ten years. The damage gradually becomes more serious as the pine ages.

Root Pruning Experiments

Up to this point little mention has been made of the actual experimental effects determined from root-pruning. As was stated earlier, very little really conclusive data can be obtained until the root-pruned trees have reached maturity, and mature stands of this type are still something to be found in the future. However, the author will attempt to mention most of the operations so far as they are completed.

Auchter[7] performed a very comprehensive experiment in Delaware which covered many phases of questions troubling nurserymen. However, this experiment only lasted through the year following the planting. The root pruning was performed on one-year-old apple and peach trees. (1) The roots of twenty trees were left unpruned (the controls). (2) The roots of twenty of each type were pruned in the usual practice, that is, any broken roots were removed, the others were thinned out some and those remaining were shortened to six inches. (3) From twenty trees of each species, all of the roots were removed, leaving only the main stem as in the "Stringfield Method," which has been recommended in some localities. In the case of two-year-old apple trees, the roots of sixty were pruned by each of the above methods, making a total of one hundred and eighty trees. All of the trees were planted April 1, 1923. Results of the experiment are in Table II.

Table II

RESULTS OF AUCHTER'S EXPERIMENT AFTER ONE YEAR

Amount of Pruning	New Growth Prod./Tree (in feet)	Increase in Trunk Cir./Tree (in mm.)	Ave. Weight of new top Prod. (gms. per tree)	Ave. Total Increase in Weight/Tree (in gms.)
None	10.16	.87	75.7	403.76
Moderate . .	9.55	.45	63.8	304.40
Very Heavy .	2.55	.31	2.0	113.80

According to the results, an emphatic advantage goes to the trees not pruned, lessening with those pruned to six inches, and allowing only very poor results on those heavily pruned. Auchter stated that the planting had been made on an unusually wet year and upon heavy clay-loam. He claims that the results would not have been as good if the year had been an average one.

Card[16] used the extreme "Stringfield Method" in the semi-arid country of Nebraska. He used fifty trees, pruned roots of twenty-five of them back about one-half, and cut back the year-old twigs about one-half. The other twenty-five were not root-pruned, but they had their one-year twigs trimmed to one-half. One year after the planting only two pruned trees showed any growth, two years after planting one-half of the pruned trees showed an appreciable growth, but they were well behind the trees which had not been root-pruned. Upon examination of the roots, the new roots were found to have developed from the central root in both cases, but the unpruned trees showed stronger new roots than the pruned trees.

Lloyd Smith[62] performed root-pruning experiments upon five species of hardwood trees; namely, hardy catalpa, green ash, hackberry, black locust and American elm. He used one-year-old seedlings of uniform size. Ten of each species were selected for each of the following treatments: The first group was unpruned, the second was pruned to ten inches, the third was pruned to eight inches, the fourth to six inches, and the fifth to four inches. The seedlings were planted at Manhattan, Kansas, April 26, 1938, and spaced two feet apart on the square. After the growth had ceased in the autumn, the trees were measured and harvested. The experiment showed no effect on the growth of the hardy catalpa, green ash, or black locust. However, the more roots pruned in the hackberry and the American elm, the greater the reduction in growth. The results show that the former three can be pruned to even four inches with no appreciable reduction in growth, while the latter two are greatly affected.

Corbett[22] found that pruning the roots of barren fruit trees about the first of August stimulated the production of fruit buds that fall, and produced a good show of flowers and fruit the following year. This is explained by Chandler[17] when he says that by severing the roots a reduction of the water and mineral supply is affected which checks growth, causes an accumulation of carbohydrates in the top, which in turn causes a general increase in the bud formation.

Another experiment was performed to increase fruit production by Drinkard[27]. His results also showed that root-pruning of growing apple trees after the years' leaf-growth has occurred greatly increases the growth of the tree and the fruit production for the following year.

Deuber[25] found that root pruning of trees "dying" of gas injury was extremely beneficial. Thus checking the progress of decay that was on the distal portions of the tap and lateral roots, a speedy recovery of the trees usually resulted.

Stoeckeler, in a letter to the author, stated that considerable work had been done at the Lake States Forest Experiment Station in root pruning with red, white, and jack pine seedlings, in the hope that "root pruning in place would be a substitute for transplanting. Thus jack pine root-pruned in early spring of the second season in seed-beds, and red and white pine root-pruned early in the spring of the third season were considered reasonably good substitutes for 1-1 jack and 2-1 red and white pine.

"The pruning was done with a heavy saw blade kept under tension and drawn by tractor at a depth of three to four inches below the surface of the seedbeds. A four-foot wide bed was pruned in one operation.

"As an example of the improvement of survival, we got fifty-five percent in the unpruned, fall planted, 3-0 red pine and seventy-four percent survival in the root-pruned stock . . . "

He continued by saying that they " . . . have not tried root pruning of transplants in place in the nursery. However, after lifting or digging of 2-2 spruce or pine transplants (they) invariably cut the roots back to a length of around six to eight inches with a machete or knife . . . . (it) makes planting faster and the job is better because the roots are not curled up."

In some respects, root-pruning and propagation by cutting have something in common. However, the author feels that a different type of cell structure and activity is involved and so will only touch on this question. Cuttings, as previously stated concerning root pruning, should be made clean and should have no ragged edges, as such wounds leave an excellent entrance for fungus and rot[28]. The larger cuttings seem to be favored by Wyman[83], as they start with more of a plant than the smaller cuttings. In cuttings there is a race against time, as there are no roots to supply the energy to heal the large wound, and often the rot gets started before enough roots are produced to withstand the invasion.[28] Various chemicals have been used in an attempt to stimulate rooting, and they have had varied results. Too often all the factors have not been considered and the experimenters have jumped at conclusions. Thus, it is interesting to note that cuttings which root with great difficulty or not at all if untreated, are the ones least likely to be benefitted by treatment with chemicals, the degree of success with treatment being proportional to the degree of success in rooting untreated cuttings[42]. Many similar results have been found by Stoeckeler (as stated in his letter to the author) on the treating of underground-pruned seedlings with chemical stimulants.

There seems to be a great deal of hereditary influence involved in the development of cuttings into better trees. If the parent was a vigorous tree, the cutting will be vigorous. It should be pointed out that if a cutting does not root quickly it does not necessarily mean that it will not eventually develop into a better tree than one which does root fast. The slow-rooter sometimes does develop into the better tree[74].

Conclusions from the Review of Literature

The site, the soil and the geographic location determine the species to be planted and the minimum cost of planting operations. If cost is a determining factor, as it usually is, in the size of the stock to be used, then the smallest stock that is safe to plant on any particular site should be used. If it is a question of underplanting, very small stock can be used, as the overtop retains the moisture in the soil well. If it is an exposed planting, larger stock should be used, both because of the longer roots, which can get the deeper moisture[83], and because of the larger tops, which can compete for light against other vegetation[69]. If a strong, compact root system with small tap-root ratio and at little expense is desired, underground root-pruned stock is the material to use[34]. However, though even underground root-pruned stock is more apt to withstand adverse planting conditions than unpruned stock, it may still be necessary to expend a little more money to procure hand-pruned or transplant stock which seems even more able to withstand poor conditions[67]. These trees have had more of a chance to attain a uniform root development[54].

Root pruning is only advantageous in the long, deep-rooted species such as Western yellow pine and white pine, red oak, etc. It is of almost no use on trees with short, flat root systems such as Englmann spruce, western red cedar, and Douglas fir.

If transplanting is done, it is almost wasted effort if the roots are not trimmed and pruned, and the injured or bad roots removed. Small trees will stand a lot of abuse if they are kept reasonably moist.

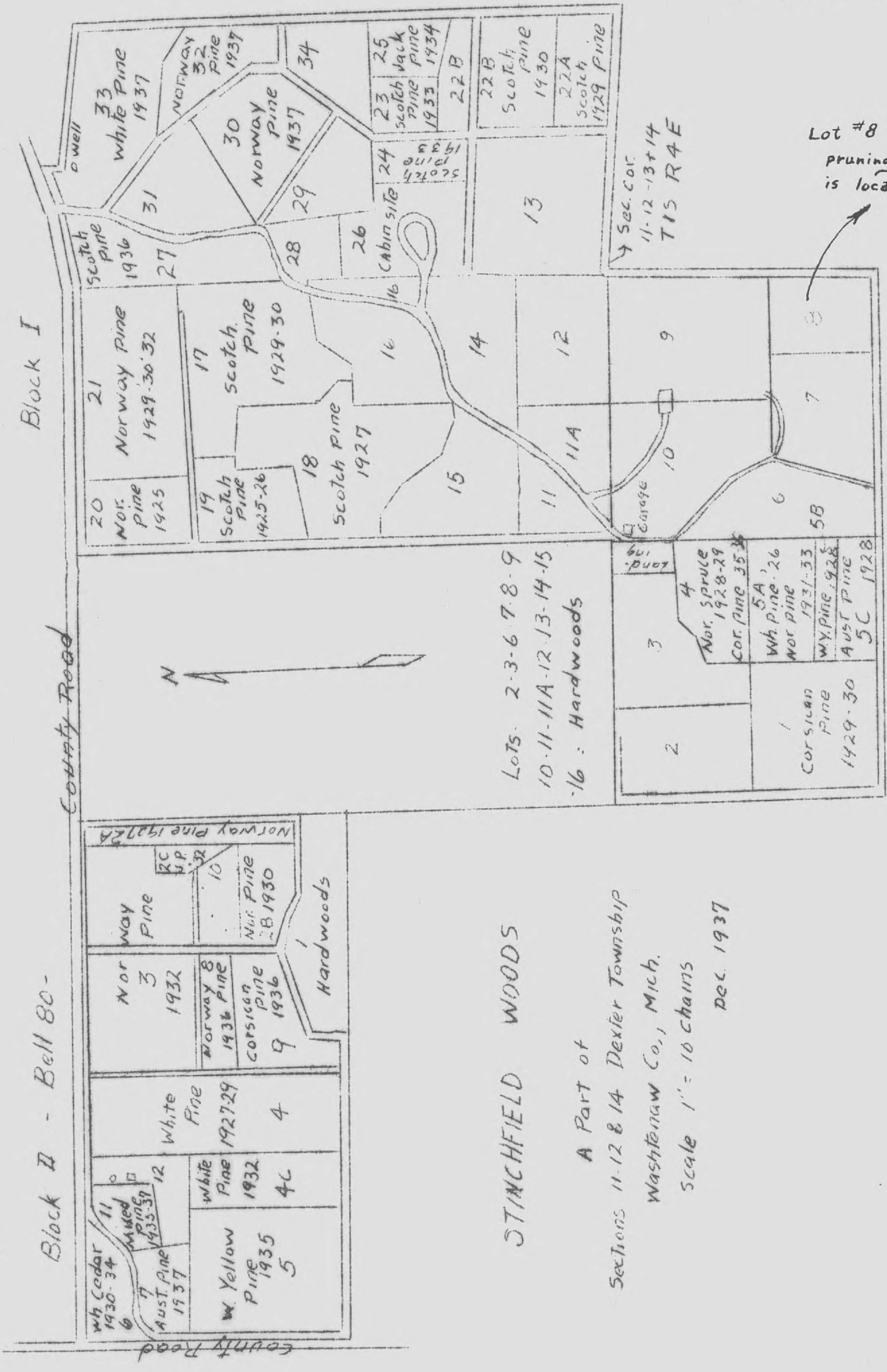
Perhaps the best way to increase the survival rate is to reduce the tap-root ratio by improving the root systems in the nursery through root-pruning and transplanting[73].

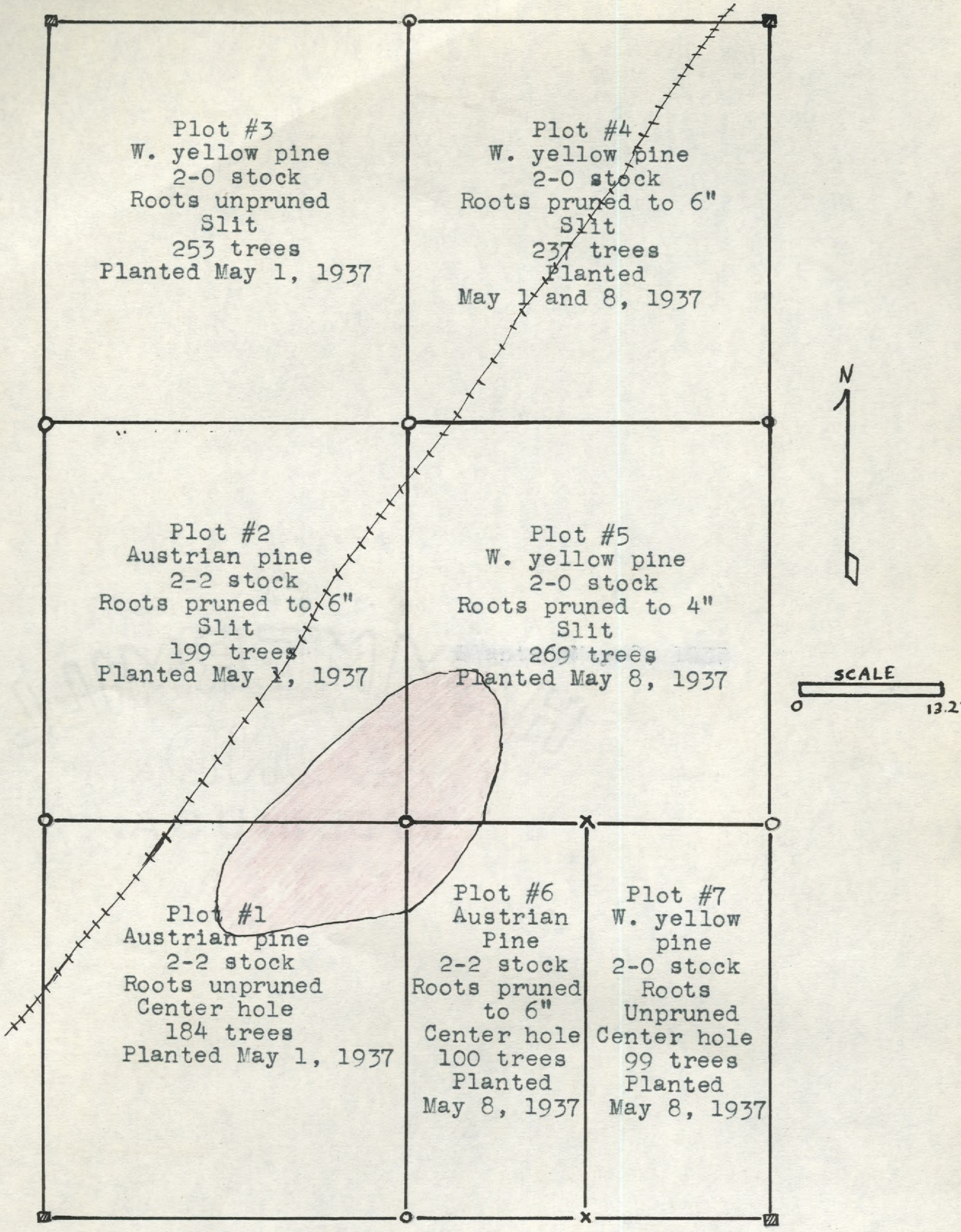
Examination of the more vigorous trees in a stand shows that not only have the tops been more vigorous both horizontally and vertically than those of the other trees, but the roots are more widespread and more densely developed than the roots of their companions[63]. No tree can achieve and maintain dominance, especially in an even-aged stand, unless its root system is of vigor corresponding to that of the top. Invasion of the soil by the roots of plants is the first phase of competition which later may result in the death or suppression of some of the plants.

Certain species are expected to grow in certain regions, and, if they are not native to the region in which they are planted, must have all the advantages possible as far as resemblance to their native condition is concerned. It is the soil and geographic location which enables certain plants to do well or badly in specific regions.

If the planted trees are likely to suffer from drought, their roots must extend deeper, and these deeper roots must have a large percent of the total absorbing area, something created by deep root pruning[69]. This has been proven at the Douglas Boulder Nursery[67].

Lot #8 where root pruning experiment is located.





EXPERIMENTAL PLANTING PLOT
Part of Lot #8, Stinchfield Woods

LEGEND: ▨ 3x3" Stakes ○ 2x2" Stakes
× Small pegs surrounded by stones.
+++++ BREAK IN THE SLOPE
⬭ AREA GIRDLED IN 1941-1942

DESCRIPTION OF THE EXPERIMENTAL PLOT

Location:

The root-pruning experiment was made on a part of Lot Number 8 of the University of Michigan property called Stinchfield Woods (See Map #1). Stinchfield Woods is located in Sections 11, 12, and 14; R. 4E., T. I. S., M. P. M. of Dexter Township, Washtenaw County, Michigan. This location is approximately 6 miles northwest of Dexter, Michigan.

The plot has its length running north and south and is divided into 7 sub-plots (See Map II). The main plot is 108 feet by 66 feet with the four corners marked with three by three-inch oak stakes painted black and white and set with their tops projecting one foot out of the ground. The subdivision corners are marked with two by two-inch unpainted stakes, with the exception of the boundary between Plots 6 and 7, which is marked by small round pegs surrounded by several stones. (See Map II).

Soil:

According to the "Soil Survey of Washtenaw County"[72], the plot consists of Bellefontaine sandy loam. It is described as follows:

> The plow soil of Bellefontaine sandy loam, to a depth of 6 or 7 inches, is grayish-brown friable, or loosely coherent, sandy loam or fine sandy loam.

Beneath this and extending to a depth ranging from 3 to 4 feet, the soil material is somewhat red, is sandy, and in places is coarse gravelly, or cobbly, but contains sufficient clay to render the mass coherent and compact. The substratum or parent drift material, is a confused mass of sand, sandy clay, gravel and boulders. The virgin soil contains only a small quantity of organic matter, but sufficient to impart a light-brown tint to the cultivated soil. The organic matter, or humus, is not so durable as in the heavier soils. The surface soils are loose and pervious, but the subsurface soil contains sufficient clay and the structure is sufficiently tight to check the free downward movement of water. The soil is only moderately retentive, but holds sufficient moisture to carry crops through ordinary periods of dry weather. The surface soil generally exhibits medium acidity, but below a depth of 2 or 3 feet the reaction is less acid and the substratum commonly contains sufficient calcium carbonate to efferfesce with acid or to give an alkaline reaction.

Bellefontaine sandy loam occurs in fairly large and in small areas which are characterized by knobs, hills, and gentle to steep slopes. The gradient of most of the slopes is from 5 to 10 feet to one-hundred, but locally is from 25 to 30 feet to one-hundred. Very little of the land is so excessively steep as to be nonarable, but slopes exceeding 10 percent are susceptible to gullying and destructive erosion when placed under cultivation. In practically all the areas shown on the map, local variations occur in the soil of cultivated land according to topographic position---more level land, steep slopes, and foot slopes. The normal soil occurs in the more level areas. On steep slopes there is considerable erosion, resulting in loss of the surface soil and exposure of the underlying clay, or even of the limy sand and gravel. At the faces of slopes or in depressions the soil is either deepened and enriched or, on the contrary, is covered with coarse unproductive wash. Because of their small size, areas consisting of spots of deep sand or of clay, and depressions containing peat or muck, are included in mapping. The variations in surface relief and the association with muck swamps and lakes are unfavorable for the successful extensive use of the land for general farming, although in small fields high average yields may be obtained. It is estimated that about 15 percent of the land is now in permanent pasture or has been abandoned for cultivated crops. About 10 to 12 percent remains in original forest or in second-growth wood lots.

Topography:

(A) The elevation of the plot is about 1,000 feet above sea level. The aspect is to the southeast, with the northwestern corner sloping steeply and the remainder of the plot being of a gentle slope.

Cover:

Originally the cover was an oak-hickory forest. At present, the land immediately surrounding the plot is planted in various species of pine. The plot area itself was clear-cut in the winter of 1936-37 (A) and since then a heavy cover of grass developed on the area.

Weather:

The weather at the time of planting was mild, but it was an exceptionally wet year (See Graph I).

DESIGN OF THE EXPERIMENT (A)

The plot was divided into the subdivisions shown by the Map II. The entire plot was furrowed in preparation for the planting, the furrows being spaced between 2 and 3 feet apart as near as was possible using a tractor and plow. Several stumps interfered with an exact, regular spacing.

Table III gives in condensed form the make-up of each sub-division of the plot.

If a 2 by 2 foot spacing as originally planned for had been carried out, the number of plants in subdivisions 1, 2, 3, 4 and 5 would have been approximately equal. The discrepancies which occurred were probably due to psychological reasons. The larger plants of the Austrian pine caused the planting crews to place the trees a little farther apart than the proposed two feet. There were three men doing the work and each one did about an equal amount of planting so as to equalize any differences in the final conclusions which might result in the personal factor.

The pruning was done with a large knife or cleaver. As many trees as could be grasped in one hand were pruned with a single stroke of the instrument. The seedlings were then planted in the various subdivisions of the plot. (Maps III, IV, V, VI, VII, VIII and IX show the approximate location of the original trees, as far as the author can determine, and the present location of the remaining trees.)

The speed with which planting can be done with a planting-bar was the reason for the adoption of that type of planting. As previously stated, one of the objectives of this experiment was to determine the survival and growth of trees planted in this way as opposed to the same for trees planted in a hole large enough to let the roots assume their natural position (i.e., the so-called center hole method). It must be remembered that the cost of planting by the various methods must be calculated on the basis of cost per surviving tree, and not on the basis of which method gives the highest survival percentage. Of course, the number of surviving trees must be large enough to give satisfactory stocking of the area. The greater speed of the slit method has given satisfactory stocking on light soils. It is generally used on such soils.

The use of the slit method to plant the 2-2 Austrian pine stock is rather unusual, as it is generally considered inadvisable to use this method with such large stock[69]. It was done to see if such a practice would be successful under the existing conditions. As dibbles with 10 inch blades were used, it would have been difficult to plant unpruned stock of this type as the roots would have been far too large for the hole made by the bar, the roots being well over 12 inches long. The lateral roots would also have caused trouble when cramped into the hole. After pruning, it was rather easy to use the slit method with this stock.

The stock used on May 8th had been heeled in during the week of May 1st to May 8th.

Samples of the stock (B) used in each subdivision of the plot were allowed to become air-dry, that is, left until all visible traces of water were gone. The roots and tops were then weighed separately to determine top-root ratios, as given in Table VI. These ratios are obtained by dividing the total weight of the tops by the weight of the roots. This is the commonly accepted method of expressing the ratio between tops and roots. The lower the ratio the greater the percentage of roots, and during dry conditions, the greater the possibility of survival.

DATA COLLECTED AND INTERPRETED

First Examination

Because the author feels the first year following the planting is the most important in the light of survival and causes of trees dying, he has taken the liberty to quote much of the description given by Mr. Towell (B).

The first examinations of the experimental plots were made during the months of March, April and May of 1938 . . . Since the experiment was designed to show the effects of both root pruning and the method of planting on survival, it was necessary to very carefully determine the cause leading to the death of every seedling that had been killed . . . . .

Each seedling was examined carefully above the ground to make certain that mechanical injury, plant competition, careless planting technique, or other related factors were not the cause of the death. After eliminating all possibilities of this nature, the dead seedlings were lifted with the aid of shovels and grub-hoes, care being taken not to damage the roots . . . those seedlings which had been severely attacked by white grubs were easily detected, and eliminated in the interpretation of survival counts . . . . The trees which showed insufficient or badly distorted root systems were considered in analyzing the results . . . .

. . . . All trees were measured to the nearest one-quarter inch in height and the differences in average heights were considered as an indication of the difference in height growth between the various plots . . . .

Since the experiment is planned to be continued for five years, approximately one-fifth of the trees in each plot could have been removed. However, it is desirable that a few be left in the ground for observation after the 5-year period, so more nearly one-sixth of those in each plot were lifted . . . . It was at first thought desirable to remove trees of average height, or an equal number above and below the average, so as not to affect next year's growth comparisons. However, this procedure would have involved the element of selection, and it was decided that better average results would be obtained by a definite sample method independent of the present heights. In Plots 1, 2, 3, 4 and 5, every third, eighth, and thirteenth seedlings in each row were selected. . . . . in the smaller plots a similar procedure was used.

. . . . . to remove the trees without injury . . . a grub-hoe was found to be the most satisfactory . . . With the grub-hoe a rather deep trench was dug on one side of the seedling. Then by inserting the instrument deeply into the trench with the blade directly under the tree, very little damage was done to the roots . . . It was possible with all the pruned stock to see the point of pruning, so from this point all root growth was measured and averaged. ."

It seems to the author that the first growing season was such an unusually fine one for newly planted stock, especially in regard to the rainfall (See Graph I), that it would seem the planting was a failure in obtaining good comparative results on normal survival effects and rates. The survival was unusually high in all of the plots and the only one which showed any really poor survival was the plot where the roots had been pruned to four inches, and even this was not a serious figure.

However, as may be seen in Tables III and IV, there was a slightly larger mortality due to pruning observed for the pruned stock as compared with the unpruned stock, particularly that which was planted with the dibble. Root bending and lack of care in planting seemed to account for a great deal of the mortality in the center-hole method, especially in the unpruned stock. In fact, mortality due to planting was quite high in all of the unpruned stock, and this reached its greatest effect on those planted by the slit method. According to Towell (B) the root systems of most of the dead seedlings in the unpruned plots were bent upwards so that the fine, fibrous roots were very close to the surface of the ground, and so dried out even with the growing year of exceptional precipitation.

As to the first year's growth in height, (See Table V) the four-inch root pruning was definitely too severe--it almost prohibited any growth. Nevertheless, the unpruned, center-hole Western yellow pine showed the poorest growth of all, and since according to Table III much mortality appears to be due to poor planting, it can be said that the poor growth could have been caused by the cramping of the long roots. According to Towell (B) there were indications that smaller stock had been used on this plot. As it was the last one planted, perhaps this was true. No height data was given by Coffman (A). The interesting fact is that this plot (Plot #7) has grown more than any of the other Western yellow pine plots according to every report since that one made in 1938. Perhaps the seedlings were smaller and so had less injury done to their roots by bending, breaking, cutting etc. If that were true it would be quite a plausible solution.

For the first year of growth of the Austrian pine, the average heights showed a much greater growth for the unpruned, center-hole plot than for any of the other plots. This, according to Towell, confirmed the opinion that, although root-pruning makes planting easier, the unpruned seedlings can start top growth more quickly and are not faced with the necessity of the development of an adequate root system.

The root growth for the pruned stock was three inches in the case of the Western yellow pine and five inches for the Austrian pine. The depth of the roots below the ground surface of those seedlings planted by the center-hole method was greater than for those planted by the dibble. The dibble-planted stock in almost every case showed the main roots had been bent upward in the slit in which they were planted. However, in the root-pruned, slit-planted trees, much of this

Table III

FIRST YEAR SURVIVAL PERCENTAGES
AND
CAUSES OF MORTALITY FOR THE VARIOUS PLOTS (1938)

Plot No.	Species	Method of Planting	Condition of Roots	No. Trees Planted	No. Trees Dead	Mortality due to Pruning	Mortality due to Planting	Mortality from other Causes	Survival
7	W.y.p.	Hole	U.P.	99	6	0.0%	2.0%	4.0%	94.0%
3	W.y.p.	Slit	U.P.	257	18	0.0%	2.3%	4.7%	93.0%
4	W.y.p.	Slit	Pruned 6"	237	3	0.0%	0.4%	0.8%	98.8%
5	W.y.p.	Slit	Pruned 4"	269	22	5.2%	1.5%	1.4%	91.9%
1	Austr.	Hole	U.P.	184	6	0.0%	1.1%	2.1%	96.8%
6	Austr.	Hole	Pruned 6"	100	1	0.0%	0.0%	1.0%	99.0%
2	Austr.	Slit	Pruned 4"	199	5	1.0%	1.5%	0.0%	97.5%

bending was eliminated.

As Coffman (A) had feared, the Austrian pine 2-2 stock was a little large for dibble planting even when root-pruning and center-hole were used, as many of the main roots were doubled quite badly.

Also, the trees planted by the slit method still had almost all their roots in one vertical plane, and there seemed very little tendency for any lateral expansion past the sides of the slit.

In spite of the different treatments received, the top-root ratio was just about equalized by 1938.

Second Examination

The second examination was made by Mr. Robert L. Metzger in June of 1939 (C). He found (See Table V and Graph II) that the unpruned Austrian pine plot led the other plots in average heights. It was closely followed by the plot that had been pruned to 6 inches and also planted by the center-hole method. The plot pruned to 6 inches and planted by the slit method was a full two inches behind the other plots.

For the Western yellow pine, the unpruned, center-hole plot rose from the least in average height the year before to the greatest in average height, so perhaps Mr. Towell was correct when he said that probably the trees in this plot (Plot #7) were shortest when planted. The trees in Plot #5, which had been pruned to 4 inches, made a great growth over that of the year before. In fact, with the exception of Plot #7 (which had grown an average of 4.86 inches), this severely pruned plot made the best growth of any plot. Plot #3 closely followed Plot #5, and the plot pruned to 6 inches and planted by the slit method grew an average of almost one-half inch less than the one pruned to 4 inches.

In the Austrian pine the center-hole methods had from 1.86 to 2.67 inches lead over the slit methods, while the center-hole method of the Western yellow pine yielded a growth 1.87 to 2.13 inches more than the plots planted by the slit method.

Unfortunately, Mr. Metzger neglected to record any survival counts or any tabulated reasons for mortality. It would have been interesting to see if any of the trees had succumbed to the competition of grass roots for moisture, and to see how many were injured or killed by rodents.

Third Examination

The third examination was performed by Mr. Robert E. Leeson in the spring of 1940 (D). (As far as the author is able to discover, all that had been turned in for the Root Pruning Experiment was one sheet of data.)

Of the Austrian pine plots (See Table V and Graph II) the unpruned center-hole method was still in the lead as far as the total average height is concerned. This was closely followed (difference of .22 of an inch) by the center-hole, six-inch pruned plot. However, there was a negative difference in average yearly growth of 2.82 inches between the ones planted by the slit method and those planted by the center-hole, unpruned method.

As to the Western yellow pine, Plot #4 (the 6-inch pruned, slit-planted plot) had a slight lead (.56 of an inch) over the year's average growth of the unpruned, center-hole method plot. There is a difference of 1.9 inches in the total average heights of the two plots, with the unpruned being the taller. The plot that was unpruned and planted by the slit method grew 1.26 inches less than the one pruned to 6 inches. The one with the least growth of all was Plot #5 (root-pruned to 4 inches). It grew 1.93 inches, on the average, less than the fastest growers.

Fourth Examination:

The fourth examination was performed by G. David Bauch in 1942, from May through September, with survival and growth measurements taken in May, and the sample trees taken in May and September.

As to the Austrian pine (See Table V and Graph II) the unpruned, center-hole method was still far in the lead over the pruned plots as far as average growth was concerned. The pruned plot that had been planted by the center-hole method had grown 2.9 inches less than the slit planted method.

The Western yellow pine plots had interesting results. The total average height of the unpruned, center-hole plot was still 3.07 inches higher than the next highest plot.

However, this plot had made only .07 of an inch less growth (18.42 inches to 18.35 inches). The other plots had 5.83 inches and 4.48 inches average growth for 1939 less than the highest (Plot #7). The really interesting thing is that the plot with the next largest growth had been pruned to 4 inches and had been planted with the slit method; while the one with the largest growth had not been pruned and was planted by the center-hole method. Thus it would seem that pruning to 4 inches is, in the long run, better than pruning to 6 inches. However, this might be site difference.

According to Mr. Bauch, there were a number of trees that died from rodent girdling. He states that there were thirty in Plot #1 and sixteen in Plot #2 which died from rodent injury. The injuries were due to both mice and rabbits.

Mr. Bauch seemed to feel that site variance had something to do with the differences in growth, however, there was no elaboration on the statement.

Fifth Examination

The fifth examination was made by the author in the fall of 1945 and the spring of 1946. Due to the war and lack of manpower, no reports had been made since 1942. Survival counts and height measurements were made in November and December of 1945, and all but three of the sample trees were dug at that time. The others were dug early in May of 1946.

As can be seen in Table V and Graph II, the Austrian pine plot that was unpruned is still growing faster than the plots that were pruned to 6 inches. However, the other plot that was planted by the center-hole method is producing 8.62 inches less growth, while the plot planted by the slit method grew only .14 of an inch less than the unpruned, center-hole plot. In overall average height, the latter-mentioned plot (#1) is 10.11 inches taller than the plot planted by the slit method, while it is 12.19 inches taller than the pruned plot planted by the center-hole method. Thus, the plot that was pruned and slit-planted (Plot #2) seems to be doing much better than the pruned plot planted by the center-hole method (Plot #6). However, the site conditions of the former plot seem definitely of a much better quality than those of the latter plot (See Map II).

The Western yellow pine, in the four year period since the last observation was made, continued to have the interesting developments first noticed by the author in the data from 1942 (See Table V and Graph II). Plot #7 is still growing much faster than any of the other plots of this species. (It had grown 12.64 inches more than any other.) Plot #5 is still the next tallest, as far as average height is concerned, but plot #3 (the unpruned, slit-planted plot) grew 3.04 inches faster than Plot #5 (the 4-inch-pruned, slit-planted plot) and 2.93 inches faster than Plot #4 (the plot pruned to six inches and slit-planted).

PHOTOGRAPHS

and

DISCUSSION

of

SAMPLE

TREES

Plot No. 1 - Tree No. 1

106" 2-2 Unpruned Austrian Pine - Center-hole Planted

Root system badly bent in planting. Very large lateral root system. However, it grew only in the direction to which it was bent when planted. Very little growth was made downward by the laterals and even the strong tap-root, after it had turned downward, had difficulty in penetration of the hard and almost impervious subsoil.

Slight root swelling where the tree had recovered from partial girdling.

Plot No. 1 - Tree No. 2

12" 2-2 Unpruned Austrian Pine - Center Hole Planted

Root system very badly bent in planting, also the stem was not planted on the vertical. The few lateral roots had attempted to penetrate the "hardpan", but grew upward again, to within 1 to 4 inches of the surface. The topsoil was very shallow and almost 75 percent gravel. Even the grass at this spot had been very sparse.

The stem had been badly girdled, but the tree had recovered. However, not before butt rot had entered the tree.

Plot No. 2 - Tree No. 1

80.4" 2-2 Austrian Pine pruned to 6 inches and slit-planted.

The lateral roots had been wrapped completely around the tap-root stub and were extended in one plane and in one direction. Indications seemed to point to a slight strangulation. The basil portion developed one functional and one not functional tap-root. Even the functional tap-root had extreme difficulty in penetrating the hard subsoil, and bent several times in the attempt. Dry site with many large and small rocks.

The lower part of the stem was partially girdled.

The tree was greatly suppressed.

Plot No. 2 - Tree No. 2

99.6" 2-2 Austrian pine pruned to 6 inches and slit-planted.

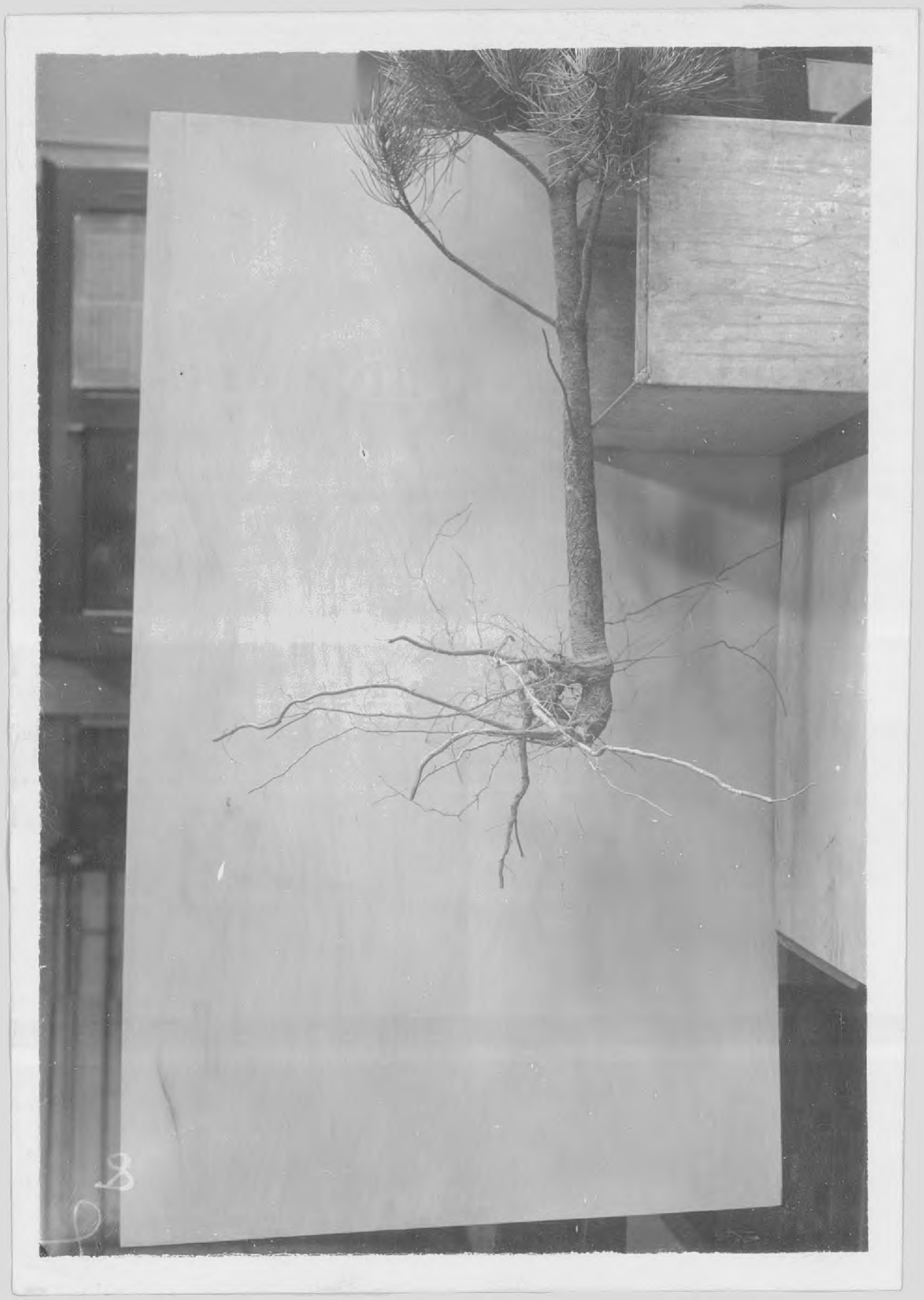
For its vigorous top the root system was very shallow. There was no tap-root, but two laterals had dipped slightly downward. It had a very heavy growth of laterals which went in all directions, although there are still evidences of the one plane tendency. One lateral had grown down the original plane over 5'.

The soil was less gravel and more sand than Plot No. 1.

Had a butt swell which contained butt rot, cause was girdling.

Plot No. 2 - Tree No. 2

Second view looking directly up at the base of the tree, perpendicular to the ground surface, showing the many planed root distribution, something considered unusual in slit planting. The soil, being quite sandy, did not pack well and so form the usual "root channel" so familiar in slit planting. The original plane caused by the dibble is still recognizable by the 3 roots to the right and the 8 plus extending to the left of the picture. However, there have been sufficient strong roots developed in other planes that there would be no danger of windthrow when the tree matures.



Plot No. 3 - Tree No. 1

62.4" Unpruned Western yellow pine; slit planted.

The root was bent double, but redoubled back and went downward again. A lateral root on one side was bent so it grew in the opposite direction to its original growth and became the longest root. This also occurred to several roots, on both sides of the tree. There is evidence that some roots tried to grow perpendicular to the planting slit, but grew at a right angle and continued along the one plane. This was a very dry soil so the roots did very little dividing and just extended themselves along the one plane looking for water. When the tap-root finally did go downward it was retarded by the "hardpan".

Plot No. 3 - Tree No. 2

74.4" Unpruned 2-0 Western yellow pine; slit planted.

The tap-root had been doubled upon itself, but had also been doubled back again, as though it had been planted and then pushed downward afterwards. The "hardpan" was about 28 inches deep here and so the taproot developed much better than Tree No. 1.

The soil was very dry and so it developed a straggly root system.

The majority of the roots were in one plane, but a few digressed.

Plot No. 4 - Tree No. 1

66.0" 2-0 Western yellow pine pruned to six inches and slit planted.

Root system strictly in one plane with a few very long and unbranched lateral roots. However, there are quite a few small many branched lateral roots, usually an indicator of good soils. The lateral roots stayed, for the most part, within a few inches of the surface of the ground.

The tap-root was dual and seemed to lack vigor, probably due to the gravel-like sub-soil.

Plot No. 4 - Tree No. 2

79.2" 2-0 Western yellow pine pruned to 6 inches and slit planted.

Considering most of the roots are on a single plane this tree had a mighty fine root system. The tap root had divided and subdivided, but was strong and straight.

The many laterals were not divided, but were strong with quite a few fibrous roots.

The soil was a coarse sandy loam.

Plot No. 5 - Tree No. 1

74.4" 2-0 Western yellow pine pruned to 4 inches· slit planted.

Roots mostly in one plane, but the laterals have many fine fibrous roots, which shows good moisture conditions. Three tap-roots have formed which are quite straight, in spite of the one stone that was in their way.
With the exception of the roots being in one plane the tree made a very good recovery from the severe pruning. In fact, in the past four years the top had almost tripled its size.

Soil is a coarse sand that has a good moisture condition.

Plot No. 5 - Tree No. 2

88.8" 2-0 Western yellow pine pruned to 4 inches; slit planted.

This tree had quite a few lateral roots but they were all in one plane.
Three of the roots had turned downward to replace the severely cut tap-root. They grew fairly straight until they met the hard sub-soil at a depth of 30 inches, here their downward progress was slowed in the gravel-like formation.

This was the best developed tree on the plot and showed very fast top growth in the last few years.

Plot No. 6 - Tree No. 1

126.0" 2-0 Austrian pine; root pruned to 6 inches; center-hole planted.

Two tap-roots had developed from the prune stub with one taking the dominance and going almost straight downward, measured to 51 inches where it broke.
The laterals were many and uniformly distributed in all planes. There were many fine fibrous roots, but they, as did the lateral roots, grew straight out horizontally and then upward into the furrow ridges on the sides of the old plow line, probably to get the humus from the decayed grass that had been plowed under.

Soil a coarse sand.

Plot No. 6 - Tree No. 2

98.4" 2-0 Austrian pine root pruned to 6 inches; planted the center-hole method.

The tap-root formed after the pruning was almost severed by some rodent, but had almost healed. A lateral root had divided one section, turning straight downward, probably in response to the slowing growth of the tap root.
There was one very long lateral root and many small ones.

Soil coarse and much sand.

Plot No. 7 - Tree No. 1

86.4" 2-0 Unpruned Western yellow pine; planted center-hole method.

Evidence points to the roots being bent in one direction when planted and then continuing on that side of the tree. The laterals were few but fairly well branched.

The tap-root was not very strong and grew on an angle.

Soil was sandy with a gravely subsoil.

Plot No. 7 - Tree No. 2

90.0" 2-0 Unpruned Western yellow pine; planted the center-hole method.

Many sided lateral growth with numerous fibrous roots.

Two laterals developed into tap-roots, probably when the original tap-root was stopped by the almost impervious subsoil, the root made a right angle and then made its way down again.

Soil sandy with a coarse gravel layer about 30 inches below the surface.

SUMMARY AND CONCLUSION

After nine growing seasons it should be possible to state fairly definite trends in the experiment's progress, and that in conjunction with the findings of other experiments, show some interesting results.

Root pruning should only be done under the proper soil conditions of moisture, fertility, physical properties, aeration and temperature. A difference in any one of these things from a normal condition will provide a modification of the root pruning system used, as to the depth pruned and the age of growing stock that would be best on the certain locality. Also an understanding of the hereditarial growing tendencies of the particular species and the type of modification of the root system that would be needed for that species. This work can be carried on in a well planned nursery and just the right type of stock can be developed.

By recognizing that it is a compact fibrous root system that is most able to secure the maximum amount of moisture and food for the plant, it is then that the length of the root system needs to be considered. If the field conditions are to be relatively good and moist then a short compact root system is sufficient. However, if the planting area is quite adverse to growing, then it is necessary to develop a deep growing system with many compact fibrous roots near the tip of the root. This can be accomplished by root-pruning and transplanting.

As to the different types of planting stock to be used in Lower Michigan, Professor Young[86] determined this in experiments on Saginaw Forest. He found 2-0 stock is not as good as 2-2 stock, as the former had a catch of only 52%, while the latter had a catch of 95%. However, there probably would have been even better catches for both if they had been root-pruned to a proper depth in the nursery.

According to Young[86], the growing conditions of this locality are not conducive to an easy life for the young tree of any species, when set out in the open amid unnatural surroundings. The mean annual precipitation of 28 inches furnishes no great margin of safety, especially when combined with erratic distribution. Also there is a provoking tendency toward rather hot, dry summers with little droughts of two or three weeks that usually come in May or in early June. These conditions along with the medium-poor soil, a glaciated structure containing a considerable admixture of gravel and small stones[87], create difficult growing conditions for any experiment. Nevertheless, the year in which this experiment was started was an exceptionally moist one, so some of these conditions were mitigated, if not made even too good for an experiment that tries to show survival and also growth tendencies.

One thing that the experiment is attempting to determine is whether planting methods, such as the slit method, will make trees less able to withstand drought conditions and fungus attacks, and if the trees will be less wind-firm when they mature, then planting methods such as the center-hole type.

So far there is a slight retardation in the growth of the trees planted by the slit method when compared with that of the center-hole method. In addition, there is a strong tendency for the trees planted by the slit method to have their roots grow in one plane. There was only one exception to this in the samples dug by the author (Plot No. 2, Tree No. 2). This tree showed that it had originally started to develop in one plane, but was now fully developed in many planes.

There seems to be a tendency for the trees growing in the more compactable soils to develop root systems in one plane after slit planting, while the trees growing in less compactable soils succeed in developing root systems in many planes.

Root pruning in the field in the conditions of this experiment, produces a retardation of top growth that is not made up for in the following years. Planting by the center-hole method produces a much faster growing plant than the slit method. (See Table V and Graph II)

Pruning to 4 inches was a terrific shock to the trees in Plot #5. However, a little over three years after the trees were planted, these trees grew enough to pass the total average growth of Plot #3 and that of Plot #4 (The other slit-planted plots). Is it possible that the severe pruning so lowers the top-root ratio, and so stimulates the root growth, that the tree is actually able to grow faster above the ground? Or is it a case of Plot #5 being located on better soil that causes this increase? Or is it a case of so many trees dying at first that the surviving trees had less root competition for moisture? Only the future will answer these questions.

A study of the Maps numbering from III to IX will show that the tallest trees are in the south side and the south-east corner of the large experimental area, this seeming to indicate better soil conditions. Also, the grass cover on the south-east corner is the thickest and heaviest of all the plots. In addition, Plots #5, #6, #7 and part of Plot #1 are on nearly flat ground, at the base of quite a steep slope. Plots #2, #3 and #4 are on the slope. The top-soil of the slope is much shallower than that of the flat part, as though at some time the soil was washed from the slope and deposited on the flat. The sub-soil is of a gravelly texture and is almost impervious to root penetration. In addition, there seems to be a strong basic reaction which in itself, would be unfavorable to pine growth. Thus, by the sub-soil being brought closer to the surface there would be a greater effect on the trees in that section.

Plot #5 does have the least number of trees on it, and so would have less moisture competition from other tree roots.

However, the less shade from trees would help a thicker mat of grass to form and the moisture competition from the grass roots should be as great, if not greater, than that from the young trees. Therefore, the light and root space competition suggestion by Mr. Bauch (E) would seem to be nullified.

Mr. Bauch also suggested the development of planting machines would tend to eliminate the use of root-pruning. The author agrees, inasmuch as larger root systems could be handled easily without bending the roots in planting. However, the author believes that root pruning in the nursery will be used more and more as the need for developing compact, fibrous root systems to help combat adverse field planting conditions will become increasingly recognized. This is especially true for underground root-pruning and hand root-pruning when transplanting.

APPENDIX

Geo. Wahr, Publisher, Ann Arbor, Mich.   Form 33—10 x 10 to 1 inch

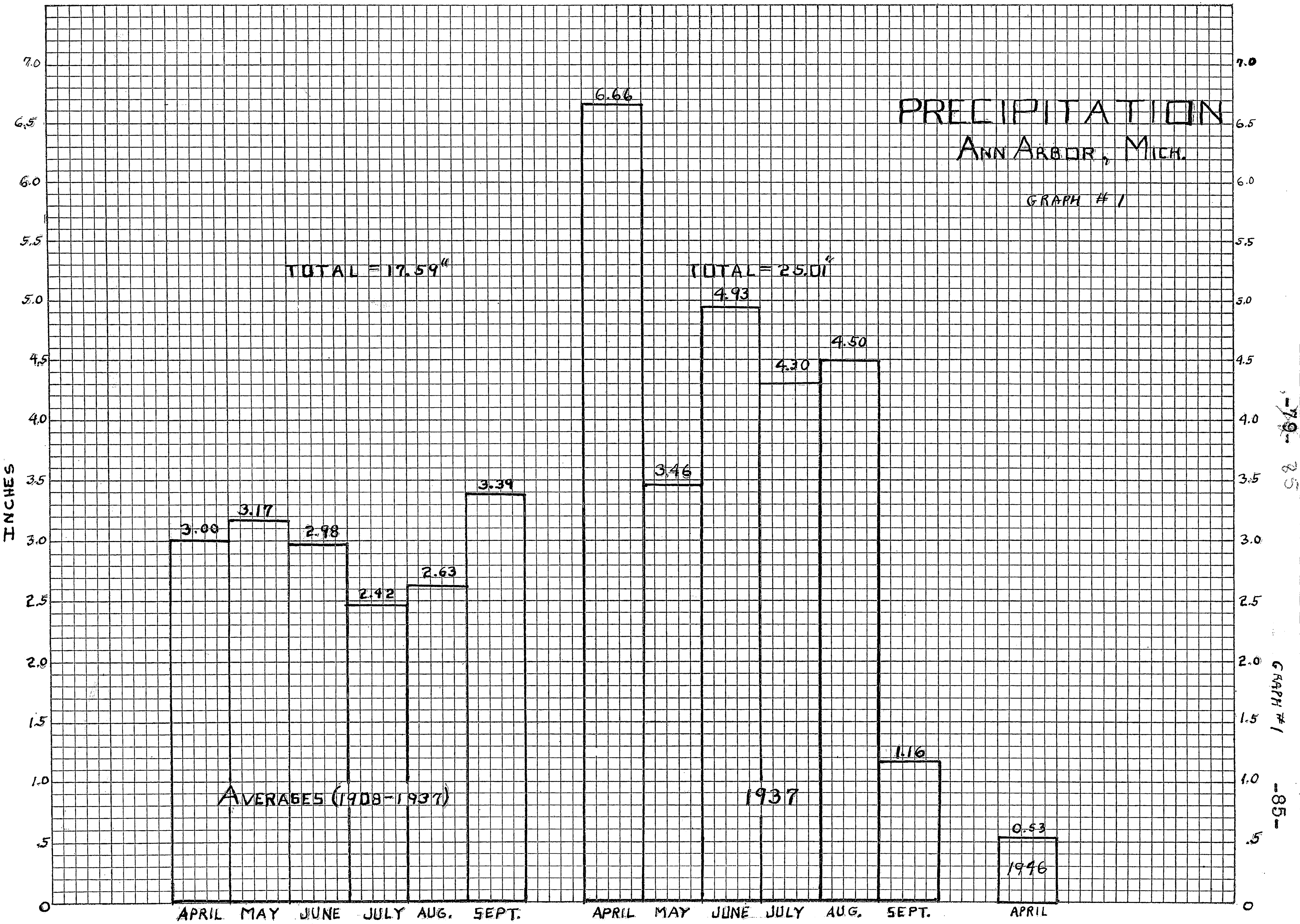


Table IV

SURVIVAL AMOUNTS
(AFTER SAMPLES WERE REMOVED)

Plot	I	II	III	IV	V	VI	VII	Total
Species	Aust. pine	Aust. pine	W. Yel. pine	W. Yel. pine	W. Yel. pine	Aust. pine	W. Yel. pine	
Stock Age	2-2	2-2	2-0	2-0	2-0	2-2	2-0	
Method of Planting	Center Hole	Slit	Slit	Slit	Slit	Center Hole	Center Hole	
Pruned or Unpruned	Un-pruned	Pruned to 6"	Un-pruned	Pruned to 6"	Pruned to 4"	Pruned to 6"	Un-pruned	
Original No. (1937)	184	199	253	237	269	100	99	1,341
No. Alive (1938) . .	147	163	197	192	205	84	78	1,066
No. Removed (1938) . .	31	31	42	42	42	15	15	218
1939	No Survival Counts Recorded							
No. Alive (1940) . .	78	86	121	120	118	52	42	617
No. Removed (1940) . .	9	7	9	9	8	5	5	52
No. Alive (1942) . .	25	58	95	81	52	37	23	371
No. Removed (1942) . .	4	4	4	4	4	4	4	28
No. Alive (1946) . .	23	48	89	77	44	27	16	324
No. Removed (1946) . .	2	2	2	2	2	2	2	14

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Table V

AVERAGE HEIGHTS (INCHES)

Plot	I	II	III	IV	V	VI	VII
Species	Aust. pine	Aust. pine	W. yel. pine	W. yel. pine	W. yel. pine	Aust. pine	W. yel. pine
Stock Age	2-2	2-2	2-0	2-0	2-0	2-2	2-0
Method of Planting	Center Hole	Slit	Slit	Slit	Slit	Center Hole	Center Hole
Pruned or Unpruned	Un-pruned	Pruned to 6"	Un-pruned	Pruned to 6"	Pruned to 4"	Pruned to 6"	Un-pruned
1937 (Approximate)	5	5	2	2	2	5	2
1938	9.31	8.40	3.39	3.17	2.60	8.44	2.36
1939	18.84	15.26	6.12	5.76	5.59	17.16	7.22
1940	26.9	21.5	9.6	9.5	8.4	25.0	11.4
1942	51.3	41.6	22.19	23.44	26.75	48.0	29.82
1946	119.57	109.46	60.59	58.91	62.11	107.38	80.86

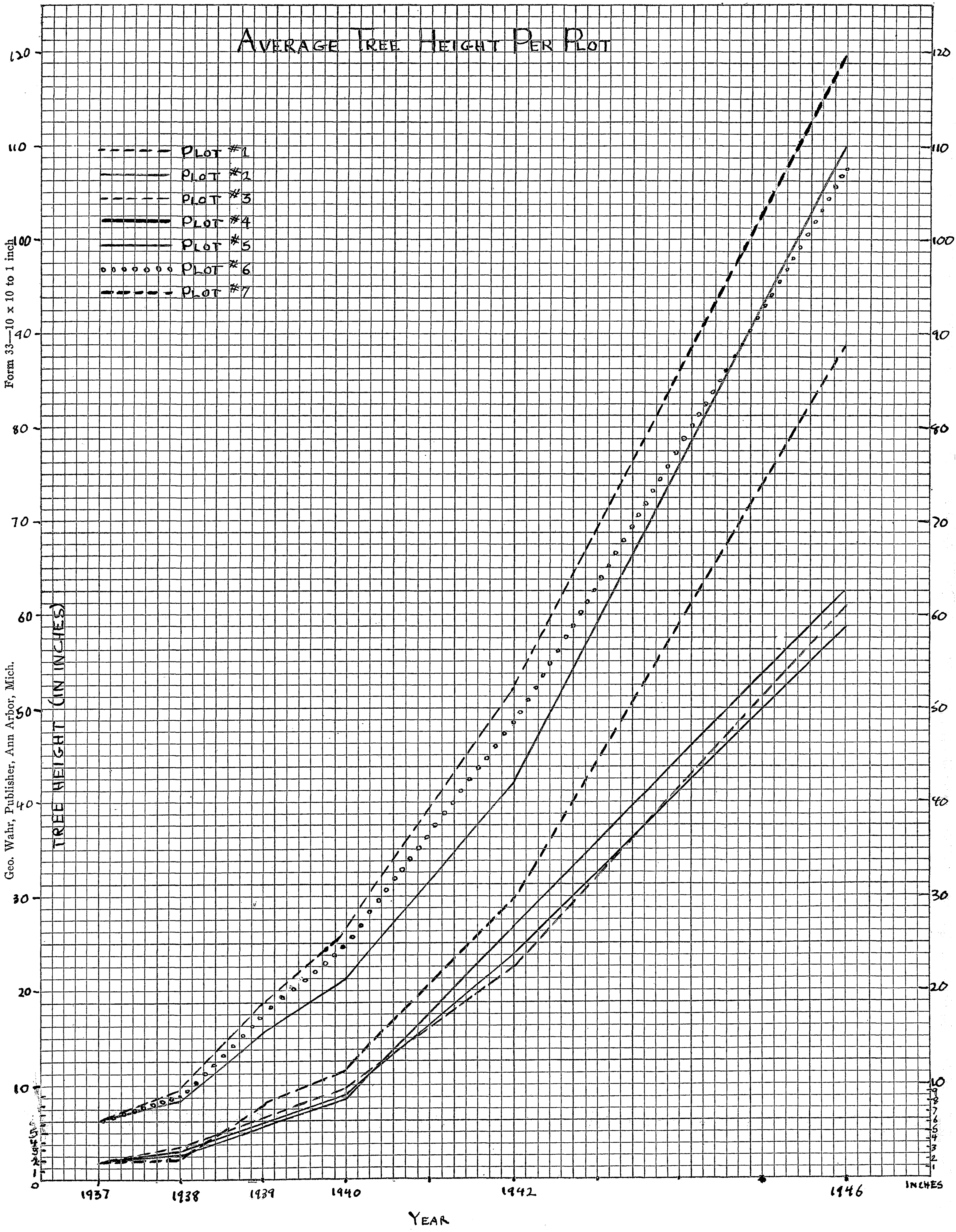

AVERAGE TREE HEIGHT PER PLOT
PLOT #1
PLOT #2
PLOT #3
PLOT #4
PLOT #5
PLOT #6
PLOT #7
TREE HEIGHT (IN INCHES)
YEAR
INCHES
1937
1938
1939
1940
1942
1946
10
20
30
40
50
60
70
80
90
100
110
120

Table VI

TOP-ROOT RATIO

Plot	I	II	III	IV	V	VI	VII
Species	Aust. pine	Aust. pine	W. yel. pine	W. yel. pine	W. yel. pine	Aust. pine	W. yel. pine
Stock Age	2-2	2-2	2-0	2-0	2-0	2-2	2-0
Method of Planting	Center Hole	Slit	Slit	Slit	Slit	Center Hole	Center Hole
Pruned or Unpruned	Un-pruned	Pruned to 6"	Un-pruned	Pruned to 6"	Pruned to 4"	Pruned to 6"	Un-pruned
1937	3.8	5.1	2.9	2.85	4.16	5.1	2.9
1938	3.65	3.68	3.58	3.64	3.76	3.80	3.38
1939	1.97	1.20	3.78	3.38	4.18	2.10	4.49
1940	4.6	5.14	4.00	6.42	4.50	5.29	5.17

Map III

APPROXIMATE DISTRIBUTION OF TREES
REMAINING IN PLOT #1
(HEIGHT IN FEET)

	7.2	12.2			[6.0]	12.0			10.8
									9.8
	8.0							9.2	
9.0			11.7						
			11.4						
13.0	10.8	10.2							
	[8.0]	9.8							
			10.6			9.4			
		9.0		13.2					
					9.8	11.6			12.2
							12.6	11.8	

Map IV

APPROXIMATE DISTRIBUTION OF TREES
REMAINING IN PLOT #2
(HEIGHT IN FEET)

10.6		9.7				9.8	8.8	6.4			6.0
		7.5		9.9	9.1	9.2				9.0	
	8.6		12.2					11.3	7.6		
						[6.7]	8.0		9.9		10.0
	9.3	8.9		[8.3]	12.6		10.5	10.2	8.2	7.8	
			12.0			7.2	10.5				7.4
	11.1		11.3								
	11.5	11.9			8.4						
									7.8		
		10.8		9.5							7.0
6.2						7.3					
	8.0										
		9.2					9.9			8.5	8.4
9.4			8.5		10.6						

Height Tree Removed [ ]

Map V

APPROXIMATE DISTRIBUTION OF TREES
REMAINING IN PLOT #3
(HEIGHT IN FEET)

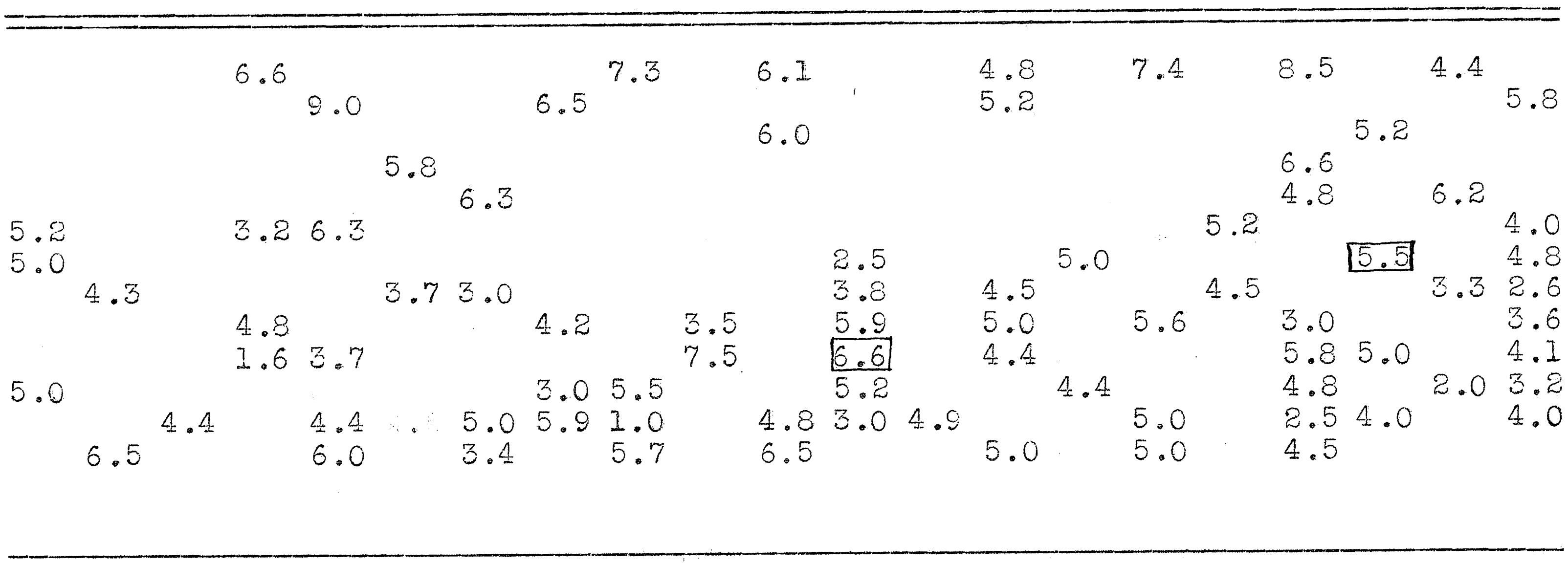
4.0			6.0		4.6		3.6		6.1	5.3			4.1			3.5				2.6	4.2
	4.2			3.2		3.5				3.0	5.2		4.4			4.1					4.5
							4.0		3.7			3.5				3.1			4.2		
									5.7		4.6				3.8		4.9				
									4.1				4.5			3.0			4.3		4.5
									[6.2]		4.5	4.3		3.2			4.4		4.7		4.2
4.8	7.2							4.6		6.2	3.4	5.8			4.7	3.5	[5.2]			5.0	
4.0	7.3													4.9					4.4		3.0
9.3									7.0			5.7				4.0		3.1		3.5	
							3.8				5.7	2.2			4.5			4.6		4.5	5.1
6.0								4.7		3.5		8.5	3.5								
7.5										6.2	X		7.3		7.2			6.5		4.6	
		7.0		6.0				5.5		8.2		7.0			3.3			6.5			
7.0			6.7							7.3				7.7						7.5	

Height Tree Removed [ ]

X Scotch Pine – Height – 11.8 ft.

Map VI

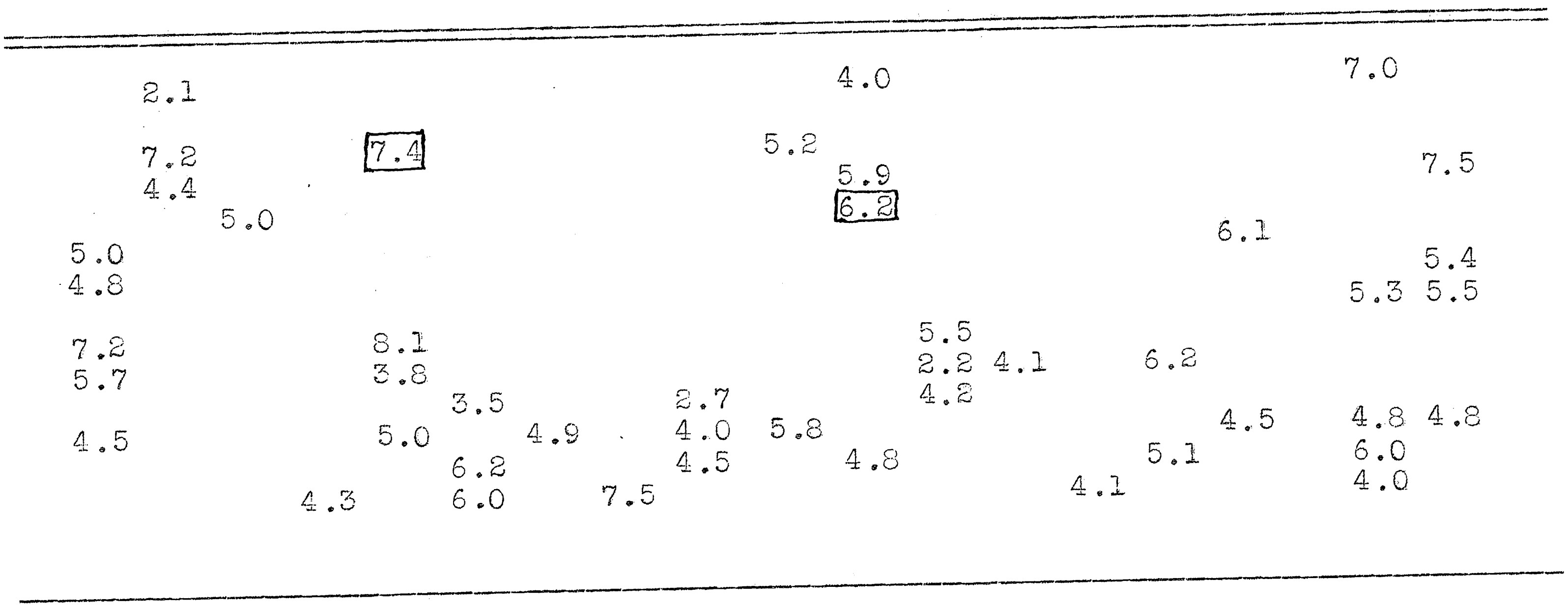
APPROXIMATE DISTRIBUTION OF TREES
REMAINING IN PLOT #4
(HEIGHT IN FEET)



Height Tree Removed □

Map VII

APPROXIMATE DISTRIBUTION OF TREES
REMAINING IN PLOT #5
(HEIGHT IN FEET)



Height Tree Removed ▭

Map VIII

APPROXIMATE DISTRIBUTION OF TREES
REMAINING IN PLOT #6
(HEIGHT IN FEET)

12.1 11.4 10.7 5.6
5.0 11.3 10.5
5.8 9.5 10.5 8.1
8.9 8.6 6.4 12.2
10.5 8.2 8.2 7.5 6.2
9.3 9.3 9.8 8.7
10.5 7.5 9.4 9.8 8.0

Map IX

APPROXIMATE DISTRIBUTION OF TREES
REMAINING IN PLOT #7
(HEIGHT IN FEET)

9.6 7.6 9.3 9.8 8.2
7.7 3.3 3.5
5.0 7.0 5.0
8.1 5.6
7.7
7.2 7.5 2.6
6.6

Height Tree Removed ☐

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*The Originals of These Reports are to be found in the Library of the School of Forestry and Conservation.

PART B

PART B

A STUDY OF NATURAL HARDWOOD REPRODUCTION IN STINCHFIELD WOODS

TABLE OF CONTENTS

PART B

TABLE OF CONTENTS (Cont.)

INTRODUCTION

Since forest managers are getting ever more conscious of the cost of maintaining fully stocked stands, the need to learn the conditions most favorable to natural reproduction of desired species is getting greater. Usually a little expense involved in creating more natural and beneficial germination conditions will save much of the heavy expense of planting extensive areas. Therefore, many field experiments have been devised to find out what to do at the proper time. Already the results have paid for themselves many times over. With this object in mind, eight permanent sample plots were established in Stinchfield Woods in 1930, and two more in 1937.

The specific problem in this case was a relatively poor site area which was badly stocked with northern hardwoods, mostly coppice trees, and which for many years had been subjected to sheep grazing and occasional fires. Thus the object was to determine the kind, character and amount of reproduction that would naturally appear in the various local conditions of the area.

In 1932, according to Towell (A), the reproduction of the original eight plots was measured and recorded, and in the spring of 1936 measurements were made again. However, this time the individual trees were marked with metal tags so that permanent records of each tree could be kept. Again in 1937 the data was taken for the plots, and the new reproduction that had come in since 1936 was tagged. That same year two new permanent plots were staked out and the reproduction on those areas were tagged and a record was made of the heights and species.

The mere recording of the frequency and abundance of reproduction is of little value[19] unless the reasons for its presence or absence are given. Various lines of research must be carried on over extended periods of time to find the explanation of the reproduction.

Silvicultural work in the subject of natural reforestation is still not being carried on to a great extent in America, and it is said[5] that while forestry has joined the great industries in developing the investigational section of the business, most of the investigations are along the industrial lines and not along the silvicultural lines. Such work is now being done at various forest experiment stations and schools. However, it will probably be many years before definite knowledge on the silvics of the various forest types and species in America will be available.

Many years have elapsed since the last data was obtained from the plots, and undoubtedly there were a few errors made in re-establishing the correct identification of trees that had lost their tags, however, it is hoped that this was held to a minimum.

REVIEW OF THE LITERATURE CONCERNING NATURAL REGENERATION

Very little literature even so much as approximates the problem involved here. There is a considerable amount of literature dealing with reproduction on areas being grazed or areas that have been burned, but there is little on what happens after grazing has stopped. However, the information available seems relatively applicable to the present situation, as it shows methods of gathering experimental data, and factors affecting germination.

In the early experiments very little attention was given to the ecologic or the silvicultural aspect of natural reproduction. The whole interest seemed to be in obtaining information by considering reproduction areas in the light of mature standards. That is to say, if there was one seedling on an area of ground equal to that occupied by a mature tree, the area was considered to be fully stocked. No consideration was made as to competition from low vegetation, bushes, or over-topping by trees, the soil condition, the climate, injury from animals, the influence of slash accumulation (fire danger), insect or fungus damage, germination of more tolerant and faster-growing species, or logging damage.

In addition, no attempt was made to determine the ideal forest conditions for seed germination, the number of trees needed, the viability of the seet, the soil condition, the moisture needed, etc. Any experiment was purely to obtain mensurational data.

Early experiments on natural reproduction seem to have started with Loudermilk in 1921[12] who used a stocked quadrat system. The system is based on the amount of area covered by mature trees, and uses one seedling for each division formed by his mature tree coverage as a completely stocked area. This system does not consider the number of seedlings per acre and seems to ignore the possibility of seedling mortality.

The next experimental work was in 1926, when strips of continuous mil-acre plots were run at definite intervals, and the same system as the above was used in recording--either a plot was stocked or it was not stocked.

A more exacting study, almost a one percent sample, was made in the Montana-Idaho region[11] by using parallel strips, 2.5 to 10 chains apart with mil-acre plots (6.6 feet by 6.6 feet), laid out at one-half to one-chain intervals. In this way, average number of seedlings per acre was computed as counts of the individual plots were taken.

In Douglas fir stands[7] a four-mil-acre plot (13.2 feet by 13.2 feet) system was used. This was also a stocked quadrat system experiment, and it found "the average number of seedlings per square". However, no square was permitted more than eleven seedlings, regardless of how many might actually be in it.

Any early studies dealing with the environmental influences seemed to concentrate on the amount of moisture available in regard to germination and root competition. Other factors of ecological aspects were apparently ignored. In addition, the experiments were performed with planted trees and not natural reproduction.

Boerker[5] showed the soil moisture to be the most important item in germination, and any other factor only tended to increase or decrease the amount of moisture. Korstian[14] worked with oaks, and his findings were fairly conclusive.

Another study dealt with the elimination of root competition by trenching in order to improve moisture conditions[15].

Excellent studies were made by Toumey and Korstian[20] who, in working together, found that natural reproduction depended on variations in soil moisture (particularly in the surface layers), variations in light intensity, and unevenness of seed distribution.

These factors affecting reproduction were given a greater elaboration by Averell[2]. The following is a list adapted from Averell and the report of Metzger (B), in addition to which there are factors added by the author:

1. Seed Supply--Seed supply depends chiefly upon seed production of the mother tree, the seed dissemination, the insect damage to the seed, and the rodent activity.

2. Seed Germination--Seed that is overlooked by insects and rodents constitutes the small percentage of the original crop which may germinate. Leaf litter or duff is probably the most important factor influencing germination. It serves as a cover which keeps moisture and temperature conditions favorable.

3. Soil--Soil influences reproduction by determining which species can grow on an area, how large it will become, and how fast it will develop.

4. Climate--The temperature varies as to exposure and aspect conditions found mostly in mountainous regions. Precipitation is a critical factor in determining the germination, as a drought condition during the growing season may almost completely prevent germination and usually kills seeds that do germinate. On the other hand, too much moisture at certain periods may rot the seed and cause damping off disease of the seedlings.

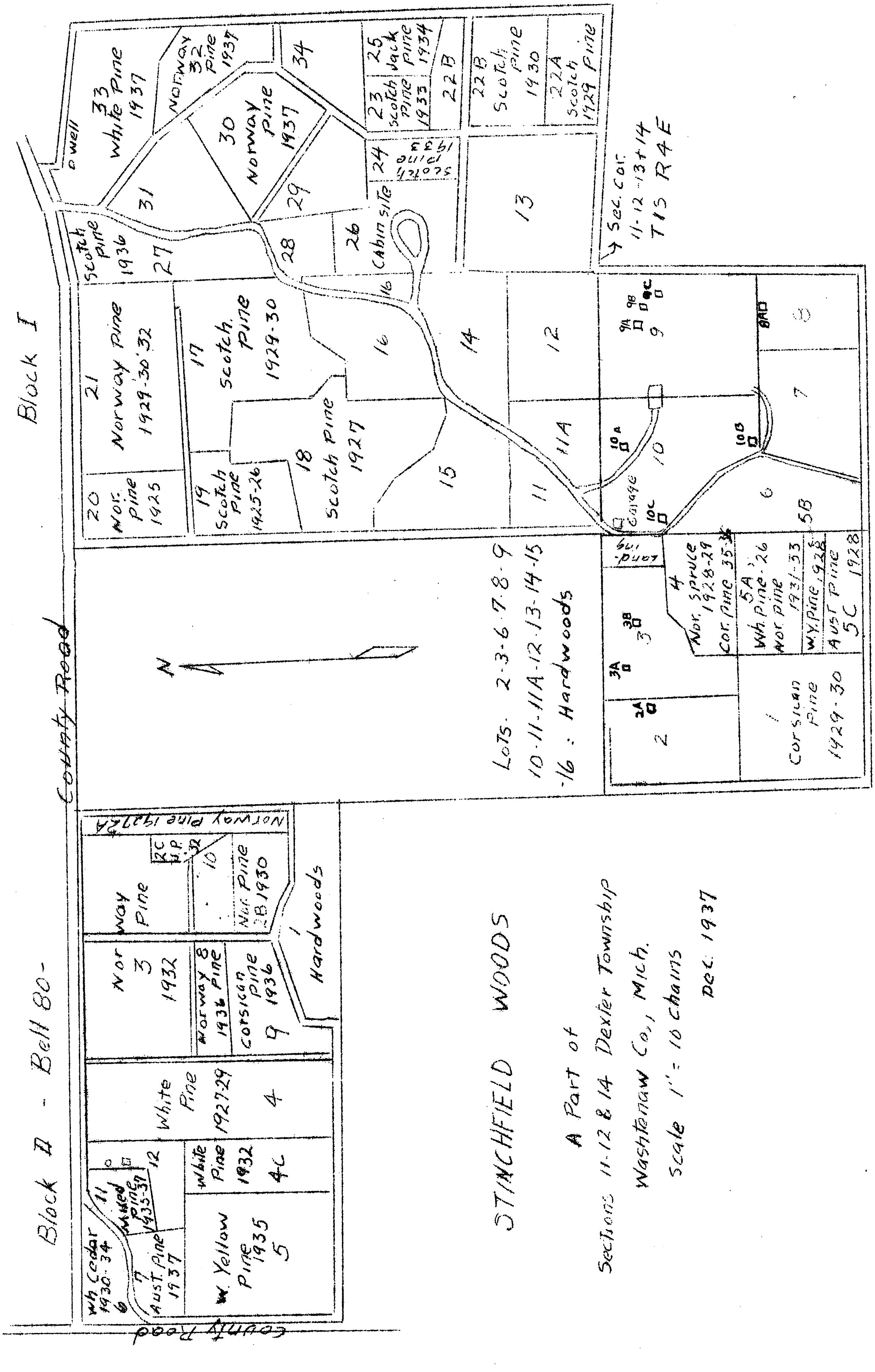
5. Shrub Competition--This factor will in many cases offer so much competition as to prevent seedlings from getting enough light or moisture to grow, even if they do happen to get enough to germinate.

6. Rodent and Rabbit Injury--These small animals will either eat the seed, the young shoots, or girdle the tree, depending on the animal species. However, rodents do good too, as squirrels often store seed in the duff

and then forget them, a type of animal planting.

7. Slash--The practical value of stored seed in the forest areas depends on the conditions of the forest floor. If the duff has been burned by broadcast or slash burning, most of the seeds are destroyed. To prevent burning off the duff, slash is usually piled, then burned.

Often seeds require a dormancy period, and they germinate the second year following seed production; these seeds are preserved by being stored in the duff. Sometimes several years pass before the seed germinates[13] because the cool leaf mold and duff of the forest floor provide an excellent storage medium. It is unknown how many years seed can be retained in the duff and still retain a reasonable degree of viability. However, it is hoped that through experiments such as this one some such facts will be obtained.

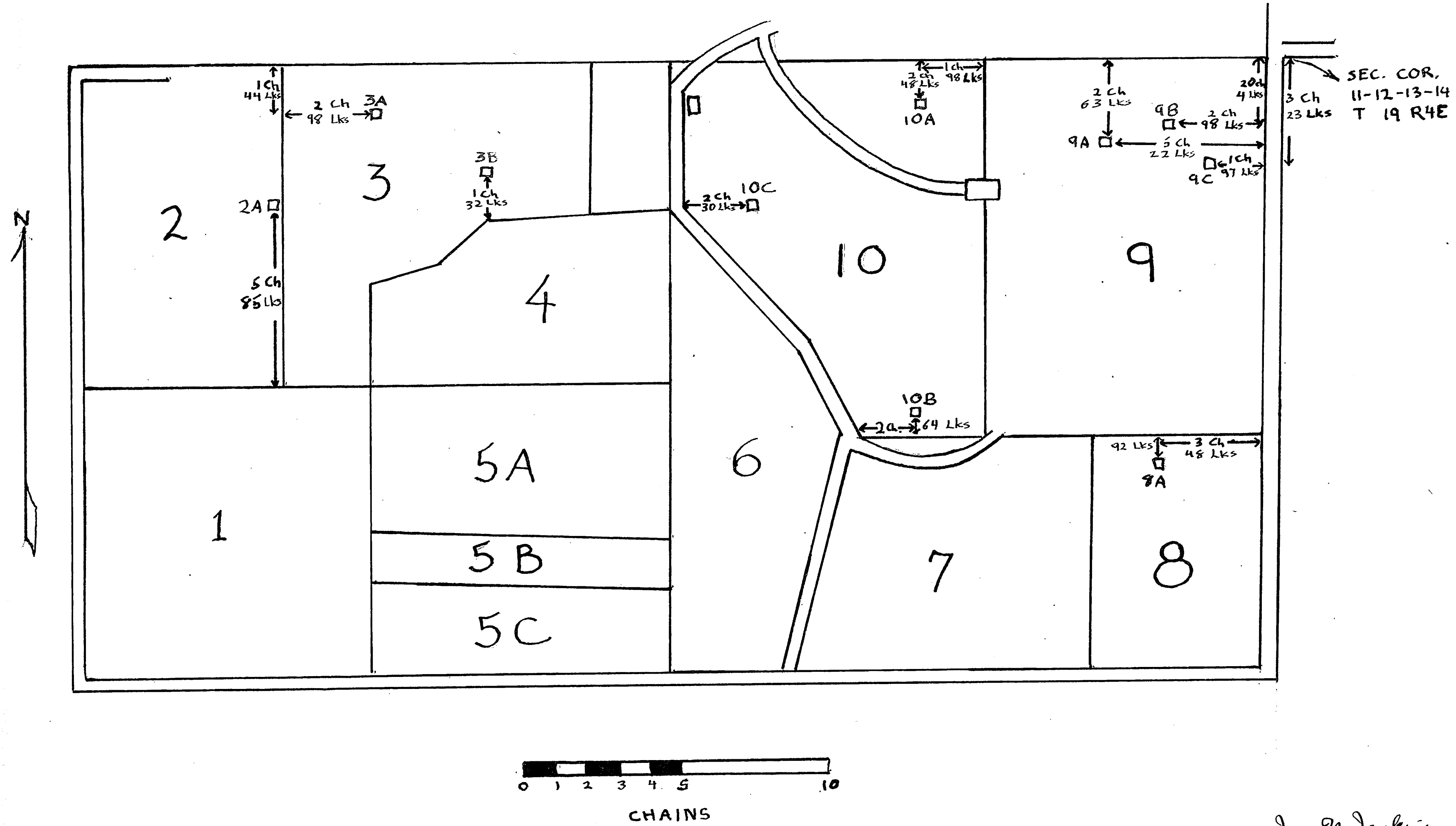

STINCHFIELD WOODS
A Part of
Sections 11-12 & 14 Dexter Township
Washtenaw Co., Mich.
Scale 1" = 10 chains
Dec. 1937
Block I
Block II - Bell 80-
County Road
N
Lots 2-3-6-7-8-9
10-11-11A-12-13-14-15
-16 : Hardwoods
Sec. Cor. 11-12-13+14
T1S R4E
Cabin site
Garage
33 White Pine 1937
30 Norway Pine 1937
21 Norway Pine 1929-30-32
17 Scotch Pine 1929-30
18 Scotch Pine 1927
19 Scotch Pine 1925-26
20 Nor. Pine 1925
27 Scotch Pine 1936
1 Corsican Pine 1929-30
4 White Pine 1927-29
5 W. Yellow Pine 1935
1 Hardwoods

A PART OF

STINCHFIELD WOODS

N½-NE¼ of SECTION 14

DEXTER TOWNSHIP, WASHTENAW CO., MICH.



Ivor N. Jenkins
5-10-46

DESCRIPTION OF THE EXPERIMENTAL SITUATION

Location

The experimental plots are located in lots numbered 2, 3, 8, 9 and 10 of the University of Michigan property called Stinchfield Woods (See Map X). The woods is located in sections 11, 12 and 14; R. 4 E., T. 1. S., M.P.M. of Dexter Township, Washtenaw County, Michigan. This location is approximately six miles northwest of Dexter, Michigan.

Composition of the Stand

The Stinchfield Woods comprises an area of more than 320 acres, approximately one-third of which is covered with hardwood timber, mostly oak-hickory. There is a considerable gap between the eight to ten-inch (D.B.H.) trees and the two-inch D.B.H. trees, because of the heavy grazing on the area for many years previous to the acquiring of the property by the University. The stand is definitely below normal in density and many of the trees are of coppice origin.

Topography and Soil

The topography of the Woods is slightly rolling on each side of the main moraine which runs almost east and west through the center of the Woods. The elevation is around 1,000 feet above sea level. There are several small glacial pot-holes in the area.

The soil is Bellfontaine Sandy Loam of a glacial origin approximately 200 feet deep, and varies from a clay loam to almost pure sand or gravel and small boulders. As to the specific description of the soil, as taken from Veatch's Soil Survey[21], see the account given under Soils, for Experiment Part A on Root-Pruning, by the author.

Weather Conditions

The climate has cool winters and mild summers with a mean average temperature of 47.4 degrees Fahrenheit[18] and an average frost-free season from May 2nd to October 13th. The mean annual precipitation is 31.37 inches, including snow, and the annual snowfall is about 37 inches. The prevailing winds are westerly[21].

DESCRIPTION OF THE PLOTS

(See Maps X and XI)

Plot 2A is established on the top of the western aspect of a glacial moraine on Lot #2. It is under the shade influence of black and white oak, also some black cherry, hickory and sassafras. The ground is a clay, sandy-loam and is covered with a heavy mat of grass which has kept the reproduction at a minimum. There was some old evidence of a burn on the area, but the limiting factor of reproduction, previous to purchase, was grazing.

Plot 3A was set up in Lot #3 at the bottom of a small glacial pot-hole just northwest of a white ash tree of some 24" D.B.H. The ground cover consists mostly of oak-leaf litter from two to three inches deep, with a very few scattered patches of grass. The crown cover of the moderately stocked area is dominated by oak, hickory and sassafras trees trees ranging from eight to sixteen inches D.B.H. The soil is a sandy gravel with traces of clay.

Plot 3B was one of the new plots established in 1937 to determine ash reproduction. It is located in Lot #3 on the flat top of the long glacial moraine which extends east and west across Stinchfield Woods. Its description is the same as that of 3A except that 3B is southeast of the previously mentioned ash tree, and the soil varies from sandy to gravelly clay.

Plot 8A is located in Lot #8 on the top of the southern aspect of the glacial moraine in an area which had been clear cut. The area immediately surrounding the plot has been planted with pine stock, while the plot itself has developed a very heavy, deep mat of grass. The soil is sand with gravel base.

Plot 9A is located in Lot #9 on a steep slope of the southern aspect of a gulley-like end of a glacial pot-hole. This plot has a very sparse cover of grass and almost no leaf litter or other herbacious vegetation. It has a gravelly soil and very little humus. Its crown cover is of oak, hickory, elm and red maple. A few hard maples have been planted here, but are still not very large (not over 200 inches).

Plot 9B is located in Lot #9 at the bottom of the pot-hole in which 9A is located, and it has a crown cover mostly of oak, with a few wild cherries, red maples and elms. The ground cover is of sparse grass mixed with virginia creeper. The soil is silty-gravel.

Plot 9C is located in Lot #9 on the steep north aspect of the same pot-hole noted in the description of Plots 9A and 9B. The crown cover is almost pure oak, mostly black oak, with a very few hickories, wild cherries, and red maples in the vicinity. The ground cover is almost nil excepting a sparse grass and a spotty, shallow leaf litter, as the slope is too steep to retain much. It has a sandy soil.

Plot 10A is located in Lot #10 on the edge of a cleared section of the flat, broad top of the glacial moraine previously mentioned. The crown cover is of hickories and wild cherries with a few maples and oaks in the vicinity. The ground cover is a medium-dense but not heavy grass, with very few other herbaceous plants. There is a very light deposit of leaf litter on the plot, and the soil ranges from gravelly to sandy-clay.

Plot 10B is located in Lot #10 on top of the moraine in a light stand of wild cherry with a few hickories, oak, and sassafras in the vicinity. The ground cover is of very sparse grass with almost no other herbaceous material. There is a one to two inch deposit of leaf litter, and a good deal of humus.

Plot 10C is the other of the two new plots established in 1937 to study the ash reproduction. There is an eighteen-inch D.B.H. white ash about one chain to the west. The plot is located in Lot #10 on the same glacial moraine previously mentioned. The ground is slightly sloping and has a north-east aspect. The soil is a sandy-clay loam with no distinct humus later, but with a slight leaf litter (from one-half to one inch deep). The grass is very sparse and there is no underbrush. The crown cover is relatively open and consists of oak and some wild cherry and hickory with D.B.H.'s from five to eighteen inches. As in all other plots, there is a gap from two to five inches D.B.H. showing the influences of previous grazing.

PROCEDURE IN OBTAINING SAMPLE PLOT DATA

The first step was to make sure that the plot corners had not been disturbed. Then the plots were divided into four strips by extending white string from stakes driven into the ground four feet apart on the north and south sides of the plots. The divisions were then parallel to the west and east sides.

On each plot a tabulation was made of each seedling or young tree. If the young tree had no metal number-tag, a new one was attached by using soft copper wire. This was also done to new reproduction that obviously had come in since the last count had been taken. Often, on some of the old plots, the tags were buried in as much as three inches of duff and decaying leaves.

Each tree was identified as to species, and the height was taken to the nearest quarter-inch.

DATA ON EXPERIMENTAL PLOTS

EXPLANATION OF TABLES VII TO XVI

Each table represents one plot.

The first column contains the number as stamped on the metal tags which are affixed to the individual seedling or young tree on the plot.

If a number in the first column is followed by one in parentheses, it means the old tag for the tree was lost and the new tag number is recorded in the column proper with the old number following in parentheses.

The second, third, fourth, etc., double columns are the individual species tagged. The first sub-column is the tree height to the nearest fraction of an inch. The second sub-column is the difference in inches between the height of the previous recorded year and that of the present year.

Each plot or table has two sections; the first section includes the trees on the area the previous recorded year, while the second section includes the trees which have germinated since the last recorded year.

Table VII

PLOT 2A

Number	Cherry		Hickory		Sassafras		Oak	
1					66	29		
22 (2)					245.2	51.2		
3					10.8	.8		
4					30	19		
5	58.8	22.3						
2832							12	
2834	18	5.5						
2833	34.8	21.8						
2835	18	7.5						
2836	16.8	10.8						
2840							6	
18 (2842)					7.2	3.0		
23 (2779)			9.6	3.1				
2784			12					
2785			7.2	1.7				
2786							7.2	2.2
2789			9.6	5.1				
2796			8.4	1.9				
2798	21.6							
2799							6	1
2803			9.6	4.6				
2804							7.2	1.7
20 (2805)					9.6	3.1		

No New Reproduction

Table VIII

PLOT 3A

Number	Ash		Sassafras	Cherry		Hickory
6				104	49.5	
7	33.5	6.0				
8	34	11				
10	24	3.5				
11	30	1				
13	18	2				
15	46	17				
16	93	46				
17				11	-22	
18	126	51.5				
19	84	34				
20	44	14				
21	27.5	8				
23				57	14	
24	33	-7.5				
25	89	51.5				
26	80	28.5				
27	75	24				
30	110	45				
31	122					
32	71	9				
33	46	5.5				
34	82	37				
35	57	28				
36	37	9.5				
37	59	22				
38	110	49.5				
39	40	5.5				
40	145	64				
41	66	31				
42	33	13.5				
43	42.5	24.5				
44	103	54				
45	171	64.5				
46	42	24				
48	50	23.5				
49	23	.5				
51	93					
53	96	22.5				
55	34	9				
56	19	3.5				
57	34	14				

Table VIII - Plot 3A (Cont.)

Number	Ash		Sassafras	Cherry		Hickory
58	23	7				
59	158	74.5				
61	36.5	.5				
62	44	5.5				
63	144	62				
64	60	23				
65	55	14				
66	30					
67	78	42				
69	102	54.5				
70	135	70.5				
78	122	23.5				
92 X	49	18.5				
71	126	55				
72	65	6				
73	44	5				
74	24	.5				
77				170	64.5	
78	116	17.5				
79	113	49.5				
80	65	18.5				
81	57	23				
82	42	14				
83	28	2				
84	40	9				
85	37	8.5				
86	37					
87	40	12				
89	157					
90	81	37				
92 X	34.5	4				
93	157	69.5				
94	98	58				
95	31	17				
96	104	54.5				
97	137	61				
101	73	27				
104	85	32				
106	29	6.5				
107	145	43				
109	36	13.5				
110	50	17				
111	130	59				
112	59	14				
114	110	41.5				

Table VIII - Plot 3A (Cont.)

Number	Ash		Sassafras	Cherry	Hickory
115	69	42			
117	120	67			
119	20	9			
122	42	15			
123	41	25.5			
125	102	45			
126	61.5	33			
127	71	37			
128	37	20.5			
2844	27.5	13.5			
2845	18.5	9			
2846	11	3.5			
2848	25.5	13			
2849	35	15			
2851	19	5.5			
2852	18	5			
2854	10	0.0			
2855	11				
2860	18	7			
2861	27.5	16.5			
2863	15	0.0			
2868	13				
2870	20	7			
2872	22	5.5			
2874	30	10			
2878	7	-6			
2879	57	13			
2880	36	13			
2881	24	8			
2882	23	13			
2883	26				
2884	24	11			
2886	31	12			
2889	11	4			
2890	9	4.5			
2891	27	5.5			
2892	32	10			
2893	79	33			
2896	65	11.5			
2897	30	20			
2898	59.5	31.5			
2900	55	35			
2901	23	13.5			
2902	74.5	60.5			
2904	34	21			

Table VIII - Plot 3A (Cont.)

Number	Ash		Sassafras	Cherry	Hickory
2907	14	5.5			
2909	28.5	14			
2807	12	4			
2808	10	0.0			
2812	17.5	8			
2815	15	7			
2820	17	5			
2821	17	8			
2825	13	5			
2829	12	0.0			
2831	24.5	15			
2832	12	3.5			
1770	16	10.0			
1772	27	15.0			
1773	28	20.5			
1774	26	16.5			
1777	16.5	8.0			
1778	21	12.5			
1779	16.5	6.5			
1782	16	7.0			
1785	82	43.5			

Table VIII - Plot 3A (Cont.)

NEW REPRODUCTION

Number	Ash	Sassafras	Cherry	Hickory
133	22			
229		11		
272	10.5			
274	13			
275	8.5			
277	15			
280	20			
282	9.5			
283	49			
287	17			
289	16			
290	15			
291	13			
293	19			
295	14			
296	11			
300	11			
301	10			
303	9			
304	10			
305	15			
306	7			
307	9			
308	12			
309	12			
310	16			
311	11			
312	18.5			
314	10			
315		9.5		
316	12			
317	13			
319	10			
320	6.5			
321	16.5			
324	10			
325	10			
326	8.5			
328	10			
329	17			
331	9			
332	8			
333	8			
334	9			
335	9			
336	20			
337	9			
338	10			

Table IX

PLOT 3B

Number	Ash		Sassafras		Cherry		Oak
3108			138				
3109			141.5	87			
3111	14.5	6.5					
3112	33.6						
3114	17	7.5					
3119	66	38					
3120	36	10					
3123	72	48					
3124	31	16					
3125	42	31.5					
3127	90	68					
25 (3129)			132	62			
3130	45.5	24.5					
3131	75.5	49.5					
3136	14.5	6.5					
3138	20.5	9					
3139	15.5	5					
3140	50.5	22.5					
3144	77	51.5					
3145	56.5	42.5					
3149	24	17					
3150					98.5	68	
3151	48						
3152	17	7.5					
3154	36.5	9.5					
3155	60	35					
3156	101	60					
3157	20.5	11.5					
3159	63.5	45.5					
3160	29	18.5					
3161	21.5	10					
3162	30	12					
3166	45.5	32					
3172	62.5						
3173	74.5	33					
3176	74.5	33.5					
3179	45.5	11.5					
3182	29	14					
3184	45.5	23.5					
3188	32.5	10.5					
3189	41	15					
3190	54	27.5					

Table IX - Plot 3B (Cont.)

Number	Ash		Sassafras		Cherry		Oak
3195	44.5	14					
3198	14.5	5					
3201	75.5	18					
3204	50.5	16					
3208					54	18	
3211	60	14					
3212	19	5					
3215	67	23.5					
3218	48	30					
3220	45.5	27.5					
3231	63.5	4.5					
3223	121	66					
44 (3224)	30	-2.5					
3225	71	46					
45 (3226)	65	39					
3227	33.5	.5					
3232	49	16.5					
3233	31	7					
3234	117.5	74					
3235	117.5	64					
3237	111.5	90.5					
3238			93.5	24.5			
3239	120	62					
3240	36	15.5					
3242	69.5	31					
3243	72	15					
3245			30	22.5			
3246	132	79					
3247	141.5						
3249	57.5	28					
3250	120	58.5					
3252	25	4.5					
3254	31	19					
3257	19	6					
3259	35	15					
3261	45.5	12.5					
3263	42	27.5					
3266	42	1.5					
3267	39.5	-2					
3269	36	-3					
3271	15	.5					
3275	26.5	10					
3276	68.5	37					
3282	83	38					
3286	25	4.5					

Table IX - Plot 3B (Cont.)

Number	Ash		Sassafras		Cherry		Oak	
3287	86.5	49.5						
3290	36	22						
3291	24	13.5						
3292	31	8						
3293	33.5							
3295	96	45.5						
3296	69.5	23.5						
3297	96	57						
3298					100.5	47.5		
3299	132	79.5						
3301	12	2.5						
3304			44.5	7				
3305	36	35						
3307	108	70						
3308			108	41				
3309	36	21						
2758	29	20.5						
2762	18	8.5						
2763	8.5	1.5						
2764							11	4.5
2769					24	15.5		
2770	7	0.0						
2772	12	4						
2776	19	9						
2777	13	4						
1450	8.4	4.4						
1456	22.8	16.3						
1459	15	5.0						
1462	15.5	8.5						
1463	25.2	21.2						
1467	42	25.5						
1479	36	24.5						
1480	19	13						

Table IX - Plot 3B (Cont.)

NEW REPRODUCTION

Number	Ash	Sassafras	Cherry	Oak
26	40.8			
27	21.6			
28	42			
30	40.8			
31	60			
32	19.2			
33	14.4			
34	61.2			
35	109.2			
36	27.6			
38			111.6	
39	45.6			
41	14.4			
42	46.8			
47	25.2			
49	21.6			
50	34.8			
51	46.8			

Table X

PLOT 8A

Number	Sassafras		Oak		Hickory	
411			32	21.5		
412					28	18.5
413			35	27		
420			23			
422					64	34
423					48	34
3054					53	41.5
3056	100					
3061	80	56				
3067	110	83				
3079	78					
2673	33					
2672	(Cherry)	62				
2674	50					
2678			11	2.5		
2683	17					
2685	13					
1433	69	48.5				
1434	114	73.5				
1435	115	90.5				
NEW REPRODUCTION						
89					28	

Table XI

PLOT 9A

Number	Cherry		Hickory		Maple		Elm		Oak	
167									154	22.6
168	58	31.5								
169	22	4.5								
173			108	87						
178	65									
179									51	39
182							38	1.5		
184							141	47		
186			45	31						
190			62	54						
192					153	131.5				
195					207	153.5				
197									84	53
198									96	59.5
199					211	119				
200							131	49.5		
201			69	40						
203									50	25.5
204			215	119.5						
205			76	33						
206	37	8								
207							159	63		
209									122	85.5
213							108	44		
214									96	64
217			49	40.5						
218									43	27.5
219									35	7
2601			77	61.5						
2602	25	16.5								
2606							27	0.0		
2611	6									
961									8	
1118			18							
1122	33									

Table XI - Plot 9A (Cont.)

NEW REPRODUCTION

Number	Cherry	Hickory	Maple	Elm	Oak
103	(Sassafras) 8				
105					12
106					8
107					41
112			33		
113	4				
220				22	
221		10			
222	16				
225					23
226	10				
227	36				
228					48
231				65	
236	7				
237	4				
238					62
239	77				
281		19			

Table XII

PLOT 9B

Number	Cherry		Sassafras		Maple		Oak		Hickory		Elm	
222							46	5.7				
224	18.5	3.2										
227	30	15.5										
229	47	23.5										
230	62	23										
232	40	4.5										
233	72	40.5										
234	22	.5										
239	83	48.5										
240	83	36										
244	84	37										
248	49	26.5										
249	43	12.5										
254	65	25.5										
255	26	11.5										
257	68											
258	113	59										
260	36	2.5										
261	48	11.5										
263	93	48.5										
264	96	51										
265	78	49.5										
267	44	10										
268	60	23.5										
269	53	22										
271	51	17										
272	42	8										
277	82	27										
280	18	-6.5										
282	39	12.5										
283	102	51.5										
284	66	14										
285	94	49										
288	67	38										
289	53	8										
290	41	14.5										
291	72	25										
292	35	4										
299					132	114.5						
302	40	11										
306	30	2.5										

Table XII - Plot 9B (Cont.)

Number	Cherry		Sassafras	Maple	Oak		Hickory		Elm
309	57	14							
312	35	6							
314	67	19							
315	32	12.5							
317	31	19							
320	8	-1							
322							63	54.5	
326	29								
327	55	27							
328	28	6							
329	63	17.5							
333	104	35.5							
335	20	0.0							
338	56	15							
339	80	28.5							
341	29	6							
344	23	1.5							
345	47	14.5							
346	18	-12							
347	52	17.5							
348	42	12.5							
349	9	-14.5							
351	56	19.5							
354	62	31							
356	78	38.5							
358	66								
360	21	2							
364	51.	11.5							
365	11.7								
366	39	12							
367	15	-9.5							
376	29	8							
377	31	12							
378	42	20.5							
2938	43	19							
2943	19	13.5							
2945							96		
2946	12	0.0							
2952	14	-.5							
2953					46	32			
2956	26	12.5							
2958					22	12.5			
2974	28	1.5							
2979					22	8.5			

Table XII - Plot 9B (Cont.)

Number	Cherry		Sassafras		Maple	Oak		Hickory	Elm
2982			76	34					
2996	72	26.5							
2997						13	-1.5		
3002	22	3.5							
3004	14	2.5							
3016	21	-.5							
2625	22	12.5							
2649	67	38							
1404	22	7.5							
1406	12	5.0							
1410	26	15.5							
1178	46	40.5							
1186	65	39.5							
1187	43	37.5							
1196	9	0.5							

NEW REPRODUCTION

Number	Cherry	Sassafras	Maple	Oak	Hickory	Elm
155	32					
156				7		
157	21					
158					27	
161	9					
162	7					
163	32					
164				9		
165				9		
167	9					
168	19					
169	19					
170	7					
171				7		
172	12					
173	22					
174	17					
175	16					
176	12					
177	3.5					
178	6					
179	84					
181	4					
182	12					
184	4					

Table XII - Plot 9B (Cont.)

NEW REPRODUCTION

Number	Cherry	Sassafras	Maple	Oak	Hickory	Elm
185	6					
186	5					
187	29					
188	6					
190	12					
191	5					
192	11					
193	7					
194	17					
195	4					
196	19					
198	13					
199	14					
200	9					
201	13					
202	3					
204	9					
205	11					
210	27					
211	9					
212	8					
213	7					
214	21					
215	14					
216	3					
217	5					
218	9					
219	17					
53			81			
54	41					
55				6		
60				6		
61	30					
64	14					
67	23					
69	34					
70	23					
71	8					
77	10					
78	7					
79	12					
81	4					
82	32					

Table XII - Plot 9B (Cont.)

NEW REPRODUCTION

Number	Cherry	Sassafras	Maple	Oak	Hickory	Elm
83	7					
84	25					
85	11					
91	36					
100	31					
101	8					
102	45					
110	8					
116						18
118				10		
120	14					
121	9					
122	11					
123	14					
126	15					
127	7					
128				7.5		
129	10					
130				9		
131				9		
134				10		
136	31					
139				9.5		
141				8		
143				7		
144				9		
145				9		
146	7					
147	18					
148	14					
149	13					
150				8		
151	6					
152					5	
153	7					
154	72					

Table XIII

PLOT 9C

Number	Maple		Oak		Cherry		Hickory	
381	23	18.5						
382					12	5.5		
385	8							
388	67	39						
389	42	34						
394	102	73						
397	87	53						
399					12	2.5		
402					22	7.5		
405					48			
406	65	43						
408							12	
410			14	7.5				
3023			13	5.5				
3024			14	7				
3029					18	9.5		
3032							14	6.5
3034					30	13.5		
3036					25	8		
3037	95	56.5						
3038			14	5.5				
3042	32	25						
3044			26	14				
3045					40	20.5		
2652			12	6.5				
2655			8	3				
2658			29	22				
2659	47	36						
2660			22	12				
2663			12	7				
1183	14							
1417					20	2.5		
1420			21	15.5				
1422							16	10.0
1424					30	16.0		
1427			13	5.5				
1428			11	5.5				
2887			6					
2894			21					
2971	36							
2991			6					

Table XIII - Plot 90 (Cont.)

NEW REPRODUCTION

Number	Maple	Oak	Cherry	Hickory
9			25	
58		12		
63		17		
74				11
76				11
87		7		
88		9		
94		15		
114		20		
226		14		
230		12		
234		12		
259		12		
334		14		
343	16			
373				21

Table XIV

PLOT 10A

Number	Cherry		Sassafras		Ash		Oak	Maple	
129	27	14.5							
131	29	18.5							
132	20	8.5							
134	58	33.5							
135					36	21			
136	52	35							
137	70	58							
138	13	3							
144	88	50							
147	80	45							
148	47	26							
149	9								
150	32	13							
151	32	13							
152	51	26.5							
154	30	14							
155	34	20.5							
156	34	20.5							
158	40	23							
159	33	10.5							
162	42	22.2							
164	58	28							
166	124	78.5							
2719			14	.5					
1484			15	7.0					
1486	19	14.0							
1491								13	8.0

Table XV

PLOT 10B

Number	Cherry		Oak	Sassafras	Hickory
425	18	11.5			
432	26	11			
435	28	20			
439	18				
440	17	9.5			
442	12	8			
446	21	9.5			
447	20	9			
455	14	7			
456	17	7.5			
462	24	13			
463	25	11.5			
465	26	19.5			
467	26	10.5			
473	12	6			
475	37	16			
478	42	33			
482	22	8			
484	24				
487	27	13			
496	29	13			
501	40	22			
509	41	20			
511	49	34			
515	35	18			
518	24	7			
521	34	17			
522	22	8			
523	44	26.5			
530	22	9.5			
533	32	17.5			
538	26	15.5			
539	29	17.5			
545	48	40.5			
549	28	6.5			
552	16	4			
557	28	14			
560	18	-1			
561	26	13.5			
564	24	10.5			
573	14	5			
577	49	39			

Table XV - Plot 10B (Cont.)

Number	Cherry		Oak	Sassafras		Hickory
578	16	.5				
579	36	20.5				
583	27	10				
586	31	11				
589	23	11				
592	24	0.0				
593	58	25				
594	99	45.5				
600				87	31	
601	18	2				
602	14	9				
605	18	13.5				
610	30	15				
615	29					
616	21	6				
620	49	43				
621	20	4				
623	50	38				
624	42	31				
625	20	12				
632	43	20				
633	27	13.5				
635	26	12				
2687	12	2				
2699	12	-5.5				
2701	10	4.5				
2705	28	23				
3075	39	31.5				
3077	18					
3082	14	6.5				
3093	18					
3094	26	8.5				
3095	24	10				
3096				96	42	
3101				103	47	
3105	24	11				
2465	42	35.5				
2475	14	8				
2476	13	7.5				
2477	24	13.5				
2496	18	13				
2497	12	5.5				
1746	19	8				
1747	13	7.5				
1748	24	7				
1750	29	20.5				
1751	18	14				
1764	18	11.5				
1766	24	18				

Table XV - Plot 10B (Cont.)

NEW REPRODUCTION

Number	Cherry	Oak	Sassafras	Hickory
115	4			
117	4.5			
119	4			
126	5			
129	2.5			
131	4			
133	5			
139	6			
144	4			
147	4			
148	5			
154	6			
159	4			
163	4			
165	14			
171	6			
179	12			
181	32			
185	5			
189	15			
193	5			
195	14			
205	4			
208	7			
218	36			
220	18			
226	5			
227	27			
229	39			
235	7			
236	14			
241	5			
245	9			
247	6			
249	5			
251	9			
255	5			
258	4			
264	4			
266	7			
274	5			
275	11			
	48			

Table XV - Plot 10B (Cont.)

NEW REPRODUCTION

Number	Cherry	Oak	Sassafras	Hickory
277	3			
281	6			
286	7			
288	5			
290	10			
292	10			
294	5			
300	9			
302	3			
305	4			
307	3			
312	14			
314	5			
319	5			
327	6			
330	5			
332	18			
334	4			
347	10			
351	4			
353	4			
358	4			
367	37			
374	5			
376	14			
378	12			
384	12			
396	12			

Table XVI

PLOT 10C

Number	Ash		Cherry		Hickory		June Berry		Sassa-fras	
3311			16.7	-.8						
3312	84	62.5								
3313	73.2	46.7								
3314			19.2	17.7						
3315	96	37.5								
3316	90	59								
3317	69.6	47.1								
3318	75.6	61.6								
3320	55.2	41.7								
3321	73.2	50.7								
3322	168	115.5								
3324	52.8	33.3								
3325	126	81.5								
3326	114	68								
2 (3327)	81.6	39.6								
3328	21.6	3.1								
3329	72	27								
3330	15.6	-.4								
3 (3331)	160	101								
4 (3332)	118	110.5								
3333							18	-5		
3334			15.6	8.1						
3336			156	61						
3338	148.8	80.8								
3339	60	18								
3340	31.2	17.2								
3341	70.8	28.8								
3342	72	38								
3343	144	82								
3345	42	18.6								
3346	48	16.5								
3347	63.5	38								
3348	163	96								
3349	93.5	42.5								
3350	165.5	91								
3351	120	62								
3352	168	97.5								
3355	247	131								
3356	144	62.5								
3357	105.5	68								
3360	69.5	25								

Table XVI - Plot 10C (Cont.)

Number	Ash		Cherry		Hickory	June Berry	Sassa-fras
3361	195.5	100					
3362	75.5	29					
3363	81.5	40					
3364	55	30.5					
3365	219.5	139					
3366			31	3			
3367	26.5	4.5					
3368	186	98					
3369	51.5	33.5					
3370	50.5	7.5					
3371	216	101.5					
3372	63.5	12.5					
3373	48	4.5					
3374	45	2.5					
12 (3375)	86.5	-11.1					
3377	90	12.5					
3378	183.5	99.5					
3379	108	60.5					
3380	195.5	88					
3381	93.5	39.5					
7 (3382)	186	98.4					
3383	162	81.5					
3384	87.5	45.5					
3385	28.8	9.3					
3386	114	56					
3387	81.5	35.5					
3389			21.6	-1.9			
3390	42.0	6.5					
3391	74.5	21.5					
3392	43	14.5					
3393	98.5	93.5					
6 (3395)			144	135.5			
3396			231.5	127			
3397			90	72.5			
3398	192	128.5					
3400	156	91.5					
3401	216	124.5					
15 (3402)			31	6.5			
3403	162	85					
3404	37.5	12.5					
3405	240	143.5					
3406	24	2					
17 (3408)	228	147.5					

Table XVI - Plot 10C (Cont.)

Number	Ash		Cherry	Hickory	June Berry	Sassafras
3410	96	34.5				
3411	165.5	57.5				
3414	117.5	38.5				
3417	85	9				
3418	48	2				
3420	91	-5				
3421	40	11.5				
3423	36	10.5				

Table XVI - Plot 10C (Cont.)

NEW REPRODUCTION

Number	Cherry	Hickory	Sassafras	Ash	Oak	Maple
6	40					
191	29					
240	15					
241			17			
242	41					
244		6				
245			10			
246	4					
247		5				
249			12			
250	14.5					
251	22					
252	6					
253			16			
254			17			
255			6			
256			4			
257						6
258					14	
259			4			
260			15			
262		4				
263	51					
264			3			

Table XVI - Plot 10C (Cont.)

NEW REPRODUCTION

Number	Cherry	Hickory	Sassafras	Ash	Oak	Maple
265		4				
266	21					
267						10
269			11			
273		17				
276	20					
278	25.5					
279			12			
285	14					
298		3				
299			12			

EXPLANATION OF TABLES XVII, XVIII AND XIX

Column 1 (Number of trees alive--Early date)

The number recorded is the total number of living trees found on the plot on the date mentioned. This includes any reproduction that has come in since the last previous data were taken.

Column 2 (Number of trees alive--Later date)

The number recorded is the total number of living trees found on the plot on the date mentioned, including reproduction.

Column 3 (Number of trees dead--Later date)

The number of trees which are assumed to have died between the last previous examination and the examination on the date mentioned is recorded here.

Column 4 (Percent Mortality--Early date to Later date)

The percentage recorded here indicates what percentage of the trees which were alive at the early date have died between that time and the later date. The percentage of each species is taken separately.

Column 5 (Number of new trees--Since Early date)

This number represents the number of trees present at the later date which have apparently come in new since the early date mentioned.

Column 6 (Percent Reproduction--Early date to Later date)

The number recorded here indicates the percentage of all the trees now alive on the plot which are new trees.

Table XVII

COMPARISON OF 1938-1939 DATA

	No. Trees Alive (1938)	No. Trees Alive (1939)	No. Trees Dead (1939)	Percent Mortality (1938-39)	No. New Trees since 1938	Percent Reproduction (1938-39)
<u>Plot 2A</u>						
Cherry	6	8	0	0.0	2	25
Oak	6	9	2	33.3	5	55.6
Hickory	0	5	0	0.0	5	100
Sassafras	5	7	0	0.0	1	100
Ash	0	1	0	0.0	1	100
<u>Plot 3A</u>						
Ash	172	177	12	7.0	17	9.6
Sassafras	7	7	2	28.6	2	28.6
Cherry	5	6	0	0.0	1	16.7
Hickory	2	3	0	0.0	1	33.3
<u>Plot 3B</u>						
Ash	173	172	19	11	18	10.5
Sassafras	16	15	2	31.3	1	6.7
Cherry	7	7	1	14.3	1	14.3
Oak	0	1	0	0.0	1	100.0
<u>Plot 8A</u>						
Sassafras	18	19	3	16.7	4	21.1
Hickory	10	10	0	0.0	0	0.0
Oak	5	7	0	0.0	2	28.6

Table XVII (Cont.)

COMPARISON OF 1938-39 DATA - Page 2

	No. Trees Alive (1938)	No. Trees Alive (1939)	No. Trees Dead (1939)	Percent Mortality (1938-39)	No. New Trees Since 1938	Percent Reproduction (1938-39)
Plot 9A						
Cherry	14	13	4	28.6	3	23.1
Oak	17	14	3	17.6	0	0.0
Elm	7	10	0	0.0	3	33.3
Maple	9	10	0	0.0	1	10
Hickory	7	10	1	14.3	4	40
Plot 9B						
Cherry	215	211	32	14.8	25	11.8
Oak	6	6	0	0.0	0	0.0
Sassafras	3	12	0	0.0	9	75
Maple	2	1	1	50	0	0.0
Hickory	0	1	0	0.0	1	100
Elm	1	2	0	0.0	1	50
Plot 9C						
Cherry	23	20	5	21.8	2	10
Oak	15	21	4	26.7	10	47.6
Maple	11	12	2	18.1	3	25
Hickory	2	3	0	0.0	1	33.3

Table XVII (Cont.)

COMPARISON OF 1938-39 DATA - Page 3

	No. Trees Alive (1938)	No. Trees Alive (1939)	No. Trees Dead (1939)	Percent Mortality (1938-39)	No. New Trees Since 1938	Percent Re-production (1938-39)
Plot 10A						
Sassafras	13	16	2	15.4	5	31.3
Cherry	34	34	1	2.9	1	2.9
Hickory	2	0	2	100	0	0.0
Maple	5	0	5	100	0	0.0
Oak	0	5	0	0.0	5	100
Ash	0	4	0	0.0	4	100
Plot 10B						
Cherry	172	189	6	3.5	23	12.2
Hickory	1	1	0	0.0	0	0.0
Sassafras	19	24	0	0.0	5	20.8
Oak	5	6	2	40	3	50
Plot 10C						
Ash	93	96	1	1.1	4	4.6
Cherry	15	29	0	0.0	14	48.3
Sassafras	2	2	0	0.0	0	0.0
Hickory	0	2	0	0.0	2	100
Beech	0	2	0	0.0	2	100

Table XVII (Cont.)

COMPARISON OF 1938-39 DATA - Page 4

	No. Trees Alive (1938)	No. Trees Alive (1939)	No. Trees Dead (1939)	Percent Mortality (1938-39)	No. New Trees Since 1938	Percent Re-production (1938-39)
Totals:						
Cherry	491	517	46	9.5	72	13.5
Oak	54	69	11	20.4	26	37.7
Hickory	24	35	3	12.5	14	40
Sassafras	85	102	9	10.6	28	27.5
Ash	436	450	30	6.9	44	9.8
Elm	8	12	0	0.0	4	33.3
Maple	27	23	8	29.5	4	17.4
Beech	0	2	0	0.0	2	100

Table XVIII

COMPARISON OF 1939-1940 DATA

	No. Trees Alive (1939)	No. Trees Alive (1940)	No. Trees Dead (1940)	Percent Mortality (1939-40)	No. New Trees Since 1939	Percent Re-production (1939-40)
Plot 2A						
Cherry	8	5	3	37.5	0	0.0
Oak	9	6	3	33.3	0	0.0
Hickory	5	5	0	0.0	0	0.0
Sassafras	7	6	1	14.3	0	0.0
Ash	1	1	0	0.0	0	0.0
Plot 3A						
Ash	177	204	1	.5	28	13.7
Hickory	3	1	2	66.7	0	0.0
Sassafras	7	4	4	57.1	1	25
Cherry	6	6	0	0.0	0	0.0
Plot 3B						
Ash	172	191	8	4.9	27	14.1
Sassafras	15	12	5	33.3	2	16.7
Oak	1	2	0	0.0	1	50
Hickory	7	8	1	14.3	2	25
Plot 8A						
Sassafras	19	15	8	42.1	4	26.7
Oak	7	5	2	28.6	0	0.0
Hickory	10	5	5	50	0	0.0

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Table XVIII - Comparison of 1939-1940 Data (Cont.)

	No. Trees Alive (1939)	No. Trees Alive (1940)	No. Trees Dead (1940)	Percent Mortality (1939-40)	No. New Trees Since1939	Percent Reproduction (1939-40)
Plot 9A						
Cherry	13	12	3	23.1	2	16.7
Oak	14	14	2	14.3	2	14.3
Elm	10	10	3	30	3	30
Maple	10	4	6	60	0	0.0
Hickory	10	10	1	10	1	10
Plot 9B						
Cherry	211	260	29	13.3	78	30
Elm	2	3	0	0.0	1	33.3
Oak	6	7	1	16.7	2	28.6
Sassafras	12	8	5	41.7	1	12.5
Maple	1	0	1	100	0	0.0
Hickory	1	0	1	100	0	0.0
Plot 9C						
Maple	12	12	2	16.7	2	16.7
Oak	21	19	4	19	2	12.5
Cherry	20	22	5	20	7	31.8
Hickory	3	4	0	0.0	1	25
Plot 10A						
Sassafras	16	14	10	62.5	8	57.2
Oak	5	3	3	60	1	33.3
Cherry	34	31	4	11.8	1	3.2
Ash	4	2	2	50	0	0.0

Table XVIII - Comparison of 1939-1940 Data (Cont.)

	No. Trees Alive (1939)	No. Trees Alive (1940)	No. Trees Dead (1940)	Percent Mortality (1939-40)	No. New Trees Since 1939	Percent Reproduction (1939-40)
Plot 10B						
Cherry	189	233	21	11.1	65	27.5
Hickory	1	1	0	0.0	0	0.0
Sassafras	24	14	10	41.7	0	0.0
Oak	6	5	1	16.7	0	0.0
Plot 10C						
Ash	96	93	5	5.2	2	2.2
Cherry	29	26	7	24.1	4	15.3
Hickory	2	1	2	100	1	100
Beech	2	0	2	100	0	0.0
Sassafras	2	0	2	100	0	0.0
Totals:						
Cherry	517	603	73	14.1	159	26.4
Oak	69	64	13	18.8	8	12.5
Hickory	35	28	10	28.3	3	10.7
Sassafras	102	77	41	40	16	28
Ash	450	490	17	3.7	57	11.6
Elm	12	13	3	25	4	30.18
Maple	23	19	6	26	2	10.5

Table XIX

COMPARISON OF 1940-1946 DATA

	No. Trees Alive (1940)	No. Trees Alive (1946)	No. Trees Dead (1946)	Percent Mortality (1940-46)	No. New Trees 1940 (Since)	Percent Reproduction (1940-46)
Plot 2A						
Cherry	5	6	0	0.0	1	16.7
Oak	6	5	0	0.0	0	0.0
Hickory	5	6	0	0:0	1	16.7
Sassafras	6	6	0	9.0	0	0.0
Plot 3A						
Ash	204	295	55	27	46	23.6
Hickory	1	0	1	100	0	0.0
Sassafras	4	2	4	100	2	100
Cherry	6	4	2	33.3	0	0.0
Plot 3B						
Ash	191	125	83	43.5	17	13.6
Sassafras	12	7	5	41.6	0	0.0
Oak	2	1	1	50	0	0.0
Cherry	8	5	4	50	1	20
Hickory	1	0	1	100	0	0.0
Plot 8A						
Sassafras	15	11	8	53.3	0	0.0
Oak	5	4	2	40	0	0.0
Hickory	5	5	0	0.0	0	0.0

Table XIX - Comparison of 1940 - 1946 Data (Cont.)

	No. Trees Alive (1940)	No. Trees Alive (1946)	No. Trees Dead (1946)	Percent Mortality (1940-46)	No. New Trees Since 1940	Percent Reproduction (1940-46)
Plot 9A						
Cherry	12	14	9	75	7	50
Oak	14	15	5	35.7	6	40
Elm	10	8	4	40	2	26
Maple	4	4	1	25	1	25
Hickory	10	12	1	10	3	25
Sassafras	0	1	0	0.0	1	100
Plot 9B						
Cherry	260	175	168	64.7	83	42.5
Elm	3	1	3	100	1	100
Dogwood	1	0	1	100	0	0.0
Oak	7	22	2	28.6	17	77.2
Sassafras	8	1	7	96.5	0	0.0
Hickory	0	3	0	0.0	3	100
Maple	0	2	0	0.0	2	100
Plot 9C						
Maple	12	13	1	8.4	2	15.8
Oak	19	27	6	31.6	14	51.9
Cherry	22	11	12	54.5	1	9.1
Hickory	4	6	1	25	3	50
Sassafras	4	0	4	100	0	0.0
Plot 10A						
Sassafras	14	2	12	85.8	0	0.0
Maple	3	1	2	66.7	0	0.0
Oak	3	0	3	100	0	0.0
Cherry	31	23	8	25.8	0	0.0
Ash	2	1	1	50	0	0.0

Table XIX - Comparison of 1940 - 1946 Data (Cont.)

	No. Trees Alive (1940)	No. Trees Alive (1946)	No. Trees Dead (1946)	Percent Mortality (1940-46)	No. New Trees Since 1940	Percent Reproduction (1940-46)
Plot 10B						
Cherry	233	148	145	62.3	70	44.3
Hickory	1	0	1	100	0	0.0
Sassafras	14	3	11	78.5	0	0.0
Oak	5	0	5	100	0	0.0
Plot 10C						
Ash	93	80	13	14	0	0.0
Cherry	26	23	16	61.5	13	56.5
Hickory	1	6	1	100	6	100
Oak	0	1	0	0.0	1	100
Maple	0	1	0	0.0	1	100
Sassafras	0	13	0	0.0	13	100
Totals:						
Cherry	603	419	360	59.6	176	42.1
Oak	64	75	27	42.2	38	50.7
Hickory	28	38	6	21.4	16	42.1
Sassafras	77	46	47	61	16	34.8
Ash	490	401	218	44.5	129	32.1
Elm	13	9	7	53.7	3	33.3
Maple	19	22	4	21.1	7	31.8
Dogwood	1	0	1	100	0	0.0

CONCLUSIONS AND SUMMARY

If an intensive study of ecologic factors were performed including things other than just the numbers and sizes of the different species of the plots, then definite statements as to the reasons for the presence or absence of reproduction could be given. As it is, only suggestions can be given that will really have little basis. However, this will be attempted.

Oak reproduction is mighty scant in the woods, in spite of the high proportion of black, red, and white oaks on the area. These are not ecologic climax types as they are relatively intolerant, especially since their seedlings cannot stand much shading. This is especially true of white oak. However, Cheyney[6] states that there are differences in the tolerance of various types of oaks. This would imply that the scarcity of oak reproduction on the various plots must be due to other causes, because, as has been previously noted, no section of Stinchfield Woods has even a relatively heavy crown-cover.

Probably the most prevalent reasons for poor oak reproduction on the Stinchfield area are the abundance of rodents such as squirrels, injury from insects, and the poor leaf litter found in most plots which causes a simulated drought condition for the acorns. This is substantiated by studies made at Yale University[14] in regard to the poor reproduction obtained from oak seed. They found that approximately twenty-five percent of the acorns are destroyed by insects, and about thirty percent did not germinate because of a simulated drought condition. In addition it was found, particularly when the supply of seeds was limited, that from ninety to one hundred percent of the acorns were destroyed by rodents.

Experiments[22] have shown that favorable moisture conditions are a very potent factor in the successful germination and survival of oak seedlings, and they require quite a good deal of leaf litter in order to retain the moisture needed for germination. In forests which have a heavy leaf litter there almost always is a good catch in oak reproduction[15].

The plots in Stinchfield Woods which were set up for the specific purpose of studying oak reproduction were plots numbered 2A, 9A, 9B and 9C. In spite of the relatively heavy crown cover of oak trees, very little oak reproduction is shown (See Tables XVII to XIX inclusive). In fact, very little of any reproduction with the exception of wild cherry on Plot 9B has caught. On this plot the young cherry trees have varied from as many as 260 trees to a low of 175, and very few have succeeded in attaining any great height. As was noticed, many of the wild cherries on almost all of the plots in Stinchfield Woods attained from two to three feet of growth, died down, and coppice formed from the base, thus indicating the relatively intolerant cherry is unable to withstand the shading after it reaches a certain height. On

Plot 9B, another factor was noticed, that being the southern edge which was at the bottom of the pot-hole (the north edge being on a slight grade) had the seedlings flooded out but re-seeding took place in the silt-loam.

Plot 8A was set up to study any reproduction that might come in on the very heavily matted grass area that was caused by a clear-cutting operation. The plot is approximately 200 feet from the edge of the woods, and so only the lighter seeds would be able to reach that area. However, about one-half of the few seedlings that were on the area are heavy-seeders (oak and hickory). This would indicate that either seeds had been deposited in the litter of the old stand before it was cut and still retained their viability, or that rodents had brought the seed from the neighboring woods and hidden them in the plot.

Probably the most interesting evidences in conjunction with this work are those of Plots 3A, 3B and 10C. The latter two plots were set up for the specific purpose of studying the white ash reproduction from three seed trees. These two plots, as was previously noted, were set up in 1937, while Plot 3A, which also was instituted to study ash reproduction, was one of the original plots. It will be noted from observing the data sheets that, with the exception of wild cherry, the white ash is reproducing much better than any other species. However, if studies are made of the Tables VII to XVI it will be seen, as stated previously, that while very few wild cherries reach much more than the seedling stage, the white ash for the most part develop into trees. The advantage of ash trees is that they produce many seeds freely about every other year[18], and exceptionally heavy crops occur at intervals of from three to five years. In addition, the seeds range from 6200 per pound[19] to 10,000 per pound[18]. This enables the seed to be carried for long distances and when the seed-bed and moisture requirements are met, excellent catches are obtained. It has been mentioned previously that there are reasonable layers of leaf mold (about two inches deep) on these plots, and this provides excellent germination conditions for the seeds. Stinchfield Woods provides excellent distribution qualities as it almost universally has light stand conditions (stocking). This provides an excellent means for the wind to carry the seeds great distances.

The prevailing wind in this area is north by west, and so the majority of the reproduction from the seed trees will be found on the east side of the mother tree. However, Plot 3A, which is located in the sheltered area at the bottom of the pot-hole, and is only about one chain to the west of a large (24" D.B.H.) seed tree, has obtained a great deal of reproduction.

Plot 10B was set up to determine the amount of wild cherry on the area which would reach maturity. Black cherry on this plot has a very high mortality. One reason for this has already been mentioned, that being the intolerance of the tree, and its consequent inability to withstand the competition of herbaceous plants and ground cover. In addition to this, a rather high mortality is undoubtedly due to the poor moisture-holding capacity of the glacial soil, especially in the gravelly sections.

Much better reproduction has been established on the low, moist sites and on the protected areas, than on the higher, drier ridges.

As to the totals for all the stands, there has been a definite mortality increase in the trees of almost all the species, ever since the experiment was first set-up. The only exception to this is the case of the hickory, and this has decreased only slightly. This can only mean that some of the young trees have attained enough height to be able to shade out other young trees.

This is especially evident in the plots numbering 3A and 3B for the ash; and plots numbering 10B, and 9B for the black cherry. Nevertheless, on these same plots and in just about the same percentages, there has been an increase in the number of very small seedlings appearing on the open areas of the plot. The author thought at first that it was only old trees that had lost their tags, until a check had been made of the metal tags taken from the dead trees, these showing that this was not the case.

Sassafras is beginning to show the effects of being shaded out by the more tolerant species, by the increase in the number of larger trees of this species which have died since the last census was taken.

The white ash trees have shown a remarkable growth, and in the next few years there should be quite an increase in the numbers of the smaller trees which succumb to the dense shade and root competition of the larger trees. Even now this is quite evident. The ash are growing quite straight and are almost disease-free, in the faster growing trees. However, the suppressed trees are having their existence shortened by the oyster-shell scale (Lepidosaphes ulmi). The infestation of this insect has not reached any significant proportions, but just seems to be hastening the death of those trees which are already showing signs of deterioration.

It is very difficult to reach any definite conclusions on such a short time experiment, and it will be very interesting to see the developments in the future.

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