# THE GROWTH OF SHELTERBELTS
# IN IOWA

BY

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# THE GROWTH OF SHELTERBELTS IN IOWA

## INTRODUCTION

### General

Prior to their westward migration during the middle of the Nineteenth Century, the early settlers established their homes in the timbered areas along the streams and rivers, primarily for the wood, fuel, and protection afforded by these natural forests. The discovery of gold in 1848 brought about a westward migration of the people for the next few decades. Many who started for California were attracted by the agricultural possibilities offered on the fertile plains of the Central States. The adoption of the Homestead Act in 1862 increased the possibilities for successful farming to such a great extent that many families moved to the wind-swept prairies of Iowa and the adjoining states.

The need of shelter from the cold northwest winds in the winter and the dry desiccating south winds in the summer made the farmers realize more and more the great necessity of tree planting in order to protect their homes from these destructive and unpleasant winds. To protect their farmsteads, many farmers planted fast growing, short lived, and inferior species. Consequently, one may observe these old dying, decaying, and valueless shelters on the majority of Iowa farms. McCutchen (21) found that 86.6 per cent of the farms in Story County, Iowa were without adequate protection, primarily due to the fact that there is such a large percentage of old and decadent trees of inferior species.

Many farmers are beginning to realize the value of a good shelterbelt to the farm, not only as a windbreak, but as a means of producing their own farm timbers, posts and fuel. To purchase imported materials of this type entails quite an unnecessary expense for transportation, if it is possible for the farmer to produce them on his farm. Thus, though the primary consideration for the shelterbelt is to provide maximum shelter, the ability of a species to produce fuel, posts or some other usable material demands no small amount of consideration in choosing which species to plant in a shelterbelt.

To choose a species which will furnish both maximum protection from the wind and maximum production in usable wood is no easy task, as each species has its own advantages as well as disadvantages. One species may make an ideal windbreak, but be of little value for posts or fuel, and conversely, another species may produce good posts but be of little value as a shelter tree or as a fuel wood.

In this thesis two species have been studied. It is hoped by the author that this thesis will be of some value for determining which of these two species is the better for shelterbelt plantings. The species selected for this study are Norway spruce (*Picea excelsa* Link) and hardy catalpa (*Catalpa speciosa* Warder). These species were selected for this study because of the extent to which they have been planted and to get a comparison of a coniferous and a deciduous species.

## Objectives

This thesis is chiefly a discussion of the growth of catalpa and Norway spruce shelterbelts in Iowa. Because the accuracy of the results of any experiment depends entirely upon the precision with which the data have been collected, a limited space has been assigned to a discussion of the methods used in collecting the data. Also, a field study is essentially the first step in the actual examination of a problem of this type.

Because the height growth of the trees in a shelterbelt has a direct bearing on the age at which a windbreak becomes an effective shelter, the primary objective of this thesis is to study those factors which tend to affect the height growth. The factors which appear to have an effect on the height growth are treated separately, and graphs are drawn for each factor for both catalpa and Norway spruce. These factors include the following:

1. Soil and growth in height.
2. The size of the shelterbelt (number of rows) and height growth.
3. The variation in height growth in the different rows.

Because farmers who contemplate planting shelterbelts are beginning to realize more and more the possibility of supplying their own needs for timbers, posts, and fuel, the secondary objective of this thesis is the presentation of yield tables for the two species studied. These tables were prepared in order that the farmer may have some idea as to the amount of wood products obtainable from his land. In addition to a brief discussion of the construction and use of the yield tables, the graphical illustrations used in constructing the yield tables are presented. Because the collected data contained the necessary figures, the apparent effect of spacing on basal area and height growth was sought as a third objective.

# LITERATURE REVIEW

## Growth on Shelterbelts

Because the growth study of shelterbelts is the primary objective of this thesis, it may be of some value to review some of the literature pertaining to growth on other plantations. It must be noted that there is a limited amount of literature available as to growth of Norway spruce in America since it is an exotic species. On the other hand, a wealth of material is available regarding growth of catalpa plantations.

### Height and diameter

Scott (30) reports that catalpa in a plantation in Webster County, Iowa is exceptionally good. He says, "the stems are very straight and clear of limbs for a height of 20 to 25 feet." Scott published the following figures for five catalpa plantations in Iowa:

| County | Plot No. | Age | Av. ht. dom. trees | Aver. d.b.h. |
|---|---|---|---|---|
| Webster | 1 | 28 | about 40' | 6" |
| Mahaska | 2 | 28 | about 40' | 7" |
| Mahaska | 3 | 28 | about 40' | 7" |
| Iowa | 4 | 25 | about 25' | -- |
| Iowa | 5 | 24 | about 45-50' | 7" |

Hall (14) has studied the growth of catalpa quite extensively on four large plantations in Kansas. The Munger plantation which is located in Greenwood County had an average height of 20.4 feet and an average diameter of 3.6 inches at 13 years of age. On the Farlington Forest and the Hunnewell Plantation, both of which are located near Farlington, Kansas, height growth was measured at three year intervals and was as follows:

| Age | Height in feet | |
|---|---|---|
| | Farlington | Hunnewell |
| 3 | 8.0 | 10.0 |
| 6 | 15.5 | 16.5 |
| 9 | 21.0 | 22.0 |
| 12 | 26.0 | 25.5 |
| 15 | 29.7 | 27.0 |
| 18 | 33.0 | 29.5 |
| 21 | 34.5 | ---- |

Belyea (4) in a study of the height growth of six species in a plantation in 1908 to 1910 found the following height figures for Norway spruce. The spacing of the trees was 6 x 6 feet and they were measured each year in April.

| Age | Ht. in ft. | Age | Ht. in Ft. | Age | Ht. in ft. |
|---|---|---|---|---|---|
| 1 | 0.8 | 6 | 10.0 | 11 | 19.3 |
| 2 | 1.0 | 7 | 18.2 | 12 | 20.6 |
| 3 | 2.5 | 8 | 15.0 | 13 | 21.7 |
| 4 | 4.6 | 9 | 16.6 | 14 | 22.7 |
| 5 | 6.8 | 10 | 18.0 | 15 | 23.5 |

Schlich (270), from abstracts of British and Continental European yield tables gave the following height growth figures for Norway spruce:

| Age | Height in feet | | |
|---|---|---|---|
| | Quality I | Quality III | Quality V |
| 10 | 12 | 9 | --- |
| 20 | 31 | 22 | --- |
| 30 | 51 | 36.5 | --- |
| 40 | 66 | 49 | 31 |
| 50 | 80 | 60 | 40 |
| 60 | 91 | 68 | 47.5 |
| 70 | 100 | 75 | 53 |

That variation in soil has a direct bearing on the effect of tree growth is generally conceded by several investigators. Scott (29, 30) says that catalpa would grow neither on the light, loose soil located on one of the plantations that he studied, nor would it make satisfactory growth in gumbo and poorly drained soils.

Hall (14) states, "where the soil is deep and rich the trees (catalpa) have formed straight long stems with few side branches. On poor soils they are low, crooked and much branched. In the Farlington Forest returns on the best soils are almost five times that on the poorest." In one 13 year old plantation growing on light sandy soil, he found that the average d.b.h. was 2.2 inches and the average height was 13 feet, while on deep rich soil the average d.b.h. was 3.6 inches and the average height was 20 feet.

That there is a very noticeable difference in height growth in the different rows is shown by a series of measurements taken by Hall (14) on catalpa plantations in Kansas. He says, "the effect on unequal exposure to the wind is evidenced by the difference in height growth on the edge of the plantations where exposure is the greatest, and on the interior where it is the least. The effect of exposure is noticeable for 100 feet into the plantation." On the Munger Plantation which is fairly representative of the conditions that he found, Hall says, "The first row on the south showed an average height of but nine feet, the tenth row 14 feet, and the twentieth 21 feet."

The effect of the size of the plantation on the height growth of the trees is very interesting. Bates (2) in his studies with cottonwood in both groves and shelterbelts found the following differences when the quality of the situation was the same:

| Age | Height in feet | |
|---|---|---|
| | Grove | Row or narrow belt |
| 5 | 22.0 | 15.0 |
| 10 | 39.0 | 25.6 |
| 15 | 52.4 | 35.7 |
| 20 | 62.0 | 45.7 |
| 25 | 69.3 | 55.8 |
| 30 | 75.5 | 65.9 |
| 35 | 81.1 | 76.0 |
| 40 | 86.2 | 86.1 |

Opinions as to the effect of spacing on growth in shelterbelts and forest plantations are quite variable. Scott (30) in his studies with catalpa says, "comparing the plantings originally 4x4 feet and 4x8 feet, the thinner plantings have given the best results. Ten rows, 4x4 feet, 117 feet long, contained 251 trees, having 85 good posts. Ten rows, 8x4 feet, 117 feet long grew 228 trees, having 280 good posts. The trees in the wider rows have greater average height and diameter." Schiffel (26) says that increased growing space in spruce is conducive to better height and diameter growth in young stands. He further states, "stands of smaller number of trees, other factors being the same, will have taller heights, larger average diameter, but smaller total basal area and volume." He recommends a spacing of 1.75 to 2 meters in planting spruce. A more recent study as to the effect of spacing on growth is being carried on near Mandan, North Dakota. The trees were planted in 1918 and Wilson (35) has given a few results which have been thus far obtained for green ash; they are:

| Spacing | Av. ht. in ft. 1922 | Av. ht. in ft. 1928 | Av. diam. in in. 1922 | Av. diam. in in. 1928 |
|---|---|---|---|---|
| 4x4 | 5.2 | 10.1 | 1.4 | 2.2 |
| 4x8 | 6.2 | 10.9 | 1.8 | 2.8 |

Diameters were taken at ground level.

Chapman (8) says, "the relation between height growth and site quality is largely independent of one of the factors which influences diameter growth of the trees, namely, density of stand. Although in some species, especially hardwoods with deliquescent stems, total height attained is less for open grown trees than for crowded trees, this is not always the case and rate of height growth is usually retained."

On the other hand, Kasa (17) quotes the opinions of the following investigators as to the effect of spacing on height growth. He says that Nool, Jost and Warming found that shoot growth is increased by diminished light, which is brought about by closer spacing. Further he states that Mayr concludes that wider spacing does not give best height growth but that an increase in density favors height growth. Also Hall (14) in experimenting with catalpa plantations spaced 4x4 feet and 6x4 feet seems to prefer the closer spacing. He says that closer spacing, though the trees would not be as large in diameter, makes for taller, straighter trees and hence better fence posts. Haslund (15) says, "in open stands heights are shorter and forms less."

Yield

Because yield is essentially growth in volume per unit area, the actual yields of a few plantations are listed here. Scott (30), in his studies of five catalpa plantations in Iowa, gives the following yields in posts per acre:

| Age - years | Posts per acre |
|---|---|
| 28 | 2114 |
| 28 | 2265 |
| 28 | 3663 |
| 25 | 1796 |
| 24 | 1723 |

Hall (14) on the three plantations that he studied in Kansas found an average yield of 1771 posts per acre on the 13 year old Munger plantation, 3614 posts per acre on the 20 year old Farlington Forest, and 3501 posts per acre on the 18 year old Hunnewell Plantation. Because Norway spruce has been introduced into this country from Europe, no yield tables are available which give its growth in this country. Hence, the yields given here are based on measurements taken in Great Britain and Ireland, and are as follows:

| Age | Volume under bark - Cubic feet per acre | | |
|---|---|---|---|
| | Quality I | Quality III | Quality V |
| 30 | 3,500 | 2,140 | ----- |
| 40 | 5,250 | 3,680 | 1,670 |
| 50 | 6,760 | 4,930 | 2,820 |
| 60 | 8,020 | 5,910 | 3,700 |
| 70 | 8,960 | 6,730 | 4,400 |

After Schlich (27)

## History of Yield Tables

The first yield tables were probably used in Germany as early as the first of the Eighteenth Century. These tables were merely records of measurements on an area, and in many cases no periodic measurements were taken; instead the time between measurements varied considerably. However, these empirical records were used in predicting future yields for the next rotation. It was not until nearly a century later that Hossfeld (1823) conceived the idea of measuring sample plots periodically, and tabulating these measurements. Schlich (27) says, "the first normal yield tables, based on the average trees of an index stand, were published by Huber (1824) and, in the same year by Hundeshagen."

Although periodic measurements of permanent sample plots gives absolute certainty that all data of the yield table are derived from the same site, the fact that nearly a century would be needed to collect the data made the above method of little practical value. Thus, periodic measurements on a series of plots of different ages followed to save time. At once the necessity of site classification was realized in order that the plots of corresponding site qualities but of different ages could be linked together into a continuous series. The factors used as site indicators were either volume (10), number of trees (28), basal area, or height of the dominant trees.

Until yield tables, prepared as indicated above, became available, others for immediate use became necessary. Consequently the idea of measuring of fully-stocked sample plots representing all ages and site classes was conceived. Several methods of making yield tables from data collected in this manner have been devised. Probably the first of these was the indicating wood method discovered by Huber (1847) and described here by Schlich (27).

"He calculated the mean tree of a normal, mature wood, analyzed it and searched for younger normal woods, the mean trees of which possessed the same dimension as the mean tree of the mature wood had at the same age."

In 1891 Franz Baur presented a method of constructing yield tables which has been used quite extensively throughout Europe and America. His method is based on single measurements of fully stocked plots of all ages and sites. For each factor (volume, height, basal area and number of trees) the measurements are plotted as ordinates on the corresponding ages as abscissae. After these points are plotted, maximum and minimum curves are drawn for each factor. The area confined within these curves is divided into as many zones as site qualities that are desired. A mean curve is then drawn through each zone, and the mean curve for that quality is obtained. From these mean curves the tables for each factor are prepared for successive years.

In 1926 Bruce (7) introduced a method of preparing timber-yield tables which like Baur's method is based on measurements of a large number of fully stocked plots of all ages and sites. "The conventional conception of site classes was completely abandoned, and instead each plot was assigned a site-index number; this number was the height which the average dominant tree would (or had attained) at 50 years, read to the nearest foot by interpolation from anamorphic graphs." The plots were rejected primarily on the basis of basal area; the curves of which were also made by anamorphic graphs -- the plots being grouped in ten-foot site-index classes and an anamorphic graph was made for each site-index class. Anamorphosis was used in making the graphs for each of the other factors. Each of these anamorphic graphs was replotted on a system of regular horizontal coordinates and the conventional curves thus formed were used in making the tables for each factor. Bruce concludes, "the chief advantages of the method are the free use of a number of the conceptions of modern statistical technique and the careful cross checking of all results obtained. This, it is felt, should produce a satisfactory yield table at a minimum expense, because the greatest accuracy possible is obtained from a small number of plots."

Because it was evident that the lines of the anamorphosed graphs by Bruce had the same ratio at the same age, Reineke (25) immediately saw that it was possible to express the average curve of any of these factors (site, basal area, average d.b.h., and volume) as a percentage of any other curve of the same series. He says, "this attribute of anamorphically constructed series of curves (of course having a common origin) permits the expression in the form of alinement charts, the use of which eliminates the laborious anamorphic plotting of the data and the balancing of a curve for each site-index class, results in increased accuracy, and makes interpolation and checking easier."

A method has more recently been devised by Bull and is known as the "polymorphic method." The method has not been published in detail but it differs from Bruce's method in that several graduating curves were used instead of one in determining the site-index. Bull (16) says, "these curves more nearly portray the trend of height growth on all sites and for all ages within the limits of the curves than do anamorphic curves."

## Effect of Shelterbelts

### As to the shelterbelt itself

That the effectiveness of a shelterbelt depends upon the species of the trees planted, the density of planting and the height of tree is quite obvious. Each of these factors which influence the protective value of the shelterbelt have been quite widely studied by Bates (2) in the Middle Western States.

Probably the most widely studied and most important factor is height growth. Bates (2) says that if other factors are the same, the taller shelterbelt will protect more area on the leeward side than will a shorter one. Also, that the protection offered by a shelterbelt varies from 10 to 20 feet for each foot in height, depending on the velocity of the wind. He states, "The area protected is proportional to the height, and the distance to which the protection is felt increases with increased wind velocity."

The effectiveness of different species differs greatly; this is especially true of hardwoods and coniferous species. Bates (2) has investigated a number of species and has found that the area protected as well as the amount of protection varies as the density of the windbreak. The more dense coniferous species are more effective in breaking the wind, because they retain their leaves the year round, while the broad-leaved trees are most highly effective only during the time the leaves are present. The following figures show the difference in protective value of a coniferous and broad-leaved species:

| Wind velocity | Wind at five times the height of belt on leeward side in per cent of open | |
|---|---|---|
| Mi. per hr. | White pine | Cottonwood |
| 5 | 20 | 70 |
| 10 | 23 | 59 |
| 15 | 26 | 55 |
| 20 | 30 | 51 |

From Bates (2)

Trenk (33) says, "The wind follows several channels when it strikes a tree barrier, and two of these are directly associated with density -- leakage of some wind between leaves, and the passage of some wind under the branches near the ground. The greater the extent to which these channels can be stopped up, the more the wind will be diverted upward, and the more efficient will the windbreak become."

<u>As to the surroundings</u>

Bates (2) has performed a series of experiments as to the effect of the windbreak upon several factors, which are either harmful or helpful to crops that may be affected by the windbreak. He considers the shading of crops by windbreaks to be most important. He says, "The light absorbed by the trees and cut off from the crops adjacent to them is proportional to the density of the crowns, which varies with different species. Of greater importance than the difference between the various species in their shading effect is the difference between orientations. The amount of light used by the trees in north-south rows is considerably in excess of that taken up by the trees in a row whose orientation is east-west, and this shading is not only greater in volume, but greater in extent."

The extent to which the roots extended into the fields was next studied by Bates in order to determine to what extent the trees competed with the crops for soil moisture. He found that white pine had the least extensive root system, which was followed by cottonwood, green ash, osage orange, Scotch pine and Austrian pine in the order named.

The effect of windbreaks upon reducing evaporation and thus conserving the moisture in the soil was also studied by Bates. He found that a windbreak decreased the evaporation, and in extreme cases 70 per cent of the moisture ordinarily lost by evaporation was saved.

Bates further states, "The effect of a windbreak upon temperatures in the zone of its influence is much greater than is commonly supposed." He says that if other conditions are the same, the maximum and the minimum temperatures of each day at some point protected by a windbreak exceed the maximum and minimum temperatures in the open.

That windbreaks have some effect upon crops is shown by the following figures taken by Bates (2) on the north side of a twenty foot osage orange hedge in western Kansas:

| Distance from hedge | Height of corn | Distance from hedge | Height of corn | Distance from hedge | Height of corn |
|---|---|---|---|---|---|
| Feet | Feet | Feet | Feet | Feet | Feet |
| 9 | 6.10 | 49 | 5.85 | 89 | 4.35 |
| 19 | 5.80 | 59 | 4.88 | 99 | 4.95 |
| 29 | 6.55 | 69 | 4.60 | 150 | 4.65 |
| 39 | 6.15 | 79 | 4.62 | 200 | 4.65 |

Bates further says, "A similar cornfield was located on the north side of a dense, mixed grove in Nebraska. The grove, which was about 38 feet high, formed a complete barrier to the wind. The effects were even more marked. Late in June the average height of the corn in the first eighteen rows next to the windbreak was 4½ feet, while beyond this it was only about 2½ feet. At harvesting the weight of the corn at the point of greatest protection was about eighteen bushels per acre greater than in the open, or 59 bushels per acre as against 41. From this point outward the gain diminished, and at 10 times the height of the grove it amounted to about six bushels per acre. The net gain for the entire area out to 10-height, including the strip damaged by shading, and calculating for a windbreak one mile long, was 423.86 bushels, or 9.22 bushels per acre; that is, as much corn as could be grown on an area as long as the windbreak and as wide as twice the height of the trees. * * * It will, therefore, be seen that the benefit to corn, in this case, paid for all of the ground needed for an efficient windbreak, so that the timber value of the trees was a clear gain to the farmer."

Trenk (33) says that if 20 per cent of the area of the Plains country were devoted to windbreak planting, the remaining 80 per cent will still produce as much as if the whole had been devoted to crops.

# THE INVESTIGATION

## Field Study

The data used in this thesis were collected in the fall of 1932 and consisted of 91 sample plots; 47 of which were Norway spruce and 44 of which were catalpa. A fairly good distribution of age classes for each species was obtained, but there was not a very wide variation in site-index. Table I shows the distribution by age and site-index classes of the shelterbelts forming the basis for the study.

The plots which were measured are located in Central Iowa and the distribution in the various counties is as follows:

| County | Number of plots | | |
|---|---|---|---|
| | Catalpa | Spruce | Total |
| Story | 32 | 29 | 61 |
| Polk | 7 | 10 | 17 |
| Boone | 4 | 8 | 12 |
| Greene | 1 | 0 | 1 |
| Total | 44 | 47 | 91 |

The plots varied in size from 0.017 acres to 0.110 acres and all were rectangular in shape.

The measurements were recorded on field sheets; one of which is shown in Figure 1. In tables II and III the data for each plot are listed.

Table I

Distribution of Plots by Age and
Site-index Classes

| Age Classes | Site-index classes | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| | Catalpa | | | | Norway spruce | | |
| | 20-29 | 30-39 | 40-49 | Total | 20-29 | 30-39 | Total |
| 5 - 9 | --- | --- | 1 | 1 | --- | --- | --- |
| 10 - 14 | --- | 2 | 4 | 6 | 1 | 2 | 3 |
| 15 - 19 | 2 | 8 | 1 | 11 | 2 | 3 | 5 |
| 20 - 24 | 2 | 7 | 5 | 14 | 1 | 8 | 9 |
| 25 - 29 | --- | 8 | --- | 8 | 4 | 8 | 12 |
| 30 - 34 | --- | 1 | --- | 1 | 1 | 8 | 9 |
| 35 - 39 | --- | 1 | --- | 1 | 1 | 3 | 4 |
| 40 - 44 | --- | 1 | --- | 1 | 1 | 3 | 4 |
| 45 - 49 | --- | --- | 1 | 1 | --- | 1 | 1 |
| Total | 4 | 28 | 12 | 44 | 11 | 36 | 47 |

## Specimen of Field Sheet Used

| Plot No. | Aspect | Slope | Date | Crew | Dimensions | Area | Spacing |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Soil Class | Gr.Co.% | Ages test trees<br>Dia.age | <br>Dia.age | | Litter Depth | Multiple |
| Soil type | Gr. sp. | | | | Litter Kind | Age |
| S.mois.<br>S.drain. | Br.kind | | | | Hum.D. | Shape |
| Rock | Br.% | Seedling age | | | Hum.K. | |

| DBH | row 1 D | row 1 I | row 1 S | row 2 D | row 2 I | row 2 S | row 3 D | row 3 I | row 3 S | Tot. D | Tot. All | Hts. | Basal area |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | |
| 6 | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | |
| 13 | | | | | | | | | | | | | |
| 14 | | | | | | | | | | | | | |
| 15 | | | | | | | | | | | | | |

Remarks:

Fig. 1

Table II

Catalpa - Data for All Plots

| Plot No. | Age | Site index | Area sq. ft. | Spacing | No. of trees | Basal area | Soil | Aver. Ht. of dom. tree - ft. |
|---|---|---|---|---|---|---|---|---|
| 12 | 21 | 34 | 800 | 5x4 | 39 | 6.24 | Car. * | 29.0 |
| 13 | 18 | 40 | 1200 | 6x4 | 46 | 8.93 | Car. | 31.0 |
| 14 | 19 | 35 | 1800 | 6x6 | 49 | 9.09 | Clar. # | 28.0 |
| 15 | 21 | 26 | 1800 | 6x6 | 53 | 8.85 | Clar. | 22.5 |
| 16 | 22 | 35 | 1800 | 6x6 | 57 | 10.42 | Car. | 31.3 |
| 21 | 19 | 35 | 3240 | 6x4 | 134 | 12.25 | Car. | 28.0 |
| 22 | 24 | 34 | 900 | 6x5 | 35 | 7.12 | Car. | 31.3 |
| 23 | 24 | 38 | 1200 | 6x5 | 39 | 7.14 | Car. | 34.5 |
| 25 | 26 | 36 | 1800 | 6x5 | 59 | 14.00 | Car. | 33.6 |
| 27 | 15 | 38 | 1200 | 6x4 | 44 | 8.44 | Clar. | 25.6 |
| 30 | 25 | 34 | 3600 | 10x6 | 61 | 19.83 | Car. | 33.0 |
| 31 | 18 | 28 | 1200 | 8x5 | 31 | 4.51 | Clar. | 21.5 |
| 34 | 16 | 32 | 1800 | 6x6 | 50 | 8.09 | Clar. | 23.0 |
| 35 | 20 | 43 | 1800 | 6x4 | 64 | 11.27 | Car. | 35.0 |
| 36 | 10 | 44 | 1800 | 6x6 | 49 | 4.25 | Car. | 23.0 |
| 37 | 17 | 29 | 1800 | 6x6 | 47 | 7.20 | Clar. | 22.6 |
| 38 | 28 | 36 | 1800 | 6x8 | 37 | 8.15 | Car. | 35.3 |
| 40 | 12 | 47 | 1800 | 6x5 | 59 | 5.21 | Car. | 28.0 |
| 45 | 20 | 39 | 1800 | 6x6 | 45 | 8.00 | Car. | 32.3 |
| 48 | 19 | 32 | 900 | 6x3 | 47 | 3.50 | Car. | 25.6 |
| 49 | 23 | 31 | 900 | 6x4 | 38 | 5.79 | Car. | 27.6 |
| 50 | 18 | 32 | 900 | 6x4 | 37 | 4.86 | Car. | 25.0 |
| 53 | 14 | 48 | 1080 | 6x4 | 42 | 5.95 | Car. | 32.0 |
| 55 | 49 | 45 | 3200 | 8x8 | 47 | 28.15 | Car. | 47.5 |
| 57 | 23 | 40 | 2400 | 8x6 | 47 | 15.74 | Car. | 36.0 |
| 59 | 14 | 36 | 1800 | 6x6 | 47 | 4.97 | Clar. | 24.0 |
| 64 | 43 | 34 | 1200 | 6x4 | 41 | 9.35 | Clar. | 35.3 |
| 65 | 21 | 28 | 1500 | 5x4 | 69 | 9.20 | Clar. | 24.5 |
| 67 | 18 | 35 | 750 | 5x5 | 30 | 3.72 | Car. | 26.3 |
| 70 | 23 | 39 | 1350 | 6x4 | 41 | 8.54 | Car. | 34.0 |
| 71 | 17 | 38 | 1350 | 6x4 | 45 | 8.99 | Car. | 28.0 |
| 72 | 31 | 39 | 2400 | 8x6 | 47 | 18.22 | Car. | 40.3 |
| 75 | 22 | 40 | 1800 | 6x6 | 48 | 14.89 | Car. | 35.0 |
| 76 | 25 | 37 | 1800 | 6x4 | 50 | 12.30 | Clar. | 34.0 |
| 78 | 26 | 38 | 2100 | 7x7 | 39 | 12.99 | Car. | 35.3 |
| 80 | 35 | 37 | 1800 | 6x6 | 41 | 18.19 | Car. | 38.0 |
| 83 | 20 | 40 | 1800 | 6x6 | 46 | 10.50 | Car. | 33.5 |
| 85 | 27 | 38 | 1800 | 6x6 | 47 | 11.07 | Car. | 36.3 |
| 86 | 13 | 37 | 1800 | 6x5 | 65 | 4.73 | Car. | 23.0 |
| 88 | 25 | 36 | 1800 | 6x6 | 45 | 12.10 | Car. | 32.7 |
| 90 | 26 | 33 | 1800 | 6x6 | 49 | 12.92 | Car. | 31.3 |

* Car. = Carrington # Clar. = Clarion

## Table III

### Spruce - Data for All Plots

| Plot No. | Age | Site index | Area sq. ft. | Spacing | No. of trees | Basal area | Soil | Aver. Ht. of dom. tree - ft. |
|---|---|---|---|---|---|---|---|---|
| 1 | 16 | 29 | 1200 | 8x8 | 21 | 0.99 | Car.* | 14.0 |
| 2 | 43 | 30 | 3000 | 7x10 | 43 | 17.52 | Car. | 38.5 |
| 3 | 27 | 25 | 2700 | 9x9 | 31 | 4.38 | Clar.# | 20.0 |
| 4 | 30 | 29 | 3000 | 8x10 | 34 | 8.90 | Car. | 29.0 |
| 5 | 22 | 26 | 2000 | 8x10 | 36 | 3.27 | Car. | 18.0 |
| 6 | 36 | 29 | 2000 | 8x10 | 24 | 8.09 | Car. | 35.0 |
| 7 | 24 | 33 | 2000 | 5x7 | 57 | 6.81 | Car. | 25.7 |
| 8 | 13 | 26 | 1920 | 8x8 | 29 | 0.40 | Clar. | 10.0 |
| 9 | 22 | 39 | 1800 | 6x6 | 44 | 7.17 | Car. | 27.0 |
| 10 | 22 | 31 | 2400 | 6x8 | 37 | 5.46 | Car. | 22.5 |
| 11 | 45 | 35 | 2800 | 14x14 | 21 | 17.73 | Car. | 45.5 |
| 12 | 20 | 34 | 2000 | 6x8 | 40 | 5.84 | Car. | 22.3 |
| 18 | 18 | 30 | 2625 | 7x8 | 46 | 3.07 | Car. | 17.0 |
| 19 | 26 | 30 | 2400 | 8x8 | 37 | 8.17 | Car. | 25.3 |
| 20 | 39 | 33 | 5400 | 10x12 | 44 | 21.78 | Car. | 41.0 |
| 24 | 34 | 32 | 3600 | 8x8 | 52 | 16.04 | Clar. | 37.0 |
| 26 | 14 | 34 | 1500 | 6x6 | 41 | 1.68 | Car. | 14.0 |
| 32 | 40 | 23 | 3600 | 9x9 | 43 | 16.18 | Clar. | 30.0 |
| 39 | 14 | 37 | 1920 | 8x8 | 30 | 1.15 | Car. | 15.0 |
| 41 | 42 | 36 | 4800 | 8x10 | 57 | 29.96 | Car. | 45.0 |
| 42 | 34 | 38 | 3000 | 10x10 | 30 | 13.06 | Car. | 44.3 |
| 43 | 20 | 30 | 2400 | 8x8 | 47 | 5.42 | Clar. | 19.0 |
| 44 | 25 | 36 | 2400 | 8x8 | 37 | 8.77 | Car. | 29.0 |
| 46 | 28 | 26 | 2700 | 9x9 | 33 | 5.55 | Clar. | 24.0 |
| 47 | 27 | 28 | 3200 | 8x8 | 47 | 7.74 | Car. | 25.0 |
| 51 | 22 | 30 | 2400 | 8x8 | 38 | 2.66 | Clar. | 21.0 |
| 52 | 25 | 31 | 1920 | 6x8 | 40 | 4.55 | Clar. | 25.0 |
| 54 | 19 | 38 | 3600 | 9x9 | 42 | 5.59 | Car. | 22.5 |
| 56 | 33 | 34 | 1600 | 6x8 | 29 | 12.86 | Car. | 37.0 |
| 58 | 28 | 29 | 5000 | 8x10 | 58 | 10.81 | Car. | 27.0 |
| 60 | 17 | 27 | 1600 | 8x8 | 25 | 1.72 | Clar. | 14.0 |
| 61 | 30 | 30 | 2100 | 7x9 | 33 | 9.53 | Clar. | 30.3 |
| 62 | 42 | 33 | 3000 | 10x10 | 29 | 16.63 | Car. | 42.5 |
| 63 | 33 | 34 | 3000 | 8x10 | 35 | 16.21 | Car. | 37.7 |
| 66 | 18 | 38 | 2400 | 8x8 | 36 | 3.77 | Car. | 21.0 |
| 68 | 32 | 32 | 1600 | 8x8 | 24 | 9.76 | Car. | 34.0 |
| 69 | 25 | 35 | 2400 | 8x8 | 36 | 9.51 | Car. | 28.0 |
| 73 | 27 | 35 | 2700 | 7x9 | 28 | 7.12 | Car. | 31.0 |
| 74 | 30 | 33 | 1600 | 8x8 | 25 | 7.55 | Car. | 33.5 |
| 77 | 30 | 34 | 1600 | 8x8 | 22 | 6.88 | Car. | 34.0 |
| 79 | 38 | 32 | 2700 | 9x9 | 33 | 15.11 | Car. | 38.7 |
| 81 | 36 | 32 | 2400 | 8x8 | 35 | 11.11 | Car. | 38.7 |
| 82 | 26 | 37 | 1800 | 7x9 | 28 | 6.42 | Car. | 31.0 |
| 84 | 24 | 39 | 2400 | 8x8 | 52 | 7.67 | Car. | 30.3 |
| 87 | 27 | 36 | 3000 | 10x10 | 30 | 5.78 | Car. | 31.0 |
| 89 | 26 | 34 | 1600 | 8x8 | 24 | 5.41 | Car. | 29.0 |
| 91 | 20 | 34 | 1600 | 6x8 | 43 | 5.03 | Car. | 22.0 |

* Car. = Carrington    # Clar. = Clarion

Because all of the plots studied were plantations planted in straight evenly spaced rows, the distance between the rows times the number of rows measured was considered the width of the plot. The length of the plots was measured with a 50 foot steel tape. Thus, it was not necessary to use a compass in running the boundaries of the plot as is the usual procedure; however, a compass was used to make the ends of the plot at right angles to the rows.

All living trees on the plots were calipered and recorded by inch diameter classes and 3 crown classes (dominant, intermediate, suppressed). Total heights were measured on all plots. On the catalpa plots, merchantable heights to a four inch top were measured on representative trees throughout each plot. Heights (total and merchantable) were measured with a Demeritt hypsometer (9). It is believed that with careful measurement fairly accurate results can be obtained with this hypsometer. The heights were recorded by rows.

Age determinations were made by counting the annual rings on increment borings eight inches above the mean ground level. In a few cases, however, the actual age of the shelterbelt was known by the farmer, making it unnecessary to take borings. Age counts were made on trees of each crown class, and the average age of these trees was then taken as the age of the stand. In but a very few cases did the age vary more than two years above or below the average age. It did not seem necessary to add to the ages obtained, the years required to reach the height of the increment boring (eight inches) because in the case of Norway spruce transplant seedlings whihh are usually eight inches or more in height are ordinarily planted, and in the case of catalpa the species usually grows more than eight inches the first year.

For each shelterbelt in which measurements were taken, a description of the condition of the stand was recorded. The following items were included in the description: location (relative), soil ground cover, underbrush, slope, aspect, spacing, size of shelterbelt, history of the stand, and relative location and actual distance of the buildings which the stand protected.

In addition to the above measurements, it was necessary to measure a few trees on the Norway spruce plots for the purpose of preparing a volume table. This involved measuring the diameter outside bark of a few trees at eight foot intervals above the stump (12 inches).

## Office Work

As previously stated, this thesis has three objectives. Each of these was studied separately and is presented in this section. The first objective was studying of the factors seeming to have an effect on height growth, and will be covered under the heading "Height growth." The second objective of this thesis was the presentation of yield tables for Norway spruce and catalpa. The construction and use, as well as the tables themselves, will be presented under the heading "Yield tables." The third and last objective was the effect of spacing upon basal area and height growth and is discussed under the heading "Effect of spacing."

## Height growth

Because the height of a shelterbelt directly influences the protection offered, the factors which seemed to have an effect on height growth were studied first. These factors are soil, size of the shelterbelt, spacing and height growth in different rows.

The apparent effect of soil upon the height growth of both Norway spruce and catalpa is shown by the graphs in Figure 2. All of the plots measured were of two soil series, namely, Carrington and Clarion. The number of plots of each soil series are as follows:

| Soil series | Number of plots | |
|---|---|---|
| | Spruce | Catalpa |
| Carrington | 37 | 28 |
| Clarion | 10 | 16 |

In constructing the curves in Figure 2 the average height of the plot was used. Because of the small number of plots taken on Clarion soils, it might seem that it would be difficult to fit a curve with such meager data. However, the height growth on the Clarion soils was more consistent than was the height growth on Carrington soils, and in neither case did the average deviation exceed 2.11 feet. For catalpa the average deviation on Carrington soil was 2.11 while on Clarion soil it was 2.00 feet. In the case of spruce, the average deviation on the Carrington soil was 1.73 and on Clarion soil it was only 1.51 feet.

The second factor studied which seemed to have an effect on height growth was the difference in size of the shelterbelt. The size of the shelterbelts studied varied from one to six rows for spruce and from two to twelve rows for catalpa. The plots for each species were segregated into two groups -- four rows or less and over four rows for catalpa; two rows or less and over two rows for Norway spruce. The frequency of plots in each of these groups is as follows:

| Catalpa | Number of plots |
|---|---|
| 4 rows and less | 13 |
| 5 rows and over | 31 |
| Norway spruce | |
| 2 rows and less | 23 |
| 3 rows and over | 24 |

The graphs drawn to show the apparent effect of the size of the shelterbelt upon height growth are depicted in Figure 3.

A third factor which apparently has some effect on

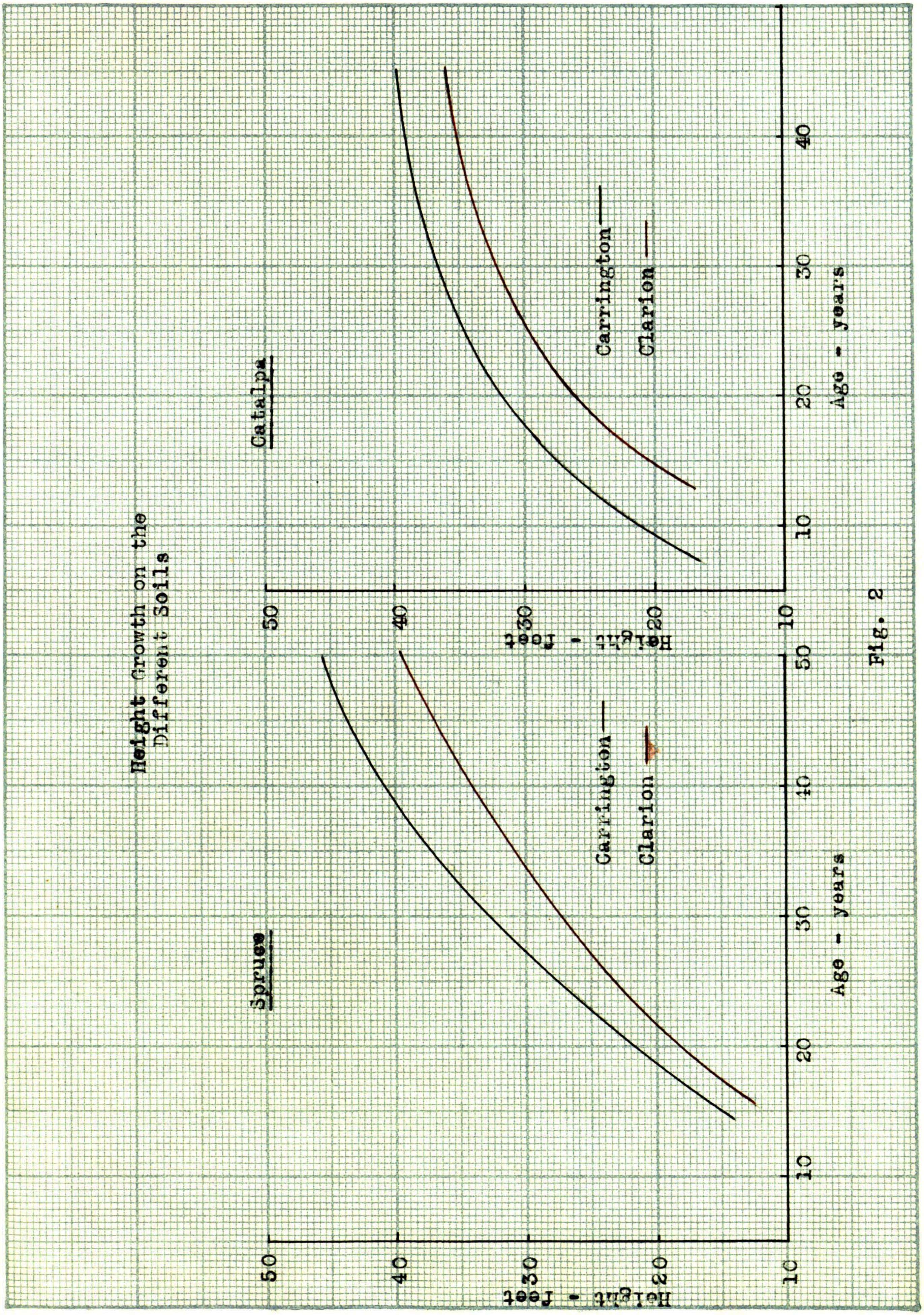

Height Growth on the
Different Soils
Spruce
Catalpa
Carrington
Clarion
Height - Feet
Age - years
50
40
30
20
10

Fig. 2

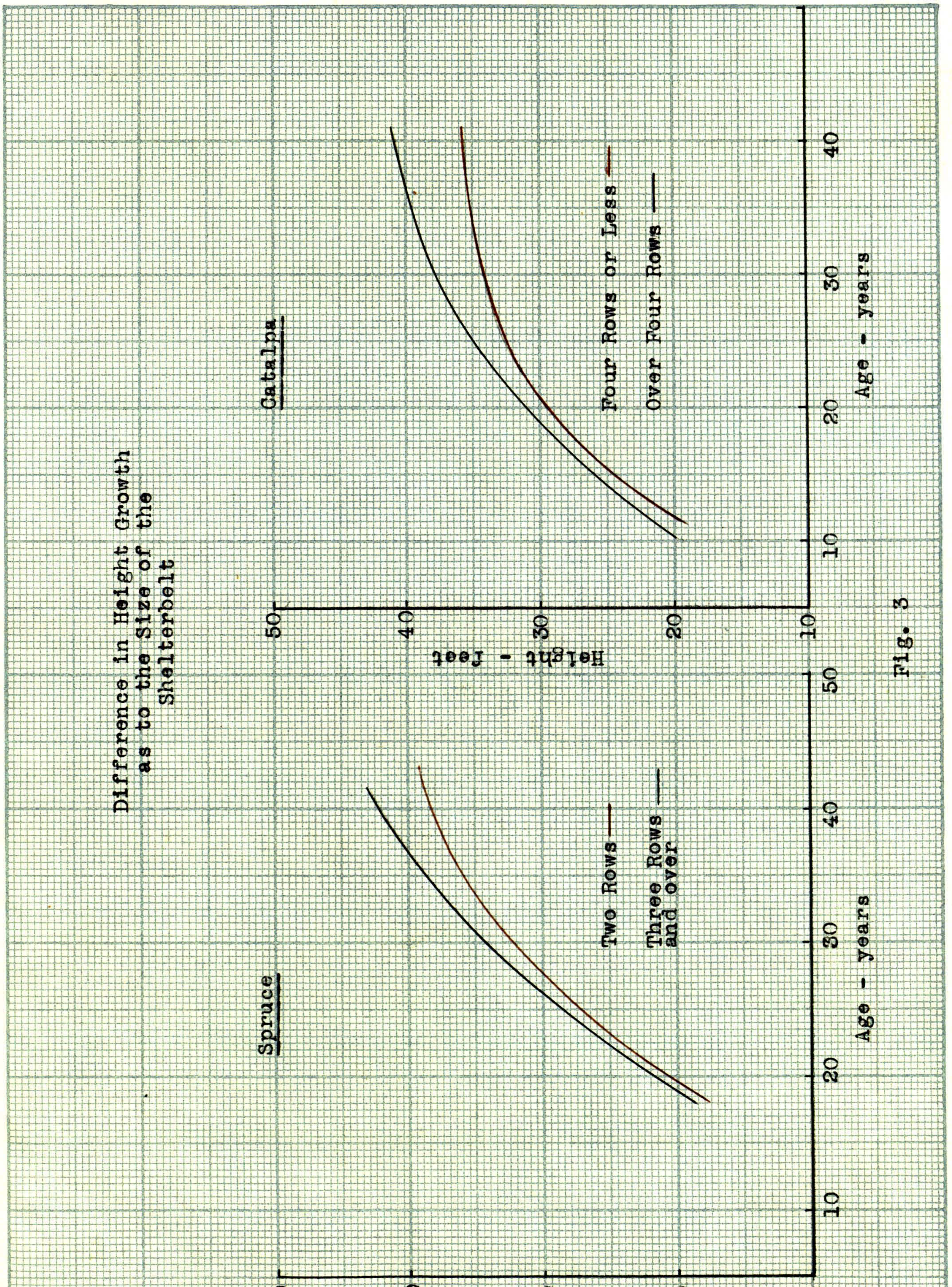

Difference in Height Growth
as to the Size of the
Shelterbelt
Spruce
Two Rows
Three Rows
and over
Height - feet
Age - years
10
20
30
40
50
Catalpa
Four Rows or Less
Over Four Rows

Fig. 3

height growth of the trees is the difference in average height as to the different rows. The tree heights, which were tallied by rows, were averaged by rows. The average height of the south row of each plot was plotted on age, and the other rows of each plot were averaged and plotted on age, and are called middle rows in the graphs in Figure 4.

## Yield tables

The construction of the yield tables in this thesis followed the methods outlined by Reineke (25). In this method each factor of the yield table is based on an average curve for that factor. These curves show the trend of average dominant height, total stand basal area, average tree basal area, and cubic-foot volume with respect to age. The conventional curves are derived from these average curves, because the conventional curves at any age can be expressed as percentages of the average curve value at the same age.

In this study the average height of a plot was not determined in the usual manner. The numerical average was taken as the average of the plot, because the uniformity of height growth made it impossible to prepare satisfactory curves of height on d.b.h.

For Norway spruce the yield is expressed in cubic-feet of unpeeled wood.

However, before a yield table could be prepared for

Difference in Height Growth in
the Middle Rows as Compared
to the South Rows

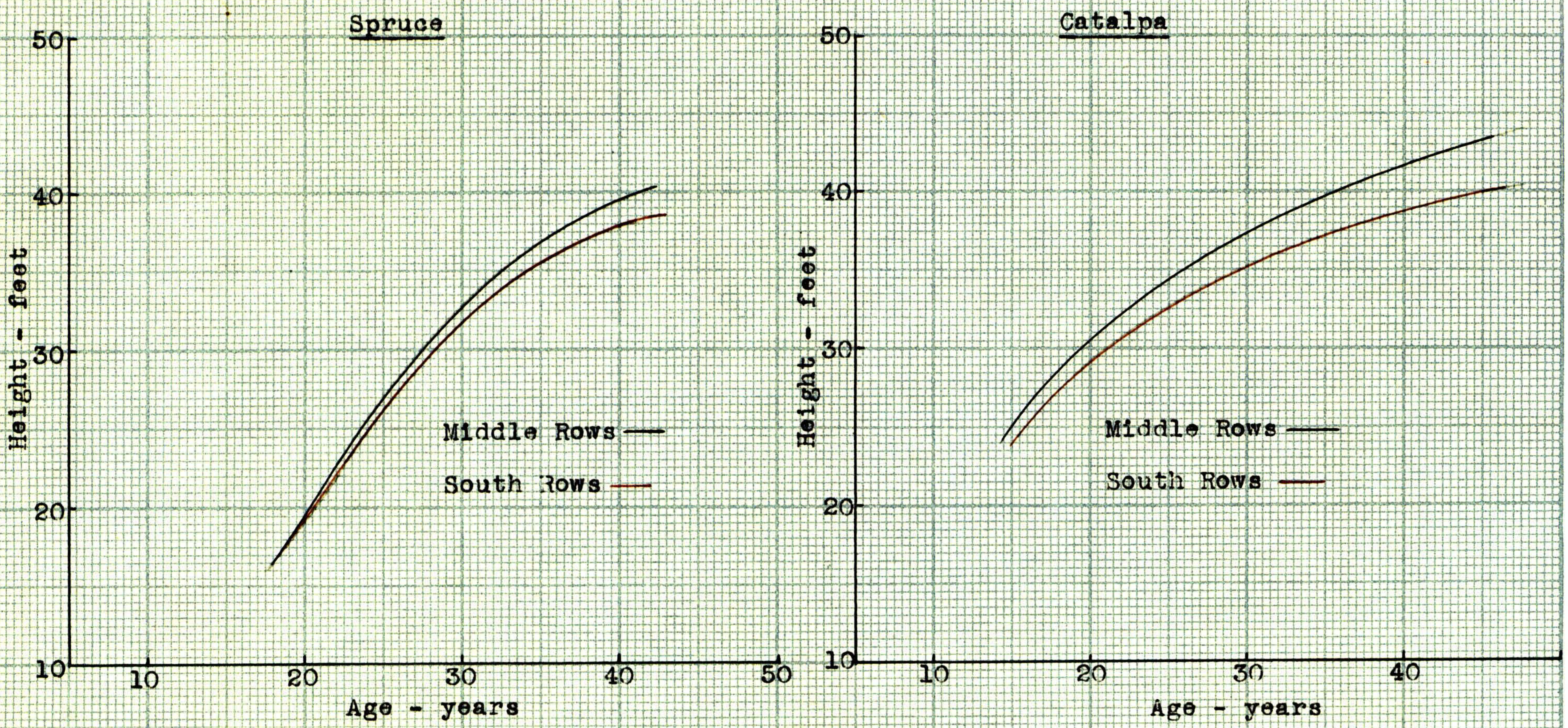



Fig. 4

Norway spruce, it was necessary to construct a cubic foot volume table for this species. The volume table was made according to the method described by Brown (5) and is shown in Figure 5. The yield table was then constructed according to Reineke. The average height curve used in the construction of the site classification chart is shown in Figure 6. The average curve of stand basal area is shown in Figure 7 and the percentage curve used for graduating the site index axis for stand basal area is shown in Figure 8. Figure 9 shows the average curve for tree basal area while Figure 8 shows the site index graduating curve for tree basal area. In Figure 10 is drawn the average curve of yield per acre and Figure 8 shows the site index graduating curve for this factor. A composite alinement chart for site classification, stand basal area and tree basal area is presented in Figure 11 and the alinement chart for yield per acre is found in Figure 12.

For catalpa the yield is expressed in linear feet and posts four inches and over. Before a yield table for catalpa was constructed, a merchantable height alinement chart (merchantable to a four inch top diameter) was made and is shown in Figure 13. The method used in constructing this chart was as follows:

(1) The trees were classified into one inch, five foot height classes.

(2) The average d.b.h., total height, and merchantable

Alinement Chart Volume Table for Spruce
Unpeeled Total Stem Volume - Cubic Feet

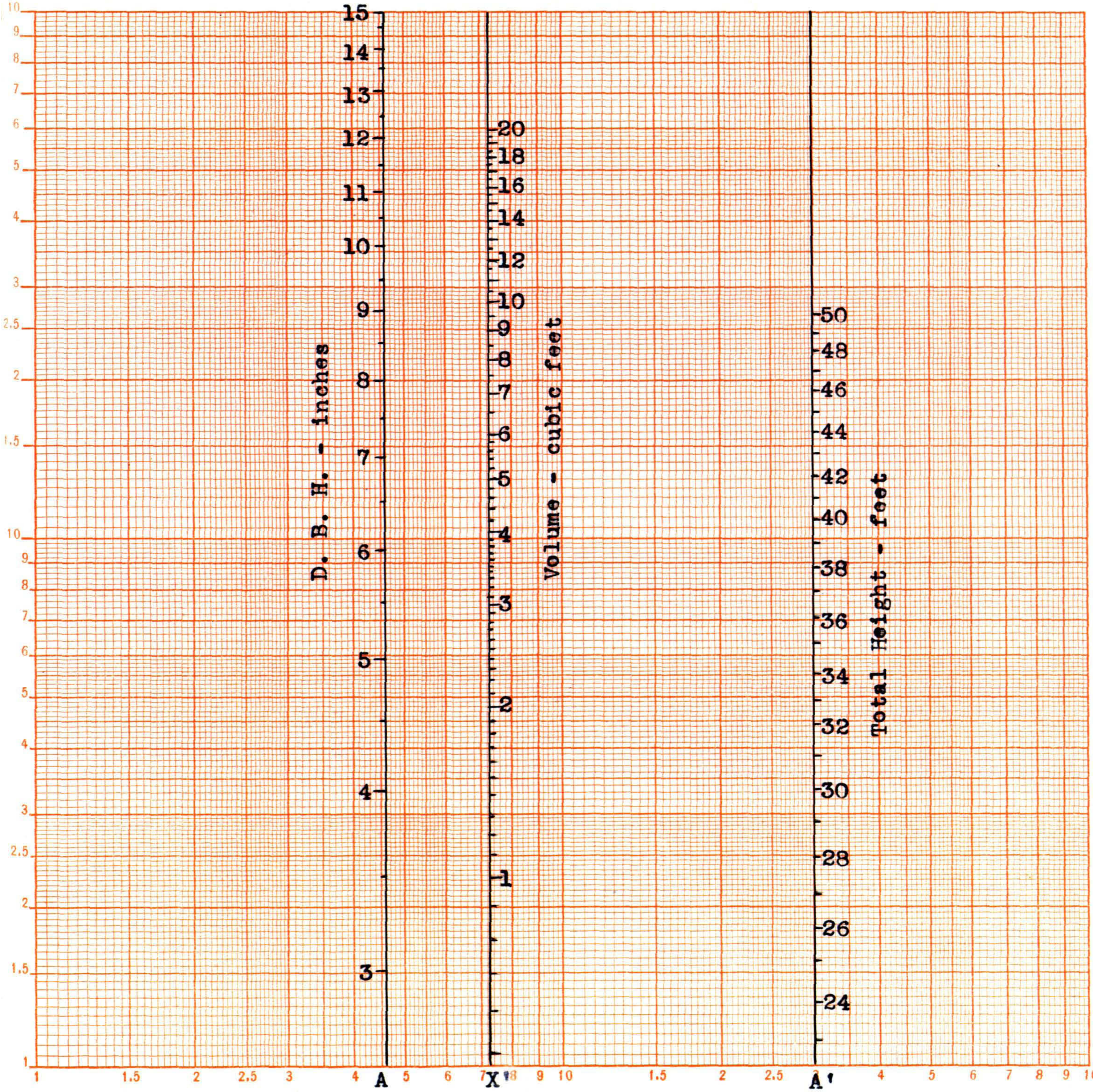



Fig. 5

Height Curve for Spruce and Catalpa
All Plots

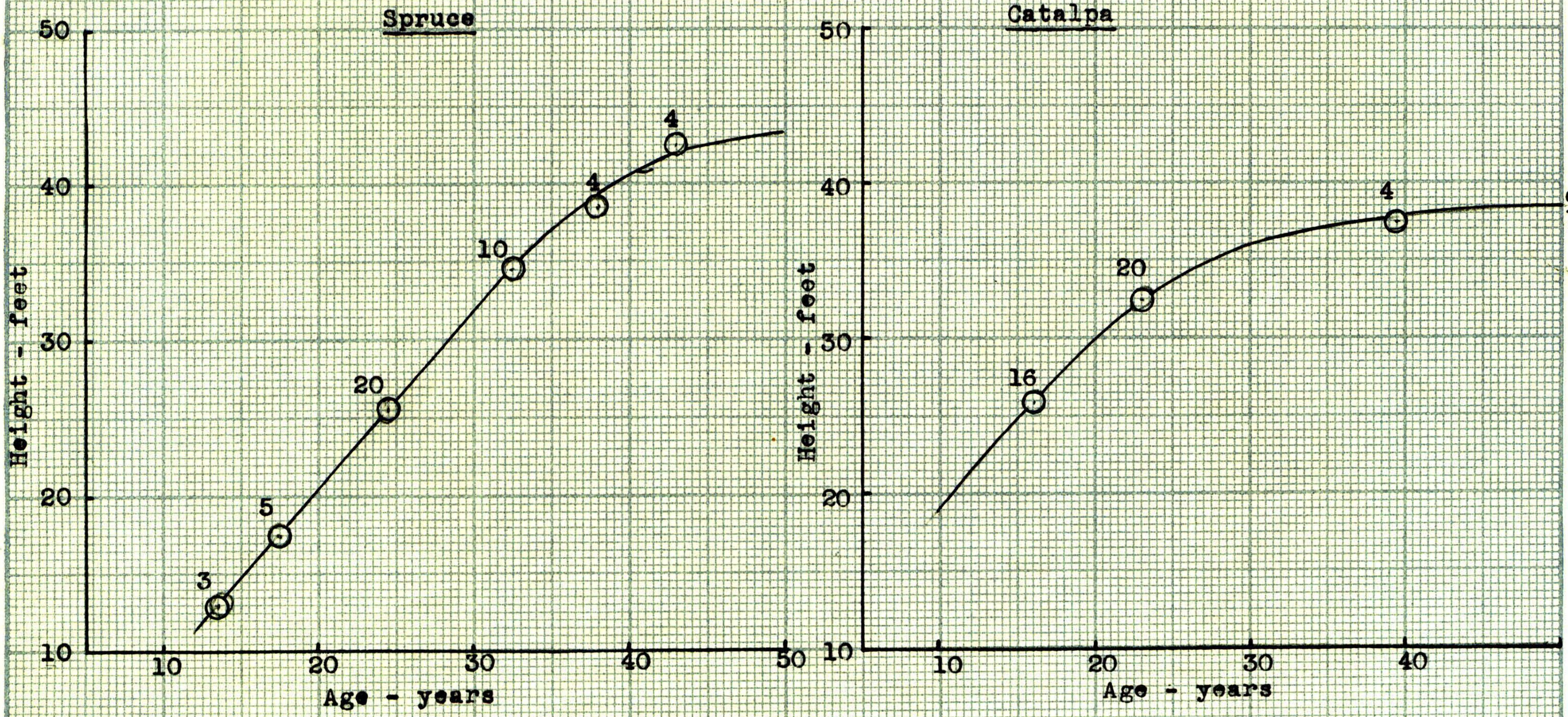



Fig. 6

height were found for each total d.b.h. class regardless of height.

(3) The average total height, and merchantable height were found for each total height class regardless of d.b.h.

(4) On logarithmic paper average merchantable height obtained in step (2) was plotted on average d.b.h.

(5) Average merchantable height obtained in step (3) was plotted on average total height (3).

(6) Curve obtained in step (4) was used as graduating curve for d.b.h. axis.

(7) Curve obtained in step (5) was used as graduating curve for height axis.

(8) Merchantable height axis was set up midway between the d.b.h. and height axis.

(9) The points for the graduating curve for merchantable height were located as follows: using the average figures found in step (2), the intersection on the merchantable height axis, obtained by laying a straight edge through the average d.b.h. and total height, is taken as the merchantable height of that class, and with this point as an ordinate, it is plotted on the corresponding merchantable height as an abscissa.

(10) An average curve is drawn through the points obtained in step (9) and this curve is used as the graduating curve for the merchantable height axis.

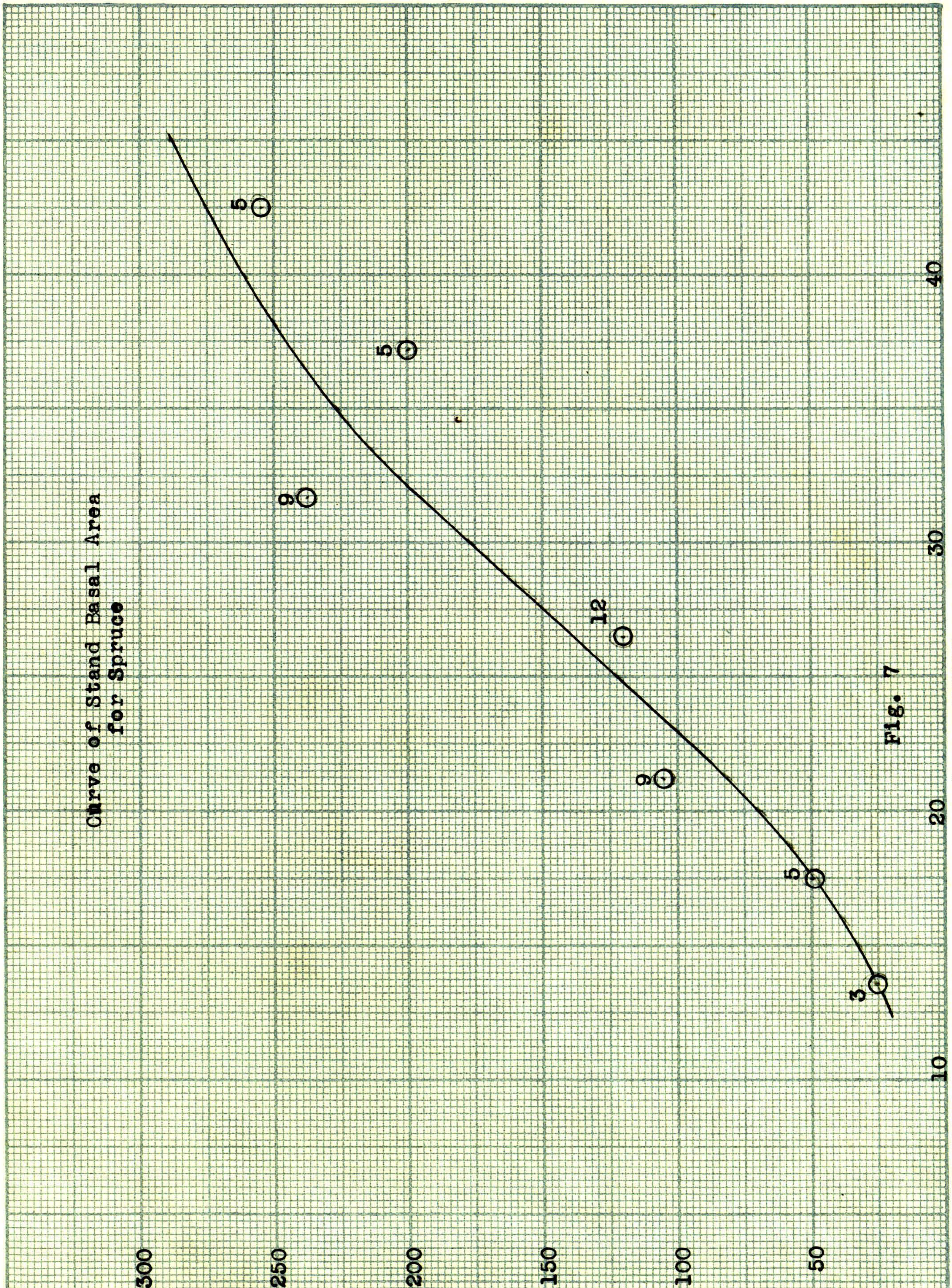

Curve of Stand Basal Area
for Spruce
Stand Basal Area per Acre - square feet
300
250
200
150
100
50
Age - years
10
20
30
40
3
5
9
12
9
5
5

Fig. 7

Form E-7



Curves Used in Preparing Alinement Charts for Stand Basal Area, Tree Basal Area, and Yield per Acre for Spruce

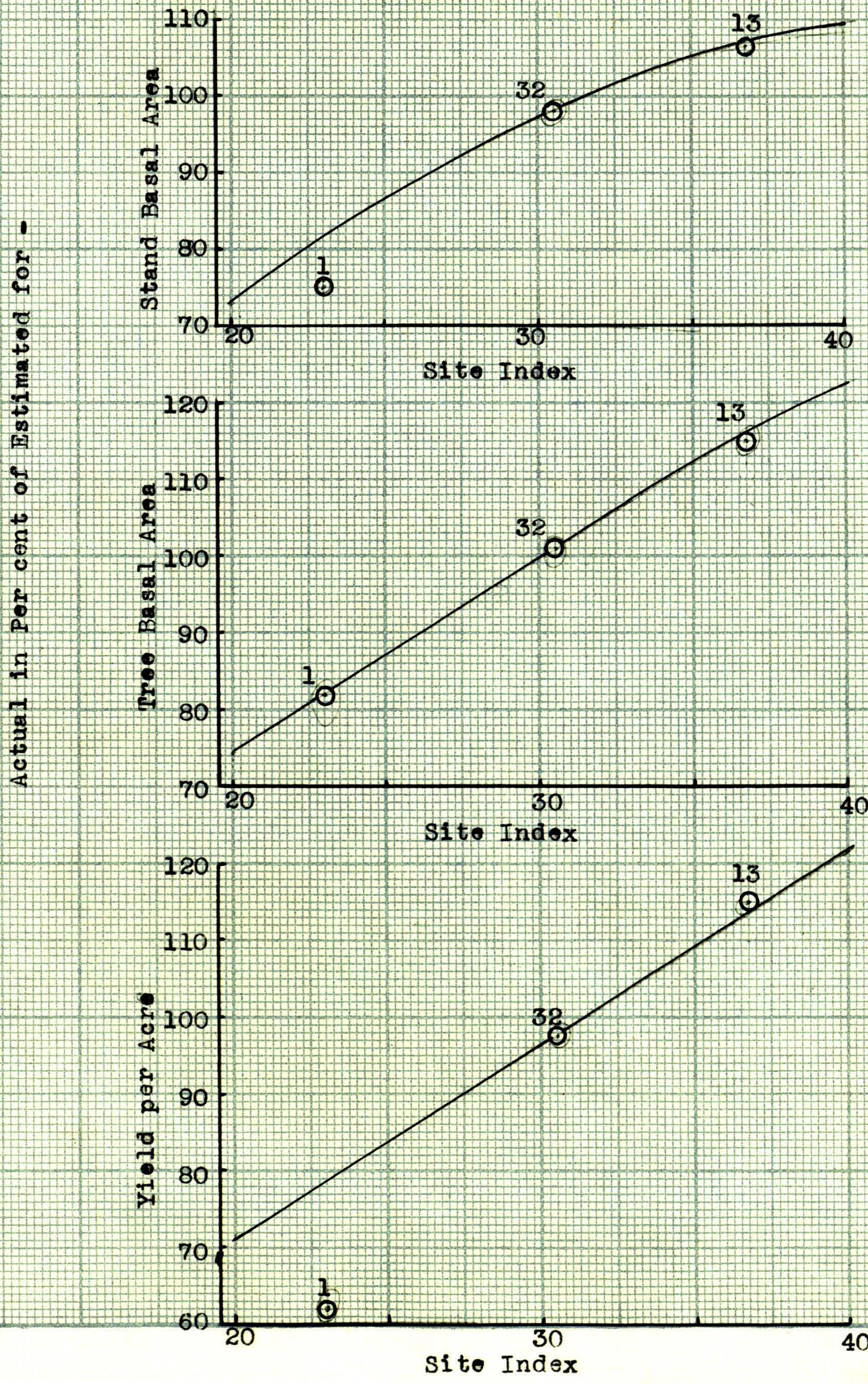
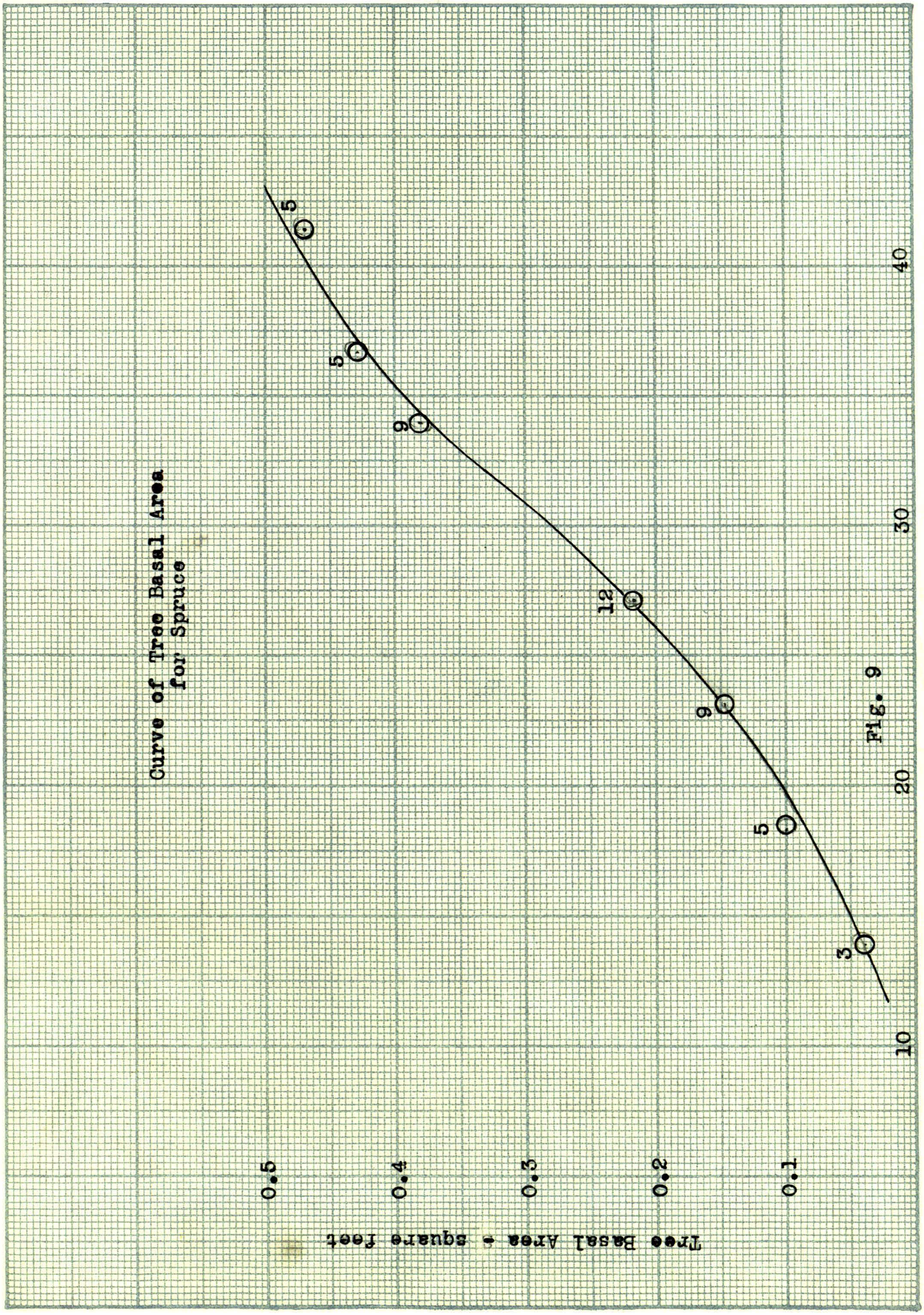



Fig. 8

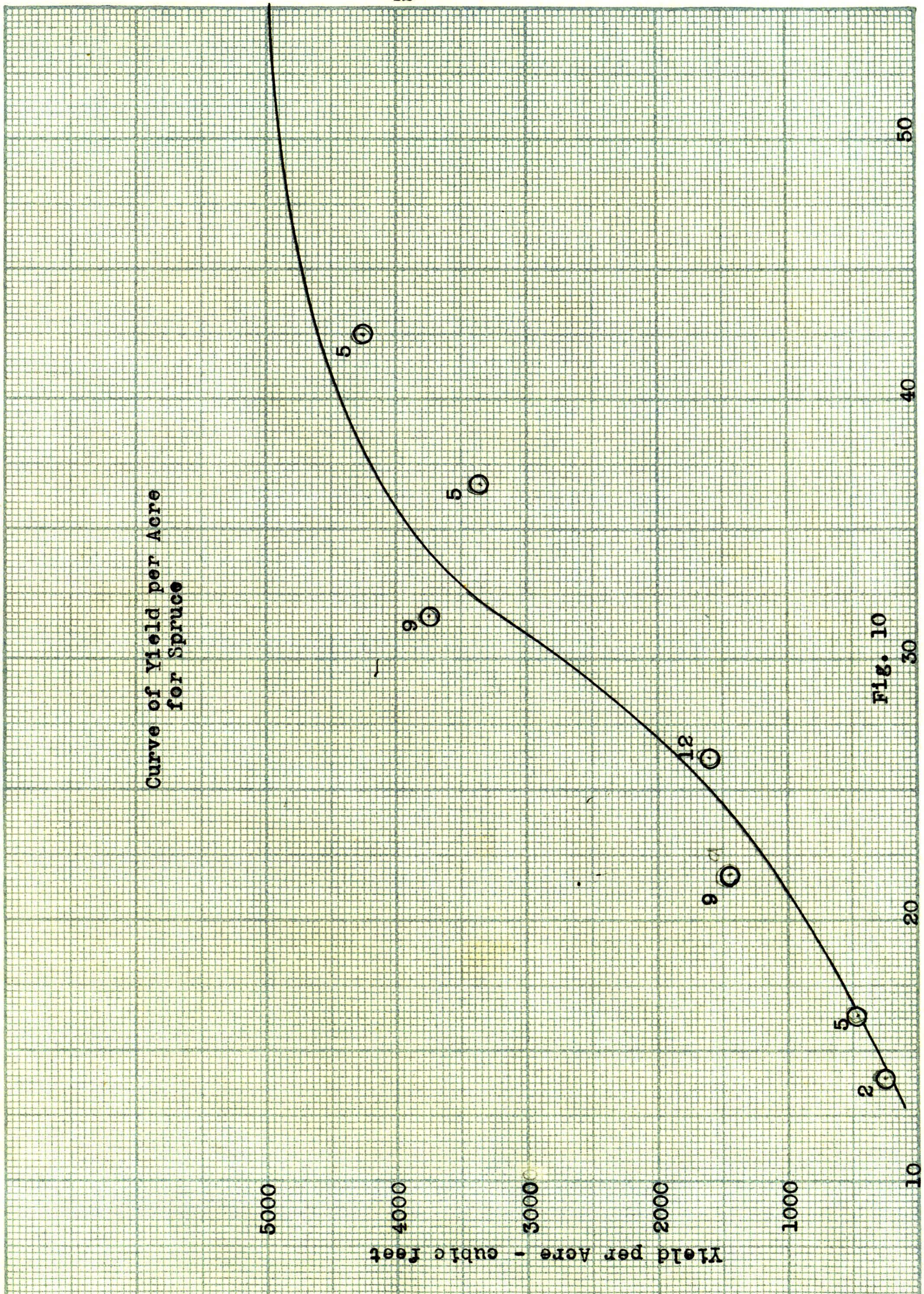
Form E-7






Curve of Tree Basal Area for Spruce

Fig. 9


Curve of Yield per Acre
for Spruce
Fig. 10
Age - Years
Yield per Acre - cubic feet
10
20
30
40
50
1000
2000
3000
4000
5000
2
5
9
12
9
5
5

Alinement Chart for Site Classification, Stand Basal Area, and Tree Basal Area for Spruce

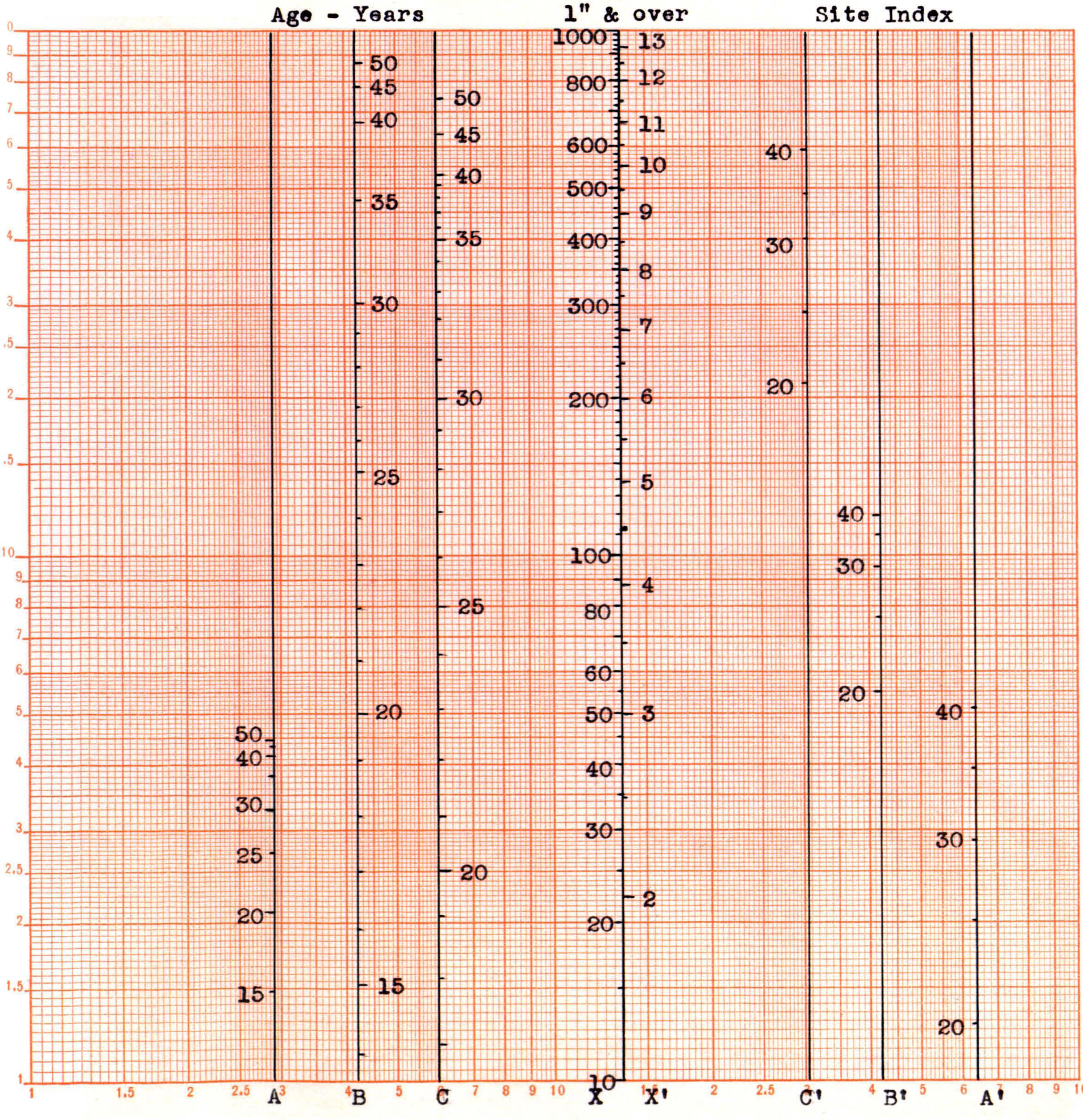



Fig. 11

Alinement Chart Yield Table for Spruce
Unpeeled Total Stem Volume - Cubic Feet

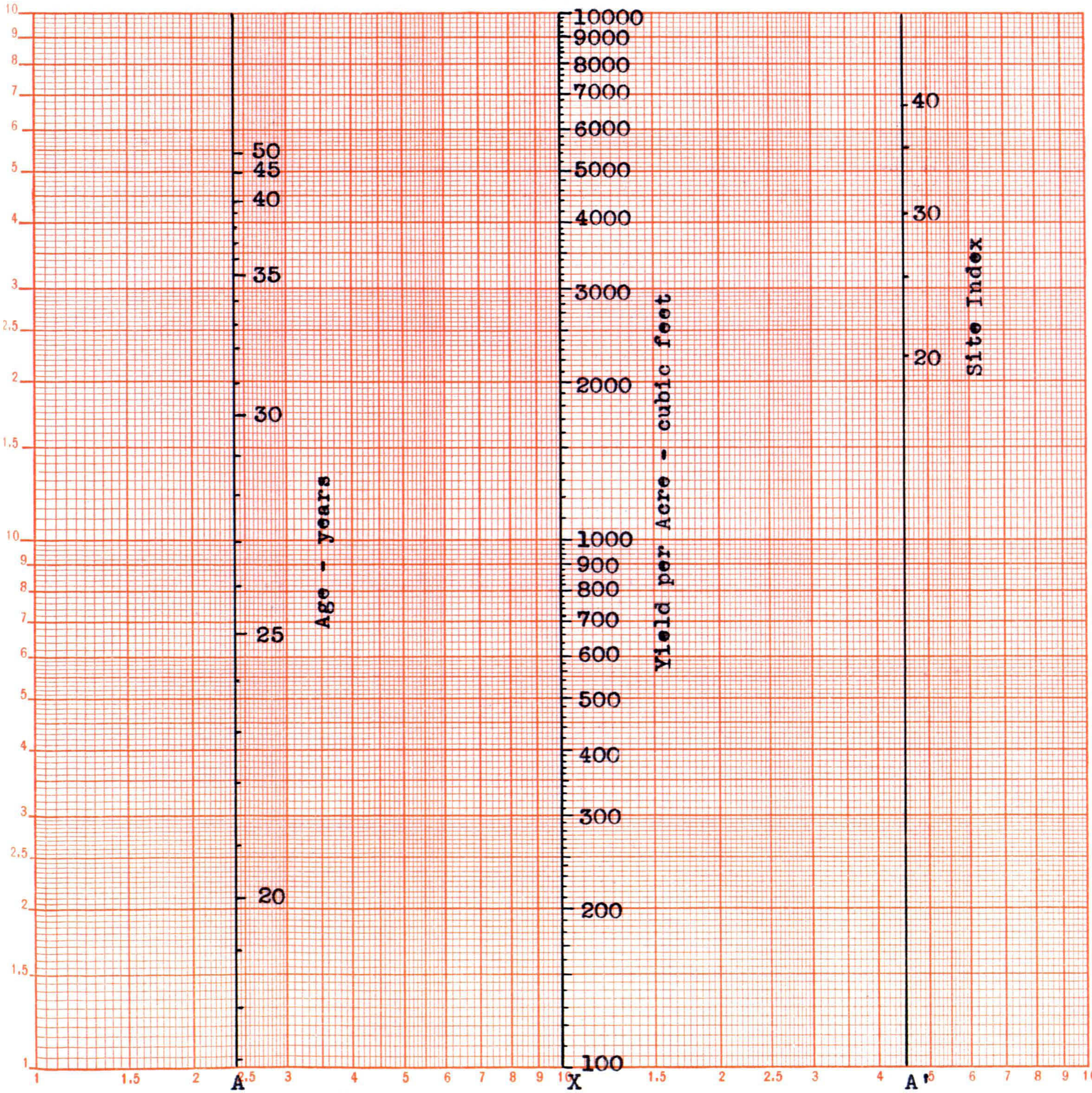



Fig. 12

Merchantable Height Alinement
Chart for Catalpa

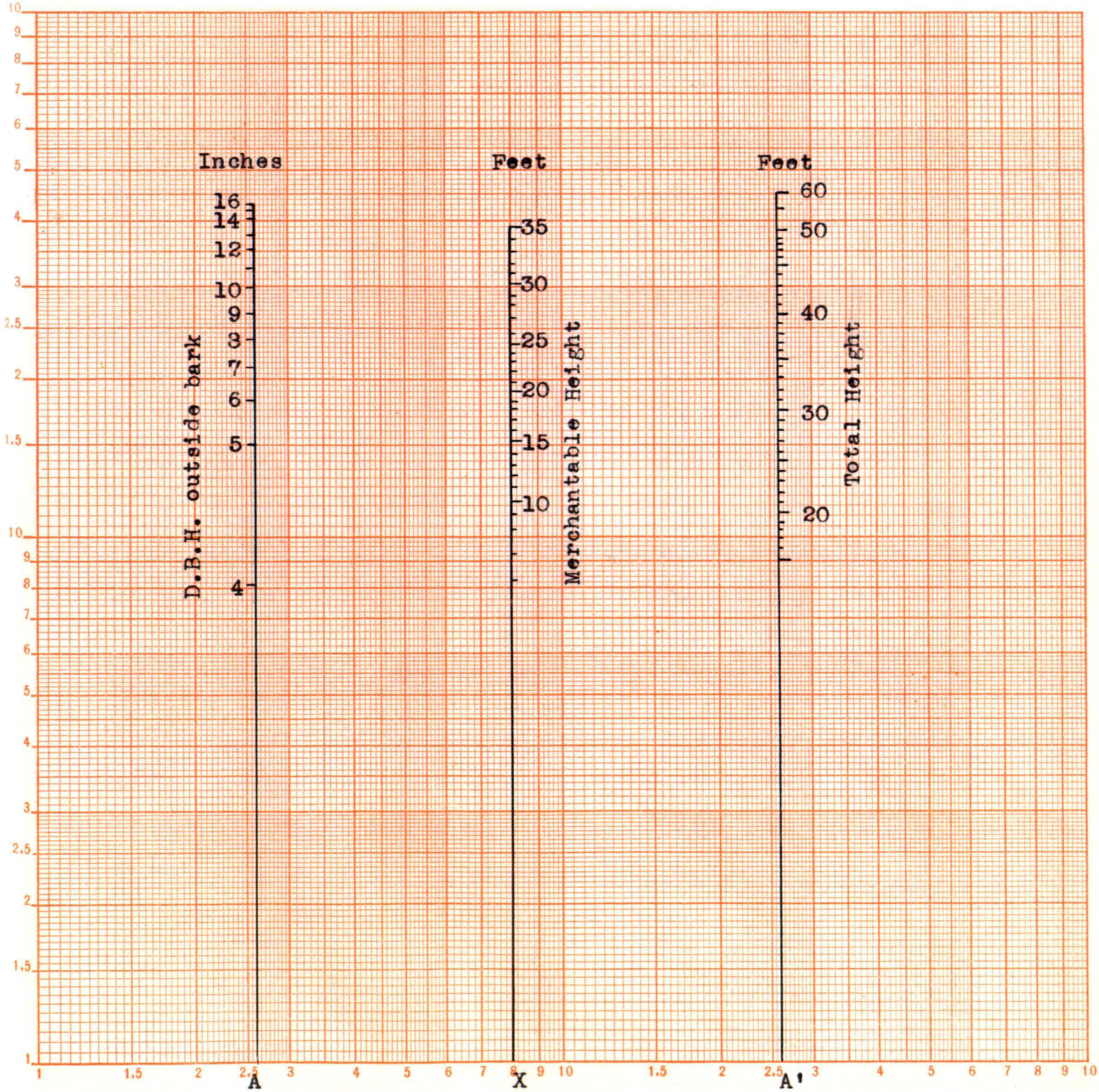



Fig. 13

As has been stated before, the yield table for catalpa was constructed in the manner described by Reineke. The average height curve used in the construction of the site classification alinement chart is shown in Figure 6. The average curve of stand basal area is shown in Figure 14 and the percentage curve used for graduating the site index axis for stand basal area is shown in Figure 15. Figure 16 shows the average curve for tree basal area while Figure 15 shows the site index graduating curve for tree basal area. In Figure 17 the average curve of yield in linear feet per acre is drawn, while Figure 15 shows the site index graduating curve for this factor. Figure 18 shows the average curve of yield in seven foot posts per acre and, in Figure 19 the site index graduating curve for this factor is drawn. A composite alinement chart for site classification, stand basal area, and tree basal area is presented in Figure 20. The alinement chart for yield in linear feet per acre is presented in Figure 21, while the chart for yield in seven foot posts per acre is found in Figure 22.

The instructions for the use of the yield tables presented in this thesis are found in Table IV.

## Effect of Spacing

Two factors which might be affected by spacing are height growth and basal area. These two factors were studied separately in this thesis.

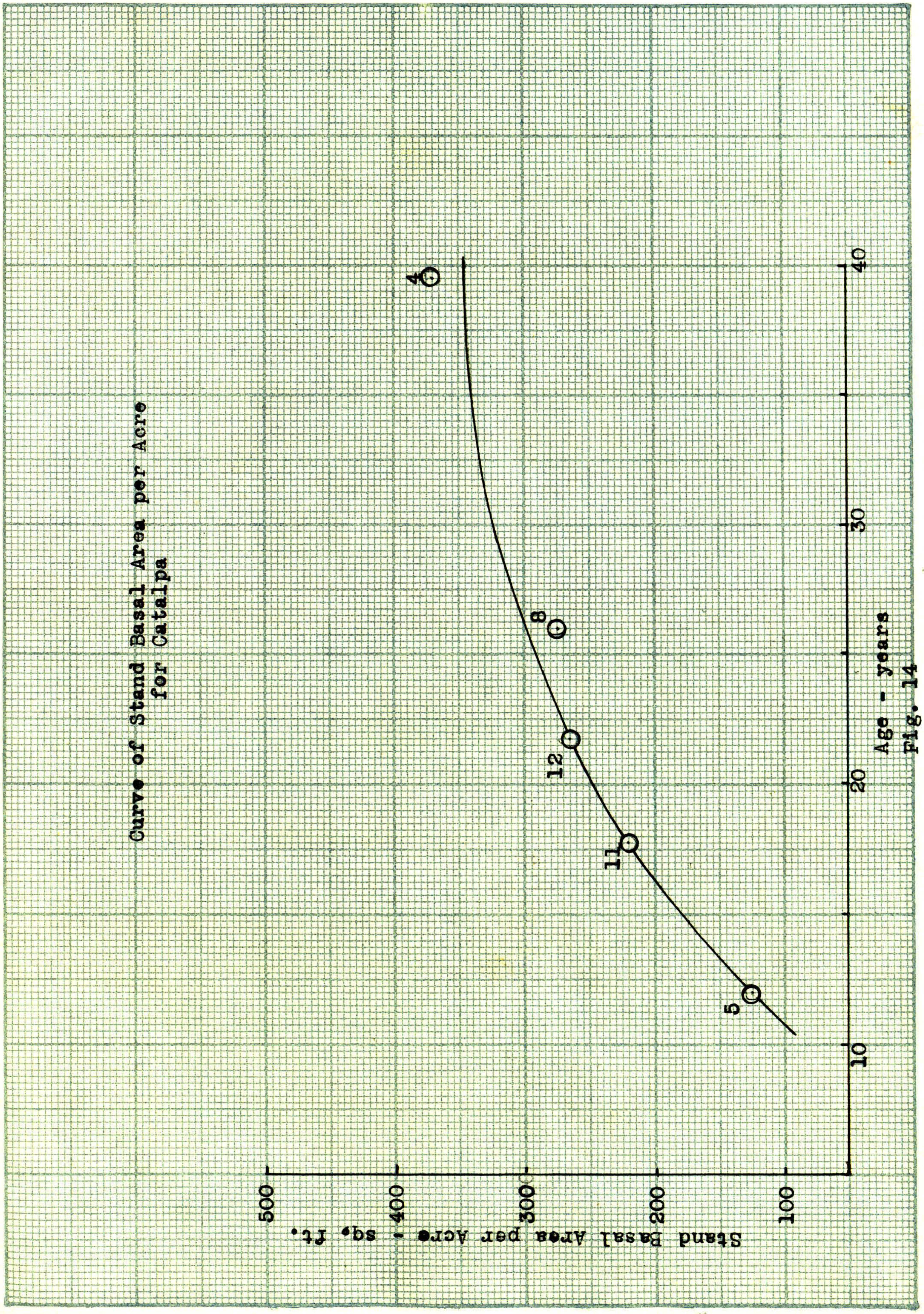

Curve of Stand Basal Area per Acre
for Catalpa
Stand Basal Area per Acre - sq. ft.
500
400
300
200
100
Age - years
10
20
30
40
5
11
12
8
4

Fig. 14

Form E-7



Curves Used for Preparing Alinement Charts for Stand Basal Area, Tree Basal Area, and Linear Feet per Acre for Catalpa

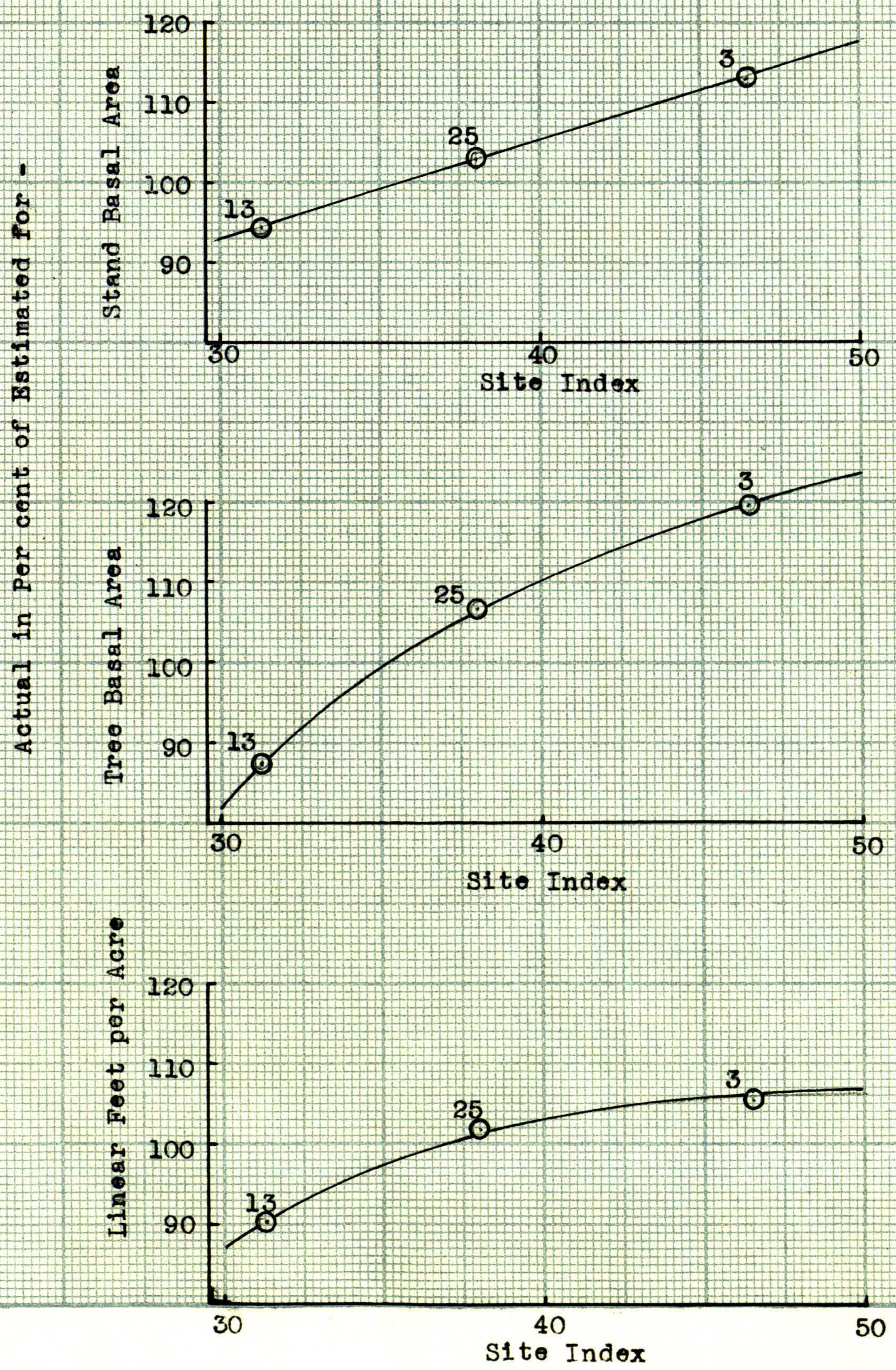



Fig. 15

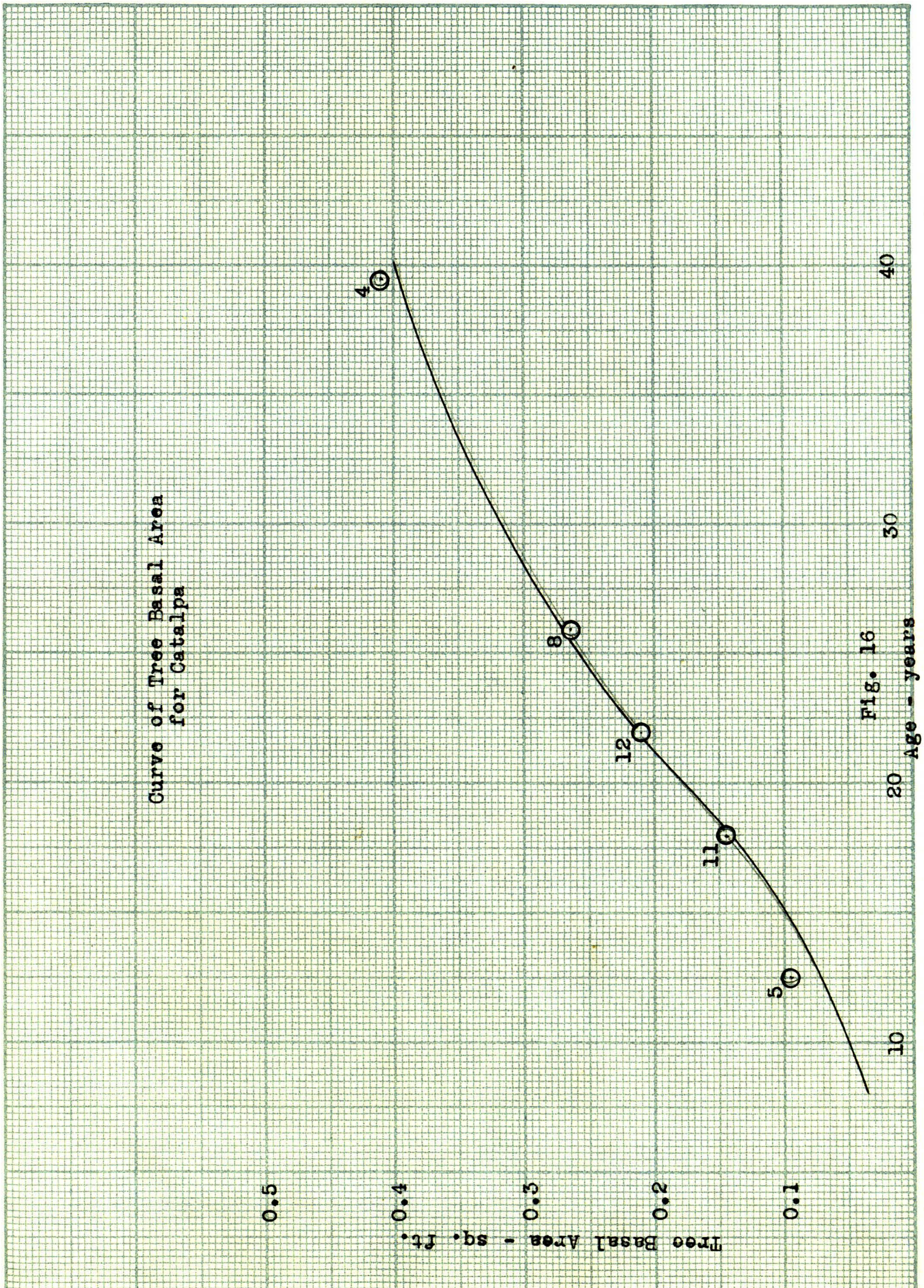

Curve of Tree Basal Area
for Catalpa
Tree Basal Area - sq. ft.
0.1
0.2
0.3
0.4
0.5
Age - years
10
20
30
40
4
8
12
11
5

Fig. 16

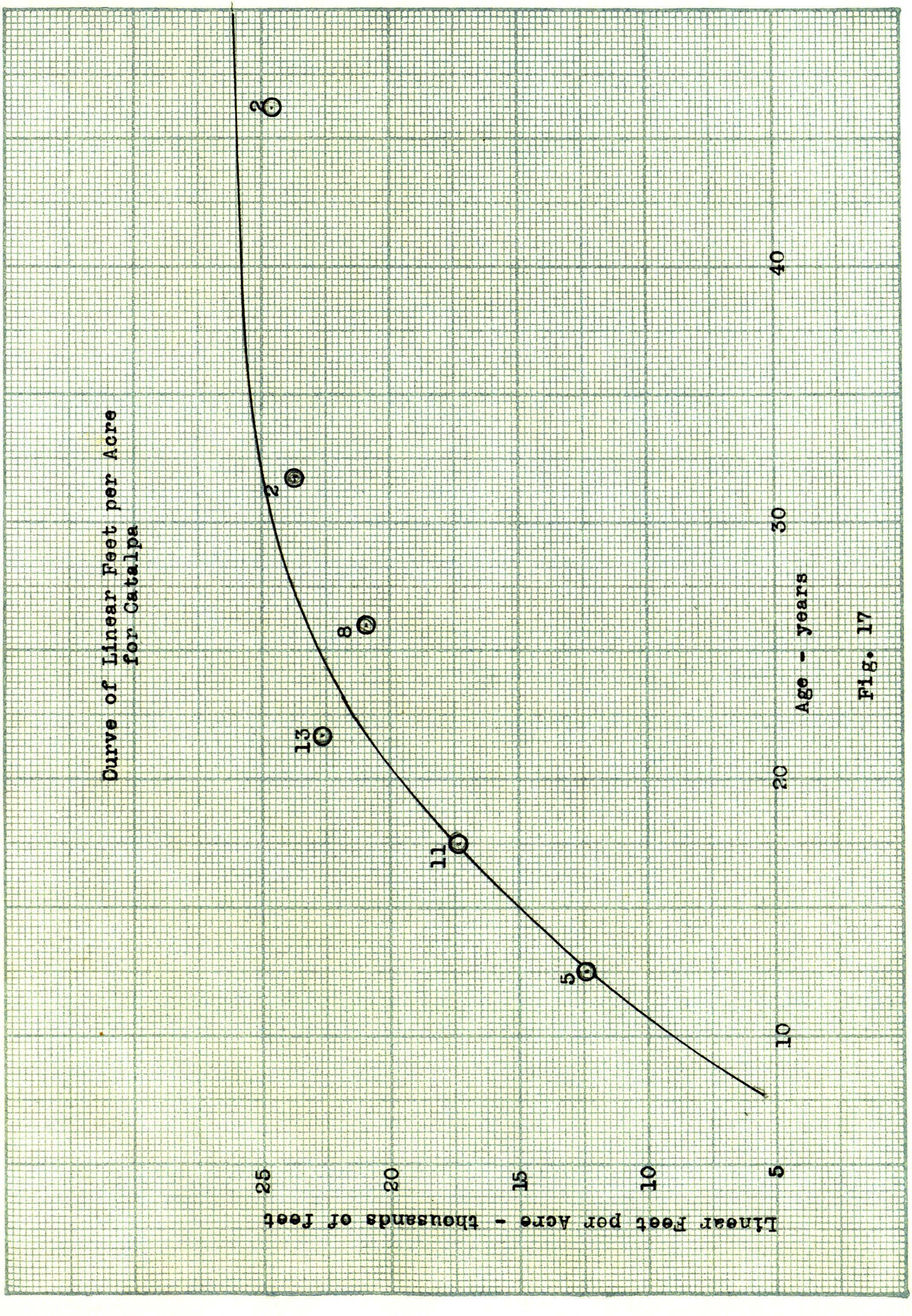
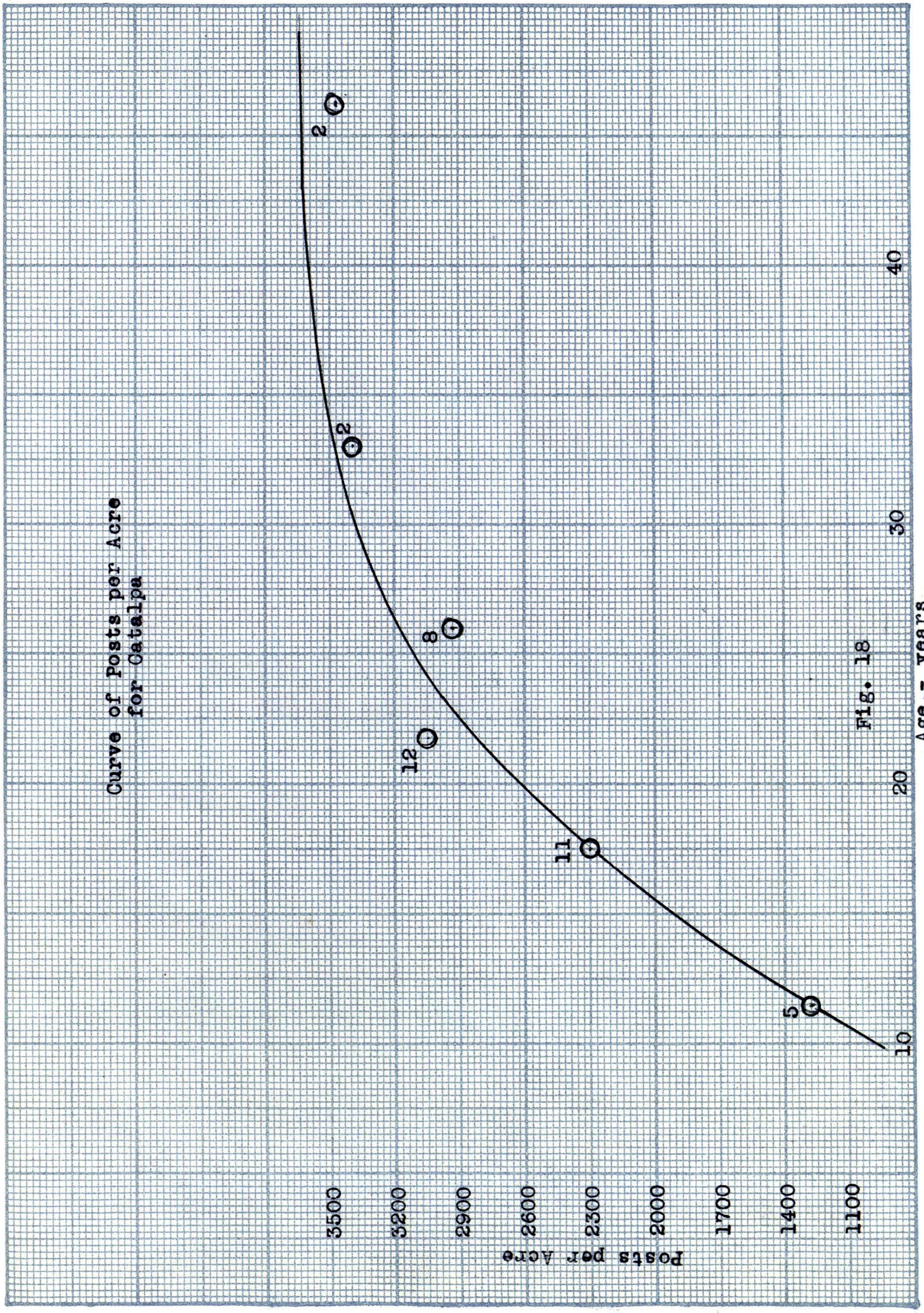

Curve of Linear Feet per Acre
for Catalpa
Linear Feet per Acre - thousands of feet
Age - years
25
20
15
10
5
10
20
30
40
2
2
8
13
11
5

Fig. 17


Curve of Posts per Acre
for Catalpa
Fig. 18
Posts per Acre
3500
3200
2900
2600
2300
2000
1700
1400
1100
Age.- years
10
20
30
40
2
2
8
12
11
5

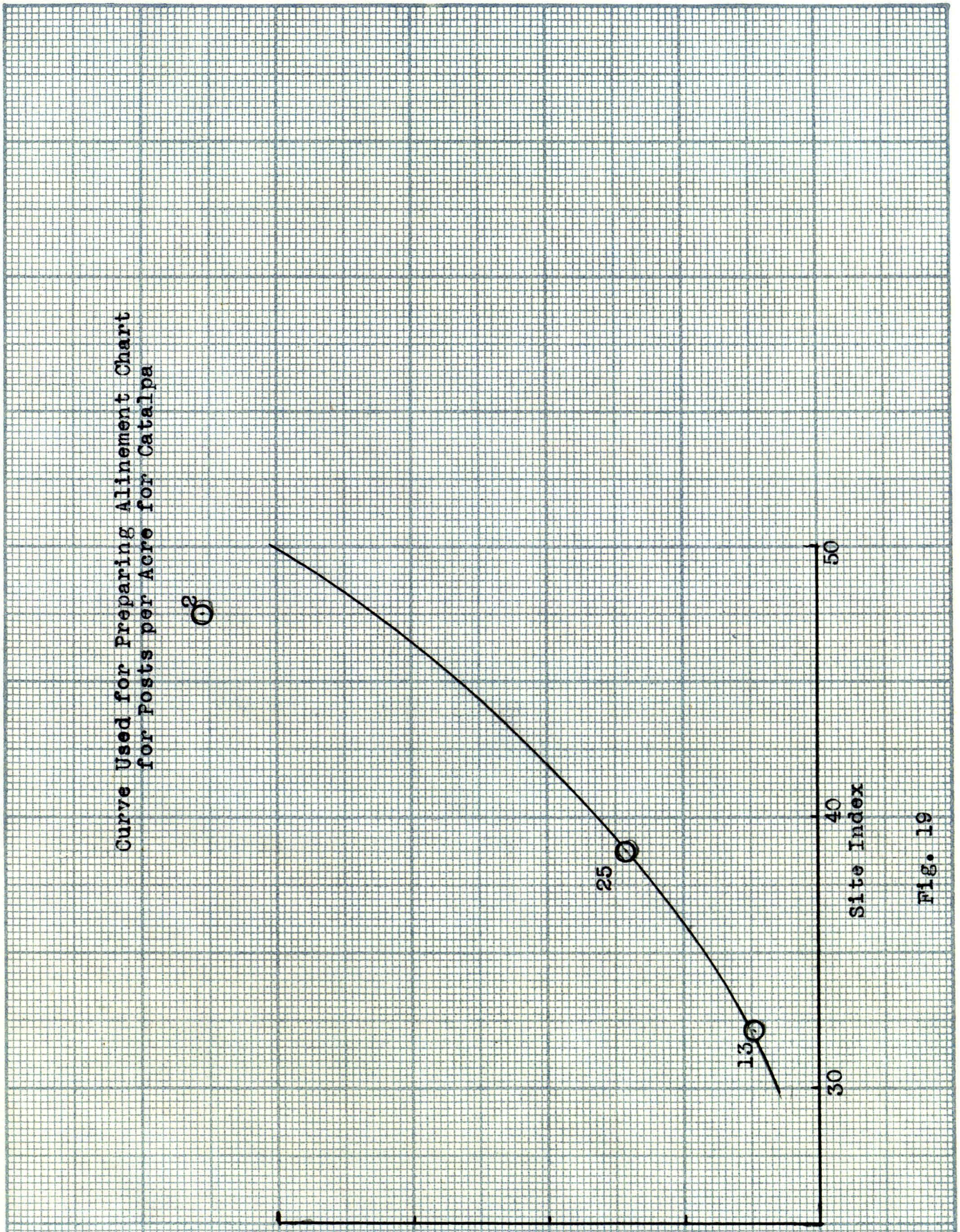

Curve Used for Preparing Alinement Chart
for Posts per Acre for Catalpa
2
25
13
30
40
50
Site Index
130
120
110
100
90
Actual in Per cent of Estimated

Fig. 19

Alinement Chart for Site Classification,
Stand Basal Area, and Tree Basal Area
for Catalpa

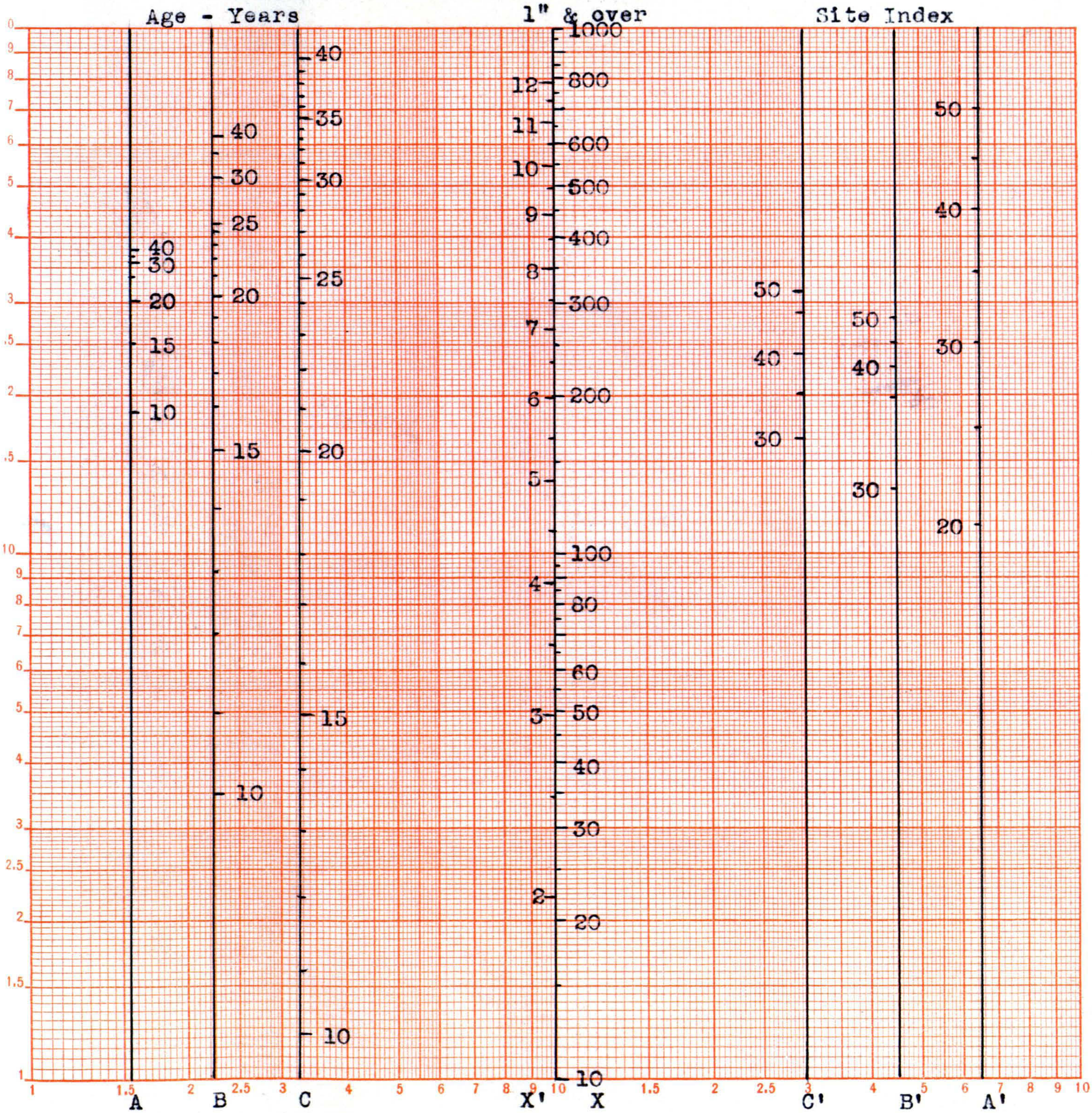



Fig. 20

Alinement Chart for Linear
Feet per Acre - Catalpa

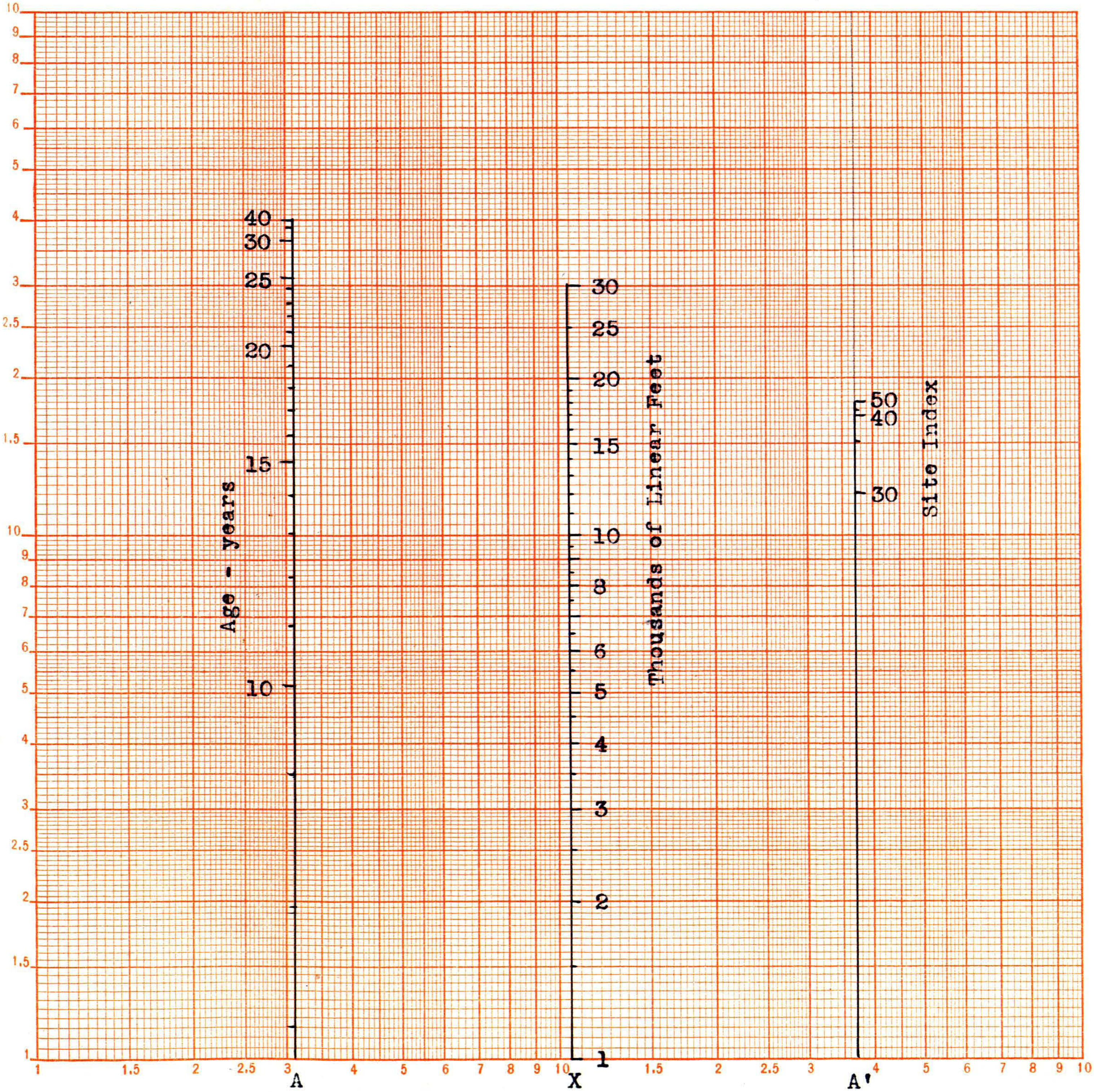



Fig. 21

Alinement Chart for Posts per Acre for Catalpa

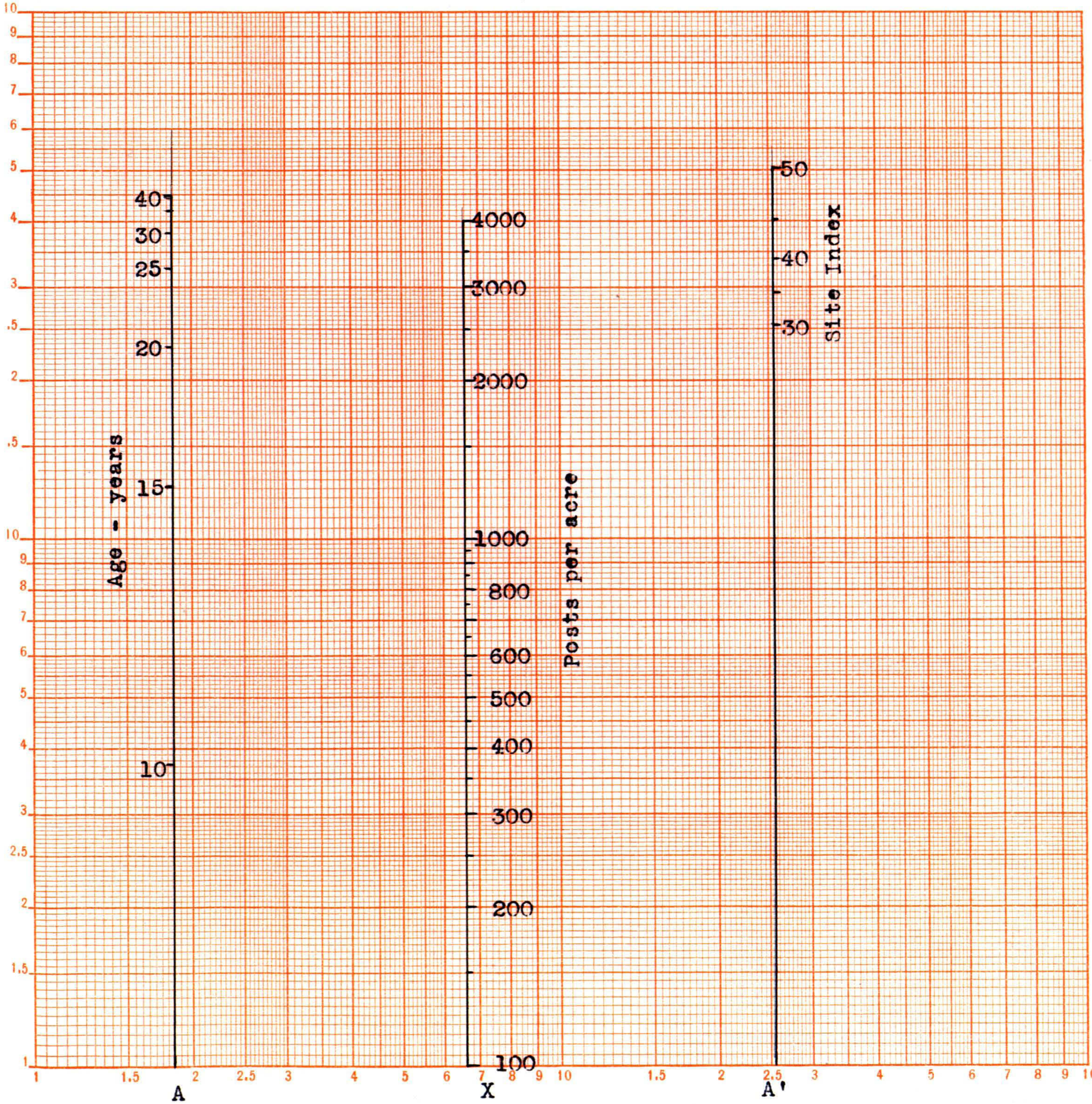



Fig. 22

## Table IV

### Instructions for Using Alinement Chart

### Yield Tables

| For | Hold Age on-- | Hold SI on-- | Read-- | Multiply by |
|---|---|---|---|---|
| Spruce, for | | | | |
| 1. Site classification (Fig. 11) hold age on A, hold ht. of aver. dom. on X, and read site index on A'. | -- | -- | -- | -- |
| 2. Height of average dominant (Fig. 11) | A | A' | X | -- |
| 3. Average d.b.h., inches (Fig. 11) | C | C' | X' | -- |
| 4. Tree basal area, square feet (Fig. 11) | C | C' | X | 0.001 |
| 5. Basal area, square feet per acre (Fig. 11) | B | B' | X | -- |
| 6. Volume, cubic feet unpeeled per acre (Figure 12) | A | A' | X | -- |
| Catalpa, for | | | | |
| 1. Site classification (Fig. 20) hold age on A, hold ht. of aver. dom. on 1/10 X, and read site index on A' | -- | -- | -- | -- |
| 2. Ht. of aver. dom. (Fig. 20) | A | A' | X | 0.1 |
| 3. Average d.b.h., inches (Fig. 20) | C | C' | X' | -- |
| 4. Tree basal area, sq. ft. (Fig. 20) | C | C' | X | 0.001 |
| 5. Basal area, sq. ft. per a. (Fig. 20) | B | B' | X | -- |
| 6. Linear feet per acre (Fig. 21) | A | A' | X | -- |
| 7. Seven foot posts per A. (Fig. 22) | A | A' | X | -- |

To study the effect of spacing on height growth, the plots were divided into two groups for each species, depending upon the spacing. In Norway spruce there were 30 plots with a spacing of 8x8 feet or less, and 17 plots with a spacing of more than 8x8 feet. In catalpa 19 plots had a spacing of 6x4 feet or less, and 25 plots had a spacing of more than 6x6 feet. For each division (based on spacing) for each species, the average height of each plot was plotted on the age of the plot. Curves were then drawn and balanced for each division for both catalpa and Norway spruce. The curves for Norway spruce are shown in Figure 23, and Figure 24 shows the curves for catalpa.

In determining whether or not spacing had any effect upon the total or stand basal area, a correlation coefficient for each factor was determined to see whether or not there was any correlation between spacing and basal area. The method used in computing the correlation coefficient is described by Wallace and Snedecor (34). The formula used in the computation is:

$$r = \frac{\Sigma AX - (\Sigma A)\, M_X}{\sqrt{\Sigma A^2 - (\Sigma A)\, M_A}\sqrt{\Sigma X^2 - (\Sigma X)\, M_X}}$$

The symbol A was given to the numbers designating the spacing. Thus, a spacing of 6x6 feet has 36 square feet to the tree, 7x7 feet has 49 square feet, and so on. The symbol

X was given to the numbers representing basal area. The basal area, X, is to be thought of as dependent upon the spacing, A.

The following correlation coefficients were determined by the above formula:

| Species | r: Tree basal area | r: Stand basal area |
|---|---|---|
| N. spruce | 0.224 | 0.234 |
| Catalpa | -0.001 | 0.080 |

Results

The results discussed here are, as nearly as possible, an interpretation of the graphs and computations which have been brought about in analyzing the data. The results are divided into the same three divisions that were used under the heading "Office Work." They are Height growth, Yield tables, and Effect of spacing.

Height growth

The factors studied which seem to have an effect upon height growth are soils, size of shelterbelts, and position of the trees in the shelterbelt. Of these three factors the first seems to have the most effect upon height growth and the latter apparently very little.

As well be noticed in Figure 2, Carrington soil seems to be more favorable to height growth of both species than

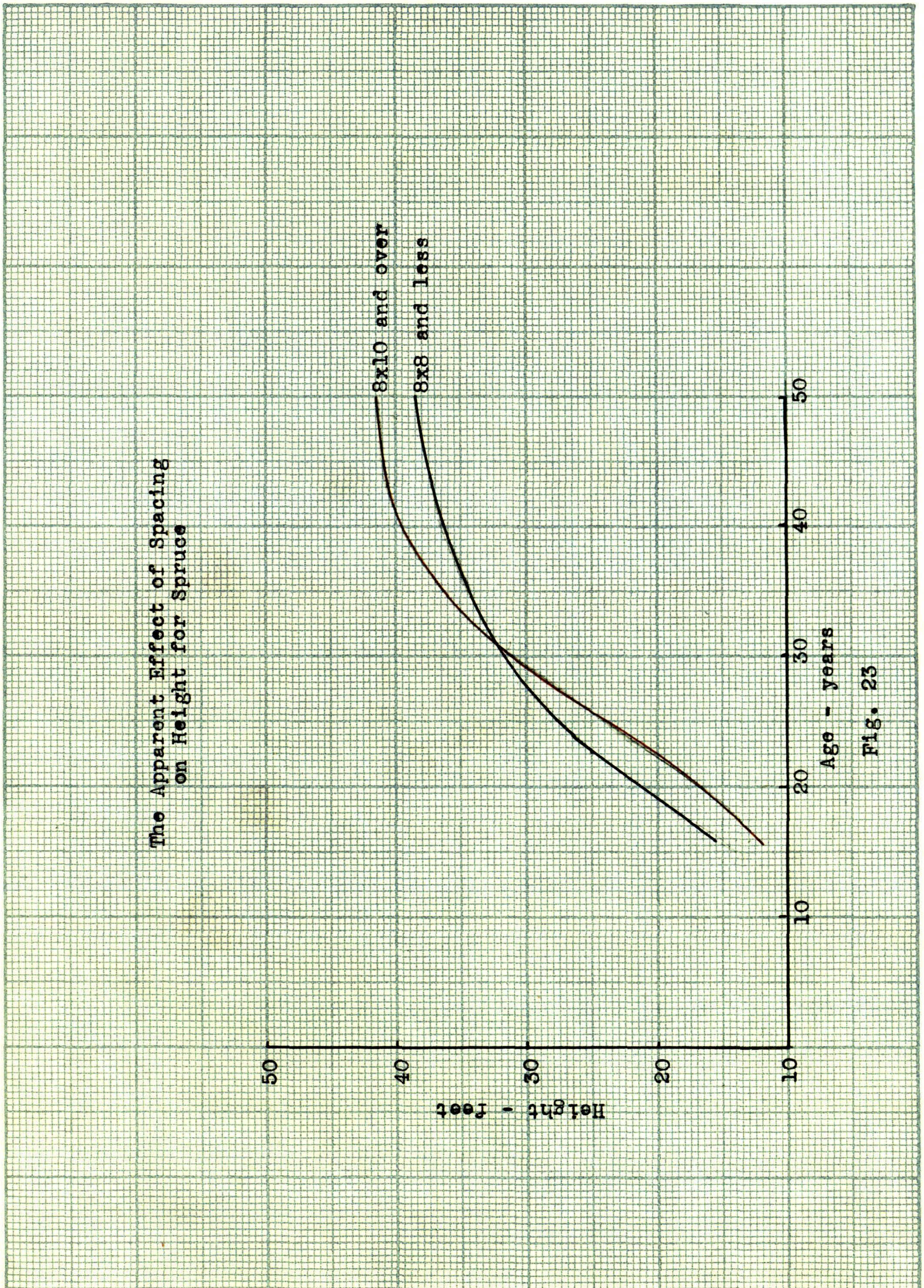
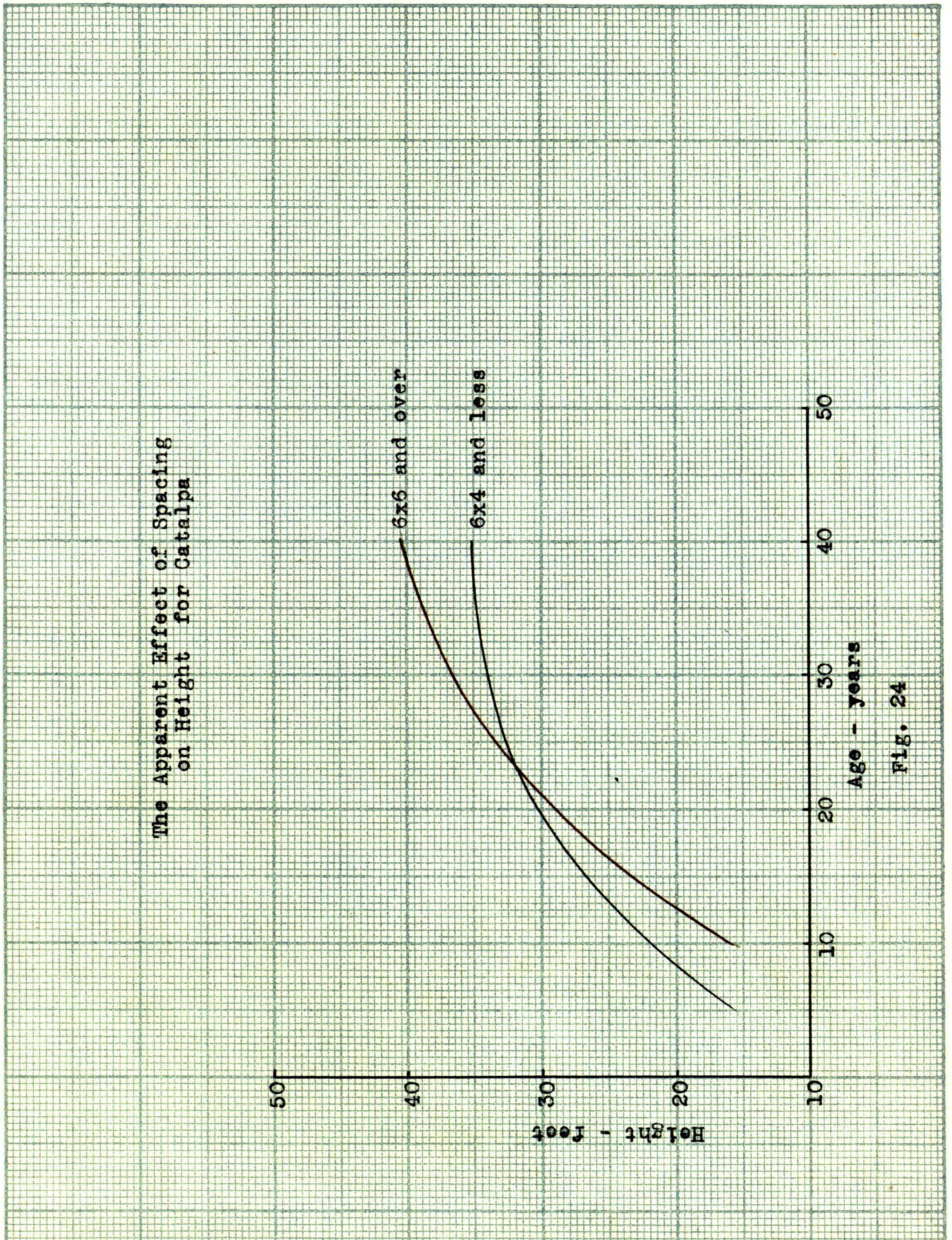

The Apparent Effect of Spacing
on Height for Spruce
8x10 and over
8x8 and less
Height - feet
10
20
30
40
50
Age - years
10
20
30
40
50

Fig. 23




The Apparent Effect of Spacing on Height for Catalpa

Fig. 24

does Clarion soil. This noticeable decrease in height growth on Clarion soils is probably due to the high lime content of this soil. In extreme cases the lime content of Clarion soil has been found to be as high as 50 per cent. According to Stevenson (32) a high lime content will cause the soil nutrients to become unavailable to the plant. If this is so, it seems that the growth of the plant would be affected and it might even cause death on soils where the lime content was extremely high.

Clarion soil is a drift soil and occurs on the brow of gentle slopes and along the tops of the low glacial ridges where the underlying lime soil has been exposed. The soil down to about 20 inches has a very low acidity and is basic from 20 inches downward. Carrington loam on the other hand occurs along gentle slopes in rolling to flat country. The upper 40 inches of this soil is of medium acidity and is usually basic from 40 inches downward.

The second factor which has apparently affected the height growth of both species is the size of the shelterbelt. Figure 3 shows that for both catalpa and Norway spruce, the shelterbelts with the greater number of rows have, on the average, attained greater height than have those with a lesser number of rows. Hall (14) says that exposure to the winds will greatly reduce growth in height. It is obvious that on a narrower shelterbelt a larger per cent of the trees would be exposed to the winds than would the trees on a wider shelterbelt. Consequently, it would seem that a narrow shelterbelt would tend to be shorter in height than a wider one. Also, in a wide shelterbelt a larger percentage of the trees is competing for light than in a narrow one, because in a narrow shelterbelt there is a larger per cent of the trees on the edges of the shelterbelt which receive ample light from the sides. Thus, the fact that a larger per cent of the trees on a wide shelterbelt is competing for light than on a narrow one might make competition for light a factor influencing height growth on different sized shelterbelts.

It is interesting to note that in Figure 3 the difference in height growth of the catalpa as affected by the size of the shelterbelt is greater than the difference in Norway spruce. Also, the catalpa shelterbelts varied from 2 to 12 rows while those for Norway spruce only varied from 2 to 7.

The factor which appeared to have the least effect upon height is the position of the trees in the shelterbelt. The curves in Figure 4 show that in the younger ages for both species the south row is very little shorter than the others, while in the older aged shelterbelts the south rows are considerably shorter than the average of the other rows. This difference in height might be caused by either exposure of the south rows to the dry south winds or by the lack of competition for light. It might be stated here than in addition to being shorter in height the trees of the south rows of the shelterbelts were probably more branchy, more poorly shaped and crooked, but had a larger average d.b.h. than did the trees of the other rows. This was especially noticeable in the case of catalpa.

It will be noticed in examining Figure 6 that the average height on the catalpa plantations is greater in the younger age classes than is the average height for Norway spruce at the same age. Further, the average height for Norway spruce is greater than the average height for Catalpa in the older age classes. Thus, though the catalpa windbreaks possibly protect a larger area when they are young, the Norway spruce windbreaks will ultimately protect a larger area and probably make a more satisfactory windbreak. Norway spruce windbreaks apparently not only reach a greater height and protect more area than do catalpa windbreaks, but the fact that the crown is longer and more dense and that the leaves are retained during the winter makes the Norway spruce windbreak the more impenetrable barrier of the two species.

## Yield tables

Upon glancing at the yield tables, it will be noted that the site index classes for the two species differ; that is, the site index classes for Norway spruce are 20, 30, and 40 and those for catalpa are 30, 40, and 40. The original data fell into these classes when the plots were classified as to site. The site classification age was 30 years. The average site index for catalpa at age 30 was 36.1, while for Norway spruce it was 31.7. Thus the average site index of catalpa falls into the 40-foot site index class and the average site index for Norway spruce falls in the 30-foot site index class.

Table V shows the yields per acre for both species and Table VI shows the mean annual increment per acre. From Table VI it may be seen that maximum yield per acre is obtained at age 40 for Norway spruce, while for catalpa the maximum yield per acre occurs at age 20. Thus, catalpa may be grown on a shorter rotation than Norway spruce and a maximum yield in posts be obtained. However, if the total stem volume for catalpa was used, the length of the rotation would probably be decreased more.

In addition to the fact that catalpa can be grown on a shorter rotation than Norway spruce, the value of catalpa for fence posts may make it a more desirable "crop" for the farmer. In addition to the posts cut from a catalpa plantation, a considerable amount of fuel may be obtained from the limbs and tops. Since catalpa sprouts vigorously, this would do away with buying seedlings after each cutting.

Tablo V

Yield in Cubic Feet por Acre -
Norway spruce

| Age | Site index | | |
|---|---|---|---|
| | 20 | 30 | 40 |
| 20 | 660 | 890 | 1110 |
| 25 | 1190 | 1630 | 2040 |
| 30 | 1930 | 2650 | 3300 |
| 35 | 2650 | 3600 | 4500 |
| 40 | 3110 | 4250 | 5300 |
| 45 | 3320 | 4500 | 5650 |
| 50 | 3450 | 4750 | 5900 |

Yield in Seven Foot Posts per Acre -
Catalpa

| Age | Site index | | |
|---|---|---|---|
| | 30 | 40 | 50 |
| 10 | 950 | 1090 | 1340 |
| 15 | 1780 | 2050 | 2500 |
| 20 | 2420 | 2780 | 3400 |
| 25 | 2900 | 3300 | 4050 |
| 30 | 3120 | 3550 | 4350 |
| 35 | 3250 | 3750 | 4600 |
| 40 | 3380 | 3900 | 4700 |

Table VI

Mean Annual Increment - Cubic Feet per Acre
Norway spruce

| Age | Site index 20 | Site index 30 | Site index 40 |
|---|---|---|---|
| 20 | 33.0 | 44.5 | 55.5 |
| 25 | 47.6 | 65.2 | 81.6 |
| 30 | 62.1 | 88.3 | 110.0 |
| 35 | 75.7 | 102.8 | 128.5 |
| 40 | 77.7 | 106.2 | 132.5 |
| 45 | 73.7 | 100.0 | 125.5 |
| 50 | 69.0 | 95.0 | 118.0 |

Mean Annual Increment - Seven Foot Posts
per Acre - Catalpa

| Age | Site index 30 | Site index 40 | Site index 50 |
|---|---|---|---|
| 10 | 95.0 | 109.0 | 134.0 |
| 15 | 118.6 | 136.6 | 166.6 |
| 20 | 121.0 | 139.0 | 170.0 |
| 25 | 116.0 | 132.0 | 162.0 |
| 30 | 104.0 | 118.3 | 145.0 |
| 35 | 92.8 | 107.1 | 131.4 |
| 40 | 84.5 | 97.5 | 117.5 |

<u>Effect of spacing</u>

That spacing has an effect upon height growth seems quite evident from the graphs in Figures 23 and 24. In the case of both Norway spruce and catalpa it will be noticed that the narrower spacing is conducive to better height growth in the younger age classes. The closer spacing causes the crowns to come together sooner and probably the competition for light brought about by the crowding of the crowns makes for better height growth. The crowns in the wider spaced windbreaks, on the other hand, do not close until a few years after the closer spaced ones; consequently rapid growth in height is possibly delayed until the crowns do begin to compete for the light.

Further, the graphs of both species show that where there is a wider spacing the height growth finally becomes greater in the older age classes. This is probably due to the stagnation of the trees in the plantations of narrower spacing, and though stagnation may occur to a certain extent in the wider spaced shelterbelts the degree to which the growth is reduced is not so great. Thus, it might be said that wider spaced shelterbelts tend to have slower early height growth than do plantations of narrower spacing, but due to stagnation the height of narrow spaced windbreaks is less in the older age classes than the height of plantations of wider spacing. Consequently, an experiment which might give some interesting results could be carried out to determine the best spacing for obtaining a maximum height growth and a maximum yield per unit area.

That spacing has apparently little effect upon the basal area of the species studied seems quite evident from the correlation coefficients obtained. However, in the case of Norway spruce plantations, there seems to be a closer relationship between spacing and basal area than for catalpa. This relationship is so small according to the coefficients, however, that it does not seem probable that a closer spacing or wider spacing, unless run into extremes, would increase or decrease the basal area per unit area enough to make the alinement chart for basal area invalid. It is quite obvious that if the stand basal area does not increase with an increase in the number of trees per unit area, the average or tree basal area will become less. Consequently, one might conclude that wider spacing makes for larger average diameter, and narrower spacing makes for smaller average diameter, but in both cases the total or stand basal area per unit area will remain about the same.

## CONCLUSIONS

Owing to the fact that the data secured as the basis of this thesis are confined to rather restricted site conditions, the conclusions here presented may not be applicable over a wide area. Since the basic data are rather meager the factual basis for conclusions is also less desirable than might be hoped for. After examining and analyzing the data secured, the writer feels that the following conclusions may be justified.

(1) Clarion soil (calcareous) seems to be less favorable to the growth of the species studied than does Carrington soil (non-calcareous). The trees on the Clarion soils were shorter in height, smaller in diameter, and more crooked and misshapen than were the trees on the Carrington soils.

(2) On the wider shelterbelts the average height for both species studied was greater than the average height of the trees on the narrow shelterbelts at the same age.

(3) Trees located in the south rows of the shelterbelts studied tended to have a larger average diameter but were shorter than were the trees in the center or on the north side of the shelterbelt.

(4) In the younger shelterbelts studied the catalpa

seemed to grow faster in height than did the Norway spruce, but after about age 35 the height of Norway spruce exceeded that of the catalpa shelterbelts.

(5) In Central Iowa catalpa can be grown on a shorter rotation than Norway spruce on the basis of maximum average volume growth.

(6) Close spacing in the case of both species studied appeared to produce taller trees early in life and shorter trees later in life than in the case of wider spaced plantations.

(7) The data seems to show that spacing may cause as much as five feet difference in height growth of catalpa and three feet difference for Norway spruce. This would cause the site index to vary for the different spacings. Consequently in using Reineke's method of yield table construction, this would involve the preparation of separate site index charts for all different spacings before a yield table could be applied upon plantations.

(8) The fact that the wider spaced catalpa and Norway spruce shelterbelts attained a greater height in the older age classes seems to show that narrow spaced plantings should be thinned for maximum wood production but not necessarily for wind protection.

(9) In this study spacing seemed to have little effect upon total or stand basal area of either species. Closely spaced shelterbelts, on the average, had about the same total

basal area as did the widely spaced ones.

(10) If spacing has little effect upon total basal area, it is obvious that the average or tree basal area will be greater on widely spaced plantings and smaller on narrowly spaced plantings.

(11) The fact that the spacing, on the species studied, has little effect upon total basal area makes the stand basal area alinement charts usable for any spacing.

(12) That Norway spruce is the most valuable of the two species studied for furnishing maximum protection from the wind is quite evident. However, its value as a farm product is probably not as great as is that of catalpa.

(13) As a windbreak, Norway spruce does not become a very effective one until it has reached the age of about 20 to 25 years, while catalpa will reach a good height and make a fair windbreak somewhat earlier in life.

(14) The fact that catalpa can be grown on a much shorter economic rotation than can Norway spruce will make for a quicker return to the farmer. Since catalpa sprouts vigorously, it would not be necessary to replant after cutting as would be the case with Norway spruce.

(15) Norway spruce is apparently valuable for planting in Central Iowa only where the primary consideration is protection from the wind. Catalpa is apparently more valuable where a fast growing species is desired to give quick but

partial and temporary protection and a maximum yield.

(16) In some instances it may be desirable to have both maximum protection from the wind and maximum yield. In such a case, a combination of these two species could be used.

## SUMMARY

Before the actual investigative work of this thesis was presented, certain introductory measures seemed essential.

The need of shelterbelts and their value to the farm home is briefly discussed in the introduction proper. Further, there is a limited discussion upon the need of shelterbelts which will furnish usable wood products as well as furnish adequate protection from the winds. Mention is made of the species studied. A brief outline of the objectives is presented.

In order to familiarize the reader with other similar investigations, a resumé of the growth on other plantations is given. An historical background of the evolution of yield tables is presented. A brief discussion of the effect of the shelterbelt upon the surroundings is included.

In the investigation a general discussion of the field study is given. The steps in the office work brought about in studying the objectives of this thesis are presented, as are the graphs and charts which were used in analyzing the data. The results are discussed and interpreted as nearly as possible.

In the conclusions a series of numbered statements are presented which summarize the deductions made throughout the course of the investigation.

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