AN INVESTIGATION OF THE TOLERANCE OF WHITE ASH REPRODUCTION

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Kenneth Wayne Guenther

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By

KENNETH WAYNE GUENTHER

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By

Kenneth Wayne Guenther

INTRODUCTION

The genus Fraxinus yields woods which are greatly desired for their physical properties, such as, strength, hardness, stiffness, shock-resisting ability, absence of odor, and excellent bending qualities. Because of the deminishing amount of ash in the Central Hardwoods Region, the center of production of this wood has shifted to Louisiana, Tennessee, and Georgia. Of the ash genus, the species most abundant and important in the United States is the white ash (Fraxinus americana L.).

White ash, a dioecious tree, occurs as a minor species in the beech—sugar maple forest type in the Central Hardwoods Region. Being tolerant in early life and less tolerant later, white ash reproduction decreases in its percentage representation in the stand with age, under normal all-aged forest conditions. It was an empirical observation of the author that white ash in the later sapling stage[1/] is rarely found under dense canopies. Under a high thin canopy, however, or in openings, the pole stage[2/] can be reached. The purpose of this study was to ascertain specifically under what canopy conditions ash reproduction will maintain its vigor and when it will not.

1/ The sapling stage is from 3 feet high to 4 inches diameter breast high (d.b.h.).

2/ The pole stage is from 4 inches d.b.h. to 12 inches d.b.h.

REVIEW OF LITERATURE

White ash is reported by Cope (4) to be not very exacting in its seedbed requirements. Sterrett (11), however, states that ash seed is especially demanding in its moisture requirements for germination and seedling establishment, but that a moderately open seedbed is sufficient. An anonymous British author (1) recommends that ash reproduction should be attempted only on moist, fresh soils and that its associates should be encouraged on the drier sites.

Toumey and Korstian (12) consider white ash reproduction as being very exacting and as deteriorating rapidly when planted on sites where available moisture falls much below that required for optimum growth. Feher (5) reports white ash as requiring 70 to 75 per cent of the water absorptive capacity[3] of the soil for optimum growth. Sterrett (11) considers the genus Fraxinus as being less exacting on loose, friable soils than on tight soils. He further states that the genus is adapted for non-acid swamp conditions if grass competition is absent and the water is not stagnant. However, he reports white ash as tolerating drier sites than most of the ashes.

The division of white ash into three ecotypes[4] has been suggested by Wright (15) after his study at the Harvard Forest Nursery. Seeds for the study were collected from throughout the botanical range of white ash. The northern ecotype found from Michigan to central Pennsylvania and New England exhibited little winter-kill, had a bushy root system, and showed a lack of pubescence and anthocyanin development.

3/ Field capacity.

4/ The product arising as a result of the genotypical response of an ecospecies to a particular habitat.

The intermediate ecotype found in a narrow belt through southern Pennsylvania, northern West Virginia, and Ohio exhibited moderate winter-kill, a bushy root system, and a high incidence of pubescence. The southern ecotype found in all remaining southern regions exhibited heavy winter-kill, had a tap root, and had leaves which were glossy above and pubescent underneath. Wright (15) believes that one of the juvenile characteristics of white ash is its inability to harden off properly even in a climate to which its progenitors are native. Because of this characteristic, young white ash progresses very slowly until mature enough to withstand winters unharmed.

White ash sprouts successfully from young trees, according to Westveld (18). However, seedlings are the major method of regeneration. He also states that seedling sprouts made two to three times the growth of seedlings and suggests conversion of seedlings to seedling sprouts if feasible.

In North Carolina, Kramer (8) found that white ash seedlings made twice the shoot growth of red oak seedlings. Starrett (11) reports that ash made practically all its growth by July and that it spent the remainder of the normal growing season in hardening the current growth.

Patton (10) found the heights of white ash reproduction under non-described canopy conditions to be: 1.5, 3.0, 4.9, 6.5, 8.1, 9.9, 11.7, 13.7, 15.6, and 17.9 feet respectively for the first ten years. During the period of from 16 to 20 years, height growth decreased and ash expressed its "crowd-enduring" characteristic. This characteristic is evidenced by the occurence of acutely angled branches and natural pruning of lower branches.

Starrett (11) describes white ash as being able to reproduce

under a comparatively dense canopy and seedlings as being able to survive for from five to twenty years in a stunted condition. He states that ash under unfavorable light conditions responds quickly to increased light. He adds, that under a canopy in Ohio seedling height was: .5, 1.2, 2.0, 3.0, and 4.0 feet respectively, for five years. He reports that in a clear-cut area in New York and Massachusetts seedling height was: .5, 1.6, 3.0, 4.6, and 7.0 feet respectively for five years. Sterrett (11) states that white ash seedlings in early life grow faster on a sandy loam soil than on a clay soil, but this advantage is not maintained. Ash is apparently more tolerant on clay soils.

As a recommended cutting practice for ash, Cope (4) suggests a completely closed canopy until harvest in order to discourage seedlings and suckers of less desirable tolerant species. At harvest he suggests clear-cutting narrow strips, or openings of approximately 100 feet in diameter, which would give satisfactory regeneration in from 10 to 20 years. He points out that cleanings may be necessary 5 years after the openings are made.

Hawley (6) proposes that under certain circumstances white ash seedlings grow best in partial shade and that the shelterwood method of cutting is desirable.

Holsoe (7) reports white ash crown lengths as varying from 1/3 to 3/4 of the stem, based on 100 trees from 3.0 to 18.5 inches diameter breast high. He also found that white ash maintains the same ratio between crown diameter and crown length throughout its development. Consequently, he believes ash is easily kept in check by the crowns of adjacent tolerants.

According to Patton (10), the final objectives for white ash at

age 70 years should be a diameter of 12.4 inches breast high, a height of 82 feet with a 50 foot clear bole, and a crown radius of 9.1 feet. Baker (2) in his Revised Tolerance Table suggests that white ash be considered as a tree having intermediate tolerance.

Lutz and Chandler (9) believe it is possible and practical to adopt forest tree species that will maintain or improve soil fertility. One such soil-improving species is white ash with its high nutrient content in its leaf litter.

The major natural agents destructive to white ash are:

1. White rot (Fomes fraxinophilus Say.)
2. Ash leaf rust (Puccinia peridermiospora ((Ellis & Tr.) Arth.)
3. Oyster shell scale (Lepidosaphes ulmi L.)
4. Ash borer (Podosesia fraxini Lug.)
5. Lilac borer (Podosesia syringae Harris)
6. Ash bark beetle (Leperisinus aculeatus Say.)
7. Browsing animals
8. Fire

PROCEDURE

The basis of this study was 26 areas of natural white ash reproduction in the beech—sugar maple woodlots of Ingham county.[5/] Small areas varying from 250 square feet to 1,700 square feet in size, with an average of 800 square feet, and containing from 10 to 200 white ash seedlings were selected for observations, providing they met the following requirements:

1. A definite, definable canopy over or or adjacent to the plot.
2. Not too much competition from ground cover.
3. Similarity as to soil type (Hillsdale sandy loam, heavy phase, or Conover loam.).

When plots were considered as acceptable in regard to the three requirements, a series of ten observations was made on each plot.

FIELD PROCEDURE

The ten observations made on each plot were:

1. Canopy opening—The presence or absence of a canopy opening over the plot was noted. If an opening existed, its area and general shape and the direction of the long axis were recorded. Definite evidence of past history such as a recently closed canopy was noted. No plots were studied if there was evidence of recent severe disturbance in the overhead or adjacent canopies due to logging or windthrow. Canopy conditions to the east, south, and west of the plot were also studied. Any significant canopy openings in those three directions

5/ There were three plots in Livingston county, in an Oak—Hickory Type.

as well as the time of day they influenced the plot, were observed and recorded.

2. Canopy height—The canopy was classified into three canopy height classes which were:

(a) Low - Saplings less than 15 feet in height; or enough saplings under a higher canopy to influence strongly conditions and give the effect of a low canopy.

(b) Medium - Young mature timber, or mature timber with enough saplings present to average medium height. General height being from 15 to 80 feet.

(c) High - Mature timber with minor influence of any other canopy height class. General height being over 80 feet.

Any subdominant height class that occurred with the predominant height class, as well as its distribution and direction from the plot were noted.

3. Canopy density—The canopy was studied with respect to its effect on the plot. The three canopy densities that were used were:

(a) Thick—The dense, low type of canopy generally associated with a closed sapling stand. No openings are present in the canopy. There may be some overtopping trees in the overstory. Considering full sunlight as 10,000 foot candles, approximately one per cent of full sunlight is present.

(b) Medium—The broad range into which most canopies would be classed. A medium to high continuous canopy height generally being present, with a few scattered openings occurring. Considering full sunlight as 10,000 foot candles, approximately one to three per cent of full sunlight is present.

(c) Thin—The sparse but still continuous canopy often exhibited by an oak—hickory stand. There are many small patches in the canopy, where the crowns do not close. Considering full sunlight as 10,000 foot-candles, approximately three per cent or more of full sunlight is present.

4. Area of plot—The approximate square foot area of the plot was determined by pacing the length and width and multiplying them together. The plot was considered the area on the ground between the trunks of the stems of the overstory. Any distinct shape of the plot as well as the direction of the long axis was also recorded.

5. Weston Foot-Candle Meter readings—Foot-candle meter readings were taken at average reproduction height with the aid of a Weston Phoronic Foot-Candle Meter, Model 614. The readings were taken only between the hours of 11:30 A.M. and 12:30 P.M. which is the period of maximum solar light. A series of from one to five readings was taken on each plot and averaged. Readings were not taken in direct sunlight when an opening existed, nor in small patches of light that sometime exist under a closed canopy. The cell in the meter was held parallel to the ground at waist height. An approximation of light conditions was sought. Readings were taken with a range of values and an average taken. The meter was held away from the observer so as to introduce no shadows. Only cloudless, clear days or sparsely intermittent cloudy days were accepted for readings. No readings were taken when clouds interferred with the sunlight. The following readings were recorded: (1) the reading number, (2) the reading value in foot-candles, (3) the date, (4) the time the reading was made, (5) weather conditions prevailing.

6. Soil type and organic matter conditions—Soil types were correlated with a United States Bureau of Plant Industry, Soil Survey Map and field checked by the use of a soil auger. The litter layer (Aoo and Ao) thickness was also observed and recorded in inches.

7. Topography and exposure—The topography of the plot was noted, and its relation to the general topography was recorded. The exposure of the plot as determined by the slope of the plot surface was also considered as a factor in description.

8. Distribution of ash reproduction and total number—The distribution of the ash reproduction on the plot was considered. The term "even distribution" was applied to a plot when approximate equality of distribution of ash reproduction occurred. When unequal distribution occurred, the condition was described; however, if possible, plots having uneven distribution were avoided. A close approximation of the total number of ash stems on the plot was made.

9. Ground competition—The tree species other than ash present on the plot, as well as grasses and herbs, and their condition of vigor and abundance was noted. Relative importance of the effect of the ground competition on the ash reproduction was ocularly estimated and recorded.

10. Measurement of ash reproduction—Height measurements were taken on all ash reproduction that was independent of shading influences by ground competition. By thus restricting the stems studied, the shading effect of the overstory canopy was isolated. Starting from the leader, the growth for each year was measured to the nearest one tenth of a foot from current growth, back until the groundline was reached. The height growth made each year was determined by measuring

the distance between terminal bud scars. Any stems that were determined to be seedling sprouts were not measured because of the advanced root systems of such stems.

OFFICE PROCEDURE

A summary sheet of all the plots was made wherein was listed the following items for each plot:

1. Plot number
2. Estimated square foot area of canopy opening, if any
3. Canopy height
4. Canopy density
5. Average of foot-candle meter readings.

It was not possible actually to make foot-candle readings on all the plots on the same day. It was possible, however, to adjust all plot average readings to a base day because adjustment factors could be computed from several plots where daily readings were repeated.

The plots located under canopy openings were separated from the plots under closed canopies. The plots under canopy openings were further divided into small openings of less than 700 square feet and large openings of more than 700 square feet. The division resulted in three plots in the small opening class and three plots in the large opening class.

The closed canopy plots were divided on the basis of adjusted foot-candle meter readings and canopy descriptions. High canopy height with thin density and high canopy height with medium density were considered as one group with available sunlight being three or more per cent of full sunlight. This group consisted of eight plots and was referred to as a light canopy. Medium canopy height with medium density, low canopy height with medium density, and low canopy with thick density

were considered as another group. This group consisted of twelve plots that had from one to three per cent of full sunlight and is henceforth referred to as a heavy canopy.

All white ash reproduction was divided on the basis of age. The age classes used were from one to nine years, from ten to fifteen years, and over sixteen years. The reproduction in any of the four canopy condition classes would therefore be subdivided on the basis of age into one, two, or three groups. Theoretically there would be a total of twelve canopy-age class divisions, but the data supported only nine such divisions, as shown in Table 1 on page 12. These canopy-age class divisions permitted a comparison of the height growth of different age classes within each canopy class and a comparison of the height growth under each canopy class for each age class. These comparisons are made in Tables 2 to 5 on pages 22 to 24 and Figures 1 to 6 on pages 25 to 30. The average annual height growths shown in Tables 2 to 5 on pages 22 to 24 were derived by dividing the total height growth made by an age class in a particular year by the number of stems in the age class that were growing that year. The cumulative height growths shown in Tables 2 to 5 on pages 22 to 24 were determined by adding each successive annual height growth, thereby giving the average total height per stem within an age class, for a specific year.

Table 1.—Summary of division of plots, by canopy conditions and of division of white ash reproduction by age classes.

Canopy Condition of Plots	Number of Plots	Age Class Division of Reproduction, in Years		
		1 to 9	10 to 15	16 plus
Heavy Canopy	12	Yes	Yes	Yes
Light Canopy	8	Yes	Yes	Yes
Small Opening	3	Yes	No	No
Large Opening	3	Yes	Yes	No

DISCUSSION

All observations, of the original 10 observations made on each plot, that were not used as a basis of comparison in this study were either held constant and hence didn't affect the problem or they exhibited no correlation. Of the observations thus disregarded were: (1) soil types (2) litter layer thickness (3) typography and exposure (4) distribution of ash reproduction on the plot (5) total number of ash stems on the plot (6) approximate shape of the plots (7) ground vegetative competition.

Parallelism of shape exists between curves in some of the age classes in Figures 1 and 2 on pages 25 and 26. Parallelism is especially consistant in Figure 2 during the period of from 1944 to 1948. This parallelism was investigated for possible correlation with per cent of possible sunshine or precipitation as shown in Figures 11 and 12 on pages 35 and 36. No definite correlation can be made between any one climatic factor and the average annual height growth. Average annual height growth is the result of a combination of climatic factors influencing the site rather than any one climatic factor causing the influence.

EFFECTS OF CANOPY CONDITIONS AND AGE CLASS OF REPRODUCTION ON VIGOR

Effect of Age of Reproduction on Vigor

Average Annual Height Growth of White Ash Reproduction Under a Heavy Canopy (Figure 1.)

All three age classes are represented in this canopy class. The

curves representing the three age classes in this figure all show a rapid decline in annual height growth during the first 4 to 6 years after establishment. This initial decline is followed by a longer period of gradual decline occurring over a period of 15 years or more. This pattern, or portion of it, is found exhibited in all the age classes in this canopy condition class.

There is some parallelism of curves expressed during the period of from 1943 to 1949. The parallelism is not too strongly expressed because of the low vigor of the two older age classes, and especially the 16-plus-year age class. This low vigor tends to mask the effect of climatic influences.

An annual height growth of four tenths (0.4) of a foot was arbitrarily considered as acceptable growth for white ash reproduction. A few years after establishment, all the age classes in the heavy canopy class had fallen below that value and never rose up to it again.

Average Annual Height Growth of White Ash Reproduction Under a Light Canopy (Figure 2.)

This canopy class has all three age classes represented by field data. The curves for the 1 to 9 and the 10 to 15 year age classes are similar during the last six years. An upward trend in vigor has occurred the last few years in those two age classes. The average annual height growth for the two younger age classes has generally been above the arbitrarily acceptable value of four tenths (0.4) of a foot.

The curve for the 16-plus-year age class does not follow the trend that is found in the curves of the two younger age classes. The 16-plus-year dropped in vigor eight years after establishment and in general

remained low in vogor thereafter. The 10 to 15 year age class should exhibit this same trend if it is significant. However, the 10 to 15 year age class did not behave in such a manner. The 10 to 15 year age class curve was based on over six times as many observations as the 16-plus-year age class curve was. Consequently, the 16-plus-year age class under a thin canopy was considered as not as significant as the 10 to 15 year age class and was disregarded.

There is a definite parallelism among all age class curves especially from 1944 to 1948. This parallelism is discussed under the general discussion on page 13.

Average Annual Height Growth of White Ash Reproduction Under Small Canopy Openings (No Figure)

Only the 1 to 9 year age class is represented in this canopy class. The figure representing the reproduction under a small canopy opening was not constructed. Since only the 1 to 9 year age class was represented there was no basis of comparison within that canopy class. The curve for this age class can be found in Figure 5 on page 29. The 1 to 9 year age class curve does show a fairly constant range of annual vigor and is above the arbitrary four tenths (0.4) of a foot annual height growth.

Average Annual Height Growth of White Ash Reproduction Under Large Canopy Openings (Figure 3)

The 16-plus-year age class in this canopy class was not represented by field data. In general the curves show a maintenance, if not an increase, of annual height growth. The average annual height growth was

generally greater than the arbitrary four tenths (0.4) of a foot.

Effect of Canopy Class on Vigor of Reproduction

Average Annual Height Growth of the 1 to 9 Year Age Class of White Ash Reproduction Under Various Canopy Conditions (Figure 4)

All canopy condition classes other than the heavy canopy exhibit close proximity in vigor. The heavy canopy has much lower vigor than the other classes as its curve shows a downward trend. The other canopy condition classes exhibit good vigor as expressed by their annual height growth. The heavy canopy curve shows less than four tenths (0.4) of a foot height growth while the other curves have growth that is greater.

Average Annual Height Growth of the 10 to 15 Year Age Class of White Ash Reproduction Under Various Canopy Conditions (Figure 5)

The curves representing ash reproduction under a light canopy or large openings are close together and are above the arbitrarily acceptable four tenths (0.4) of a foot annual height growth. The curve representing ash reproduction under a heavy canopy has a definite downward trend which places it far below the acceptable four tenths (0.4) of a foot annual height growth. No field data for reproduction under small canopy openings was available.

Average Annual Height Growth of the 16-plus-year Age Class of White Ash Reproduction Under Various Canopy Conditions (Figure 6)

The curve for the light canopy condition is to be disregarded for

the reasons explained in the discussion of Figure 2 on page 14. The curve representing heavy canopy conditions has a definite cumulative decrease in vigor as expressed by the small annual height growth. Field data for reproduction under canopy openings in this age class was not available.

Cumulative Height Growth of the 1 to 9 Year Age Class of White Ash Reproduction Under Various Canopy Conditions (Figure 7)

The cumulative height curves show how closely the canopy condition classes, other than the heavy canopy, resemble each other in their effect on height growth. The cumulative height growth for the canopy condition classes, other than the heavy canopy, approach the position of a 45 degree line.

Cumulative Height Growth of the 10 to 15 Year Age Class of White Ash Reproduction Under Various Canopy Conditions (Figure 8)

The curves for the light canopy and large openings are approximately the same shape and occupy the same position. The cumulative height growth for these canopy condition classes approximates the position of a 45 degree line. Field data for reproduction under small openings in this age class was unavailable.

The cumulative height growth of the heavy canopy class is increasing at a decreasing rate. The curve has already begun to level off. Figure 11 on page 35 shows the comparison between these curves by using a common origin. Hence, the difference between them is more apparent.

Cumulative Height Growth of the 16-plus-year Age Class of White Ash Reproduction Under Various Canopy Conditions (Figure 9)

The curve representing the light canopy is to be disregarded for the reasons explained in the discussion of Figure 2 on page 26.

A leveling off of the heavy canopy curve as described in the discussion of Figure 9 on page 33 is also found in Figure 10 on page 34. This constant reduction in annual height growth can only result in death of the trees. No field data was available for ash reproduction in this age class under canopy openings.

GENERAL DISCUSSION OF A COMPARISON OF CANOPY CONDITIONS

The effect of canopy conditions on the vigor of white ash reproduction breaks down into one of two conditions. A heavy canopy results in one condition, while a light canopy or canopy openings result in another condition. These two conditions are subsequently discussed.

Heavy Canopy Conditions

Under a heavy canopy white ash reproduction of all age classes exhibited a rapid decline of vigor during the first 4 to 6 years after germination. This rapid decline is followed by a much longer period of 15 years or more of gradual decline in vigor. These vigor reductions follow essentially the same pattern for each age class and are shown in Table 2 on page 22, and Figure 1, on page 25.

No stems were found that had increased their rate of annual height growth after having been growing at a rate of less than five hundredths (.05) of a foot per year for three or more successive years. The curve

for the 16-plus-year age class in Figure 1 on page 25 has reached an average of five hundredths (.05) of a foot height growth per stem per year. It seems evident that the majority of the trees in this age class are of such low vigor that they cannot recover and will probably die within the next few years. The maximum age of any tree within this canopy condition class was 23 years.

Reproduction under heavy canopies had poorer current vigor in all its age classes than reproduction under other canopy conditions; refer to Table 2 on page 22, and Figures 4, 5, and 6 on pages 28, 29, and 30 respectively. An arbitrary value of four tenth (0.4) of a foot height growth per stem per year was considered as acceptable growth. The reproduction under a dense canopy falls below this value 4 to 6 years after germination. No recovery is ever achieved and a gradual decline of vigor occurs. The principle cause of low vigor of white ash reproduction under these heavy canopies has undoubtedly been low light intensities, though it is possible that relatively severe root competition may also have been of major importance as a factor. This conclusion was reached because an objective of the study was to select plots where, within practicability, canopy condition and the resultant solar light intensity were the only variables.

Cumulative height growth for reproduction in all age classes is inferior to that of the reproduction under other canopy conditions as shown by Table 2 on page 22, and Figures 7, 8, 9, and 10 on pages 31, 32, 33, and 34 respectively. Under heavy canopies total height has begun to level off, while under the light canopies and under the canopy openings the total height is still steadily increasing. This inferior cumulative height growth of reproduction under a heavy canopy was due

to its low vigor as expressed by its small annual height growth.

Data taken in the field showed five stems that were dead under a heavy canopy. The age of these stems was from 10 to 17 years. These were the only stems that were found that were dead. They give an indication of the range of age during which reproduction under a heavy canopy will die.

Because of the poor vigor of ash reproduction under a heavy canopy (three per cent or less of full sunlight) it is suggested that white ash regeneration should be sought under a heavy canopy only in special cases. That is, only when it is proposed that some type of release cutting will be made. These release cuttings should be made before the majority of the reproduction is 10 years old because loss in vigor due to delay may result in death.

Light Canopy Conditions and Canopy Openings

The light canopy, small canopy openings, and large canopy openings result in essentially the same vigor conditions for white ash reproduction. This statement is substantiated by Figures 7, 8, and 10 on pages 31, 32, and 34 respectively, showing annual cumulative heights for the reproduction under a light canopy and under canopy openings.

Vigor within the 1 to 9 and within the 10 to 15 year age classes are very similar as illustrated by Figures 4 and 5 on pages 28 and 29 respectively. The vigor of the 16-plus-year age class under a light canopy as shown in Figure 2 on page 22 was not considered typical and was disregarded. The reasons for disregarding that age class data are explained in the discussion of Figure 2 which is on page 22.

The various age classes of reproduction under light canopy

conditions or under canopy openings showed a relatively small range of variation of vigor. That is, all age classes were approximately the same in vigor. This is in contrast to the vigor under heavy canopy conditions where a pattern of vigor decrease is evidenced.

White ash reproduction under a light canopy (three or more per cent of full sunlight) or under canopy openings had superior growth, within the same age class, to reproduction under a heavy canopy. The good vigor of ash reproduction under a light canopy or under openings was sustained as shown by Tables 3 and 5 on pages 23 and 24, and Figure 8 on page 32. Even after 15 years of growth there appeared to be no need of release cuttings under those canopy conditions. The reproduction maintained a steadily rising cumulative growth. It is probable that release cuttings will not be needed as seriously as they are needed under heavy canopy conditions. Consequently it is suggested that white ash reproduction should be sought under light canopies or under canopy openings.

Table 2.—Summary of average annual height growth and average annual cumulative height growth of white ash reproduction under heavy canopy conditions (based on 12 plots).

Year growth was made	Age Class 1 to 9 Years			Age Class 10 to 15 Years			Age Class 16-plus Years		
	Average annual growth (0.1 ft.)	No. of stems	Cumulative height (0.1 ft.)	Average annual growth (0.1 ft.)	No. of stems	Cumulative height (0.1 ft.)	Average annual growth (0.1 ft.)	No. of stems	Cumulative height (0.1 ft.)
1926							7.00	1	7.00
1927							7.00	1	14.00
1928							4.00	2	18.00
1929							4.00	2	22.00
1930							5.20	5	27.20
1931							2.71	7	29.91
1932				5.00	1	5.00	3.75	12	33.66
1933				6.00	1	11.00	3.39	18	37.05
1934				4.00	1	15.00	3.20	25	40.25
1935				4.88	16	19.88	2.92	25	43.17
1936				4.13	38	24.01	2.16	25	45.33
1937				3.48	60	27.49	2.44	25	47.77
1938				2.78	72	30.27	2.32	25	50.09
1939				2.40	82	32.67	2.16	25	52.25
1940				2.43	93	35.10	1.92	25	54.17
1941	5.56	9	5.56	2.28	94	37.38	1.84	25	56.01
1942	4.55	22	10.11	2.18	94	39.56	2.00	25	58.01
1943	2.97	40	13.08	2.75	95	42.31	3.28	25	61.29
1944	3.01	61	16.09	2.39	95	44.70	2.08	25	63.37
1945	2.33	72	18.42	1.19	95	45.89	1.28	25	64.65
1946	2.91	79	21.33	1.98	95	47.87	1.16	25	65.81
1947	2.01	79	23.34	1.48	95	49.35	.96	25	66.77
1948	2.59	79	25.93	1.18	95	50.53	.56	25	67.33
1949	2.42	79	28.35	1.19	95	51.72	.48	25	67.81

Table 3.—Summary of average annual height growth and average annual cumulative height growth of white ash reproduction under light canopy conditions (based on 8 plots).

Year growth was made	Age Class 1 to 9 Years			Age Class 10 to 15 Years			Age Class 16-plus Years 17/		
	Average annual growth (0.1 ft.)	No. of stems	Cumulative height (0.1 ft.)	Average annual growth (0.1 ft.)	No. of stems	Cumulative height (0.1 ft.)	Average annual growth (0.1 ft.)	No. of stems	Cumulative height (0.1 ft.)
1931							5.00	1	5.00
1932							2.00	1	7.00
1933							4.50	2	11.50
1934							4.43	7	15.93
1935				4.75	4	4.75	2.71	7	18.64
1936				4.92	12	9.67	4.57	7	23.21
1937				4.26	23	13.93	5.00	7	28.21
1938				4.19	32	18.12	2.29	7	30.50
1939				4.10	39	22.22	2.00	7	32.50
1940				4.18	44	26.40	2.14	7	34.64
1941	8.00	9	8.00	3.50	44	29.90	1.29	7	35.93
1942	5.35	20	13.35	3.52	44	33.42	1.43	7	37.36
1943	4.64	28	17.99	4.20	44	37.62	3.00	7	40.36
1944	4.38	34	22.37	5.07	44	42.69	3.29	7	43.55
1945	3.39	36	25.76	3.68	44	46.37	1.14	7	44.79
1946	5.22	36	30.98	4.86	44	51.23	2.00	7	46.79
1947	4.59	37	35.57	4.16	44	55.39	1.29	7	48.08
1948	6.50	38	42.07	6.50	44	61.89	1.86	7	49.94
1949	6.08	38	48.15	5.34	44	67.23	1.86	7	51.80

17/ This data when plotted shows eratic position and should be disregarded.

Table 4.—Summary of average annual height growth and average annual cumulative height growth of white ash reproduction under small canopy openings (based on 3 plots).

Year growth was made	Age Class 1 to 9 Years		
	Average annual growth (0.1 ft.)	Number of stems	Cumulative height (0.1 ft.)
1941	6.20	5	6.20
1942	6.50	18	12.70
1943	6.35	26	19.05
1944	4.39	33	23.44
1945	4.17	36	27.61
1946	4.51	37	32.12
1947	4.37	43	36.49
1948	4.00	45	40.49
1949	5.91	45	46.40

Table 5.—Summary of average annual height growth and average annual cumulative height growth of white ash reproduction under large canopy openings (based on 3 plots).

Year growth was made	Age Class 1 to 9 Years			Age Class 10 to 15 Years		
	Average annual growth (0.1 ft.)	No. of stems	Cumulative height (0.1 ft.)	Average annual growth (0.1 ft.)	No. of stems	Cumulative height (0.1 ft.)
1936				6.00	1	6.00
1937				1.00	1	7.00
1938				1.00	1	8.00
1939				5.00	2	13.00
1940				5.67	3	18.67
1941	6.67	3	6.67	4.67	3	23.34
1942	4.85	13	11.52	3.67	3	27.01
1943	4.19	21	15.71	5.67	3	32.68
1944	4.84	37	20.55	6.00	3	38.68
1945	3.80	41	24.35	4.00	3	42.68
1946	3.84	49	28.19	6.33	3	49.01
1947	4.30	56	32.49	6.33	3	55.34
1948	5.24	63	37.73	3.00	3	58.34
1949	6.81	63	44.54	5.00	3	63.34

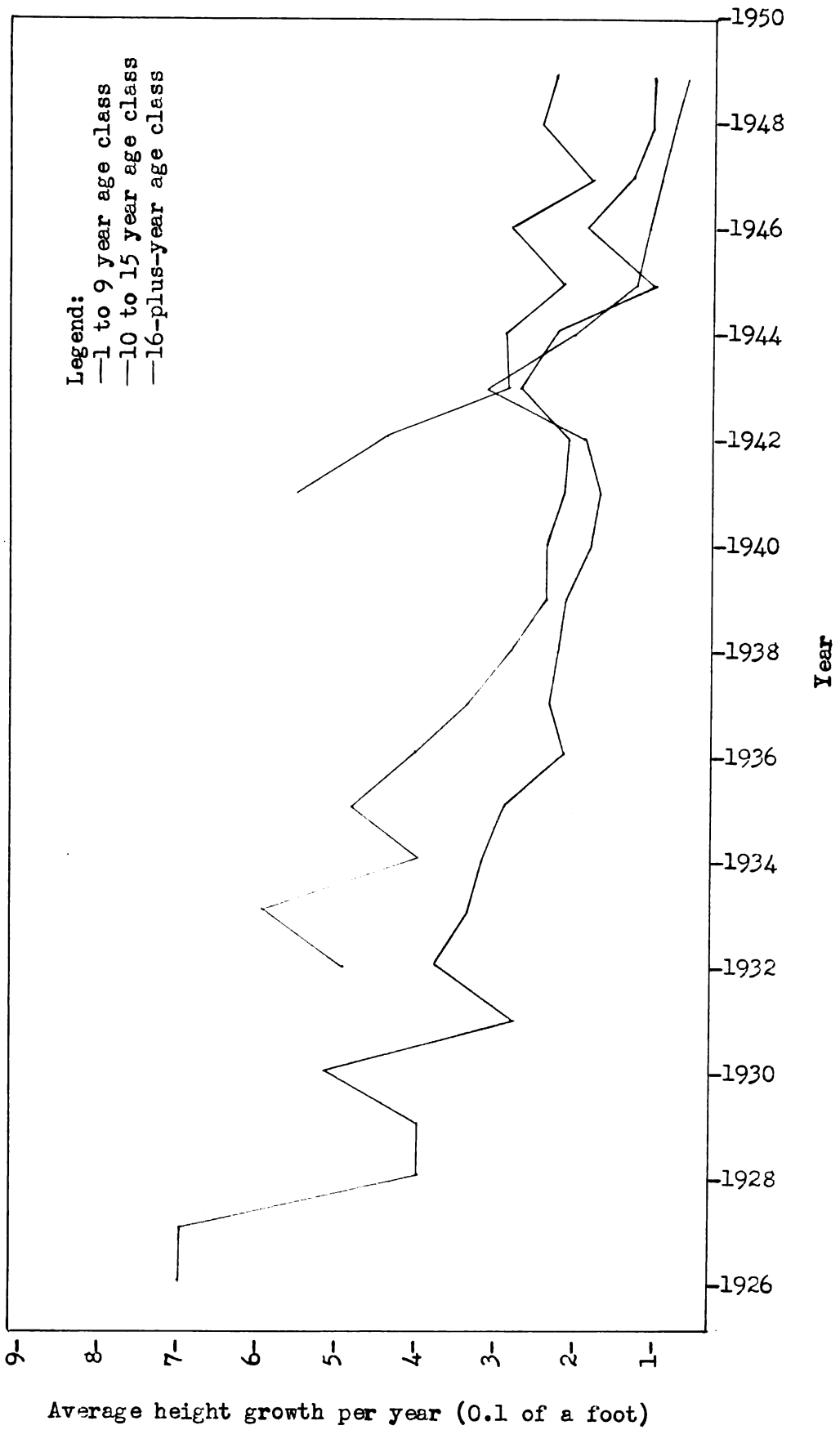


Figure 1.—Average annual height growth per stem, of white ash reproduction under heavy canopy conditions.

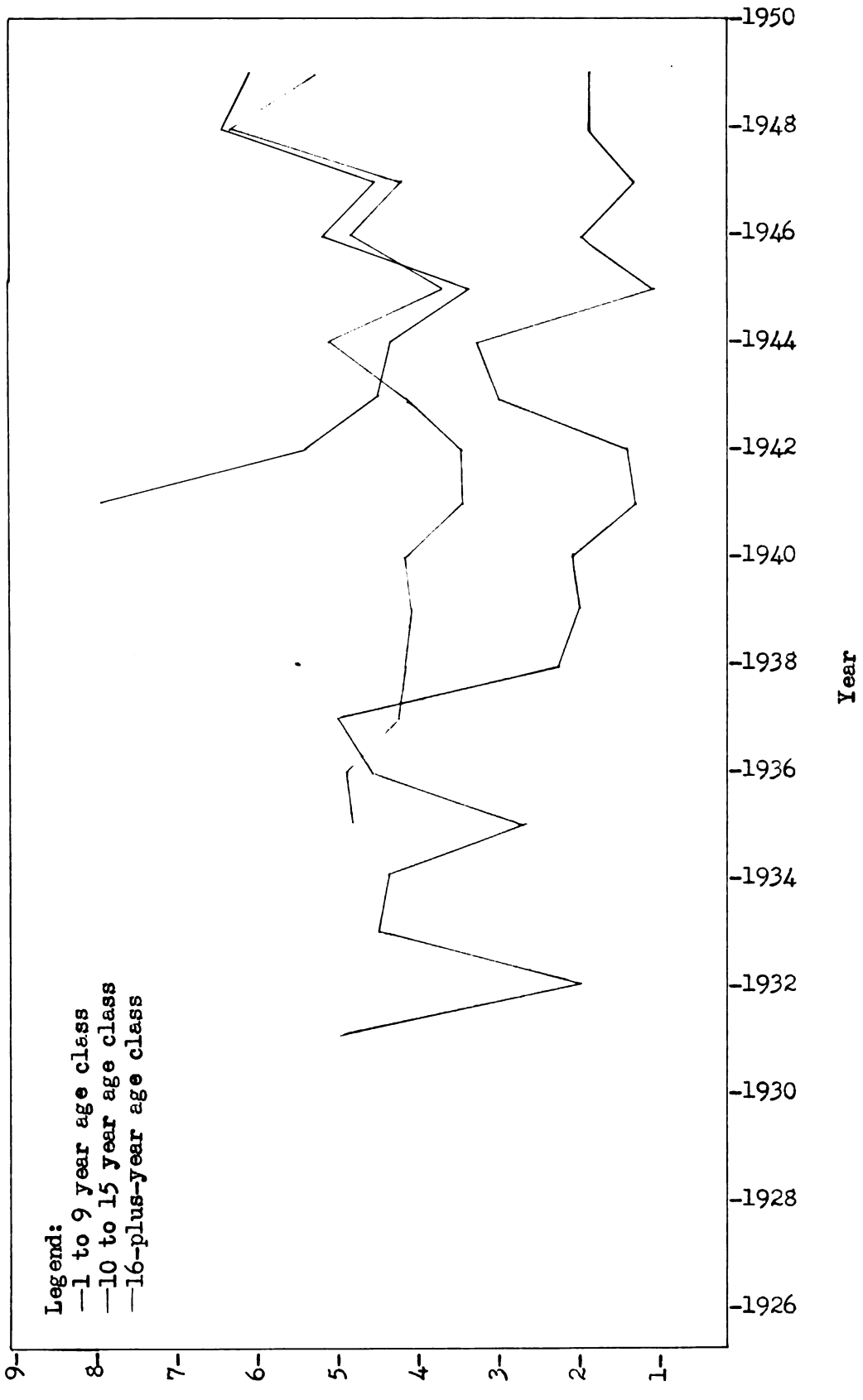


Figure 2.—Average annual height growth per stem, of white ash reproduction under light canopy conditions.

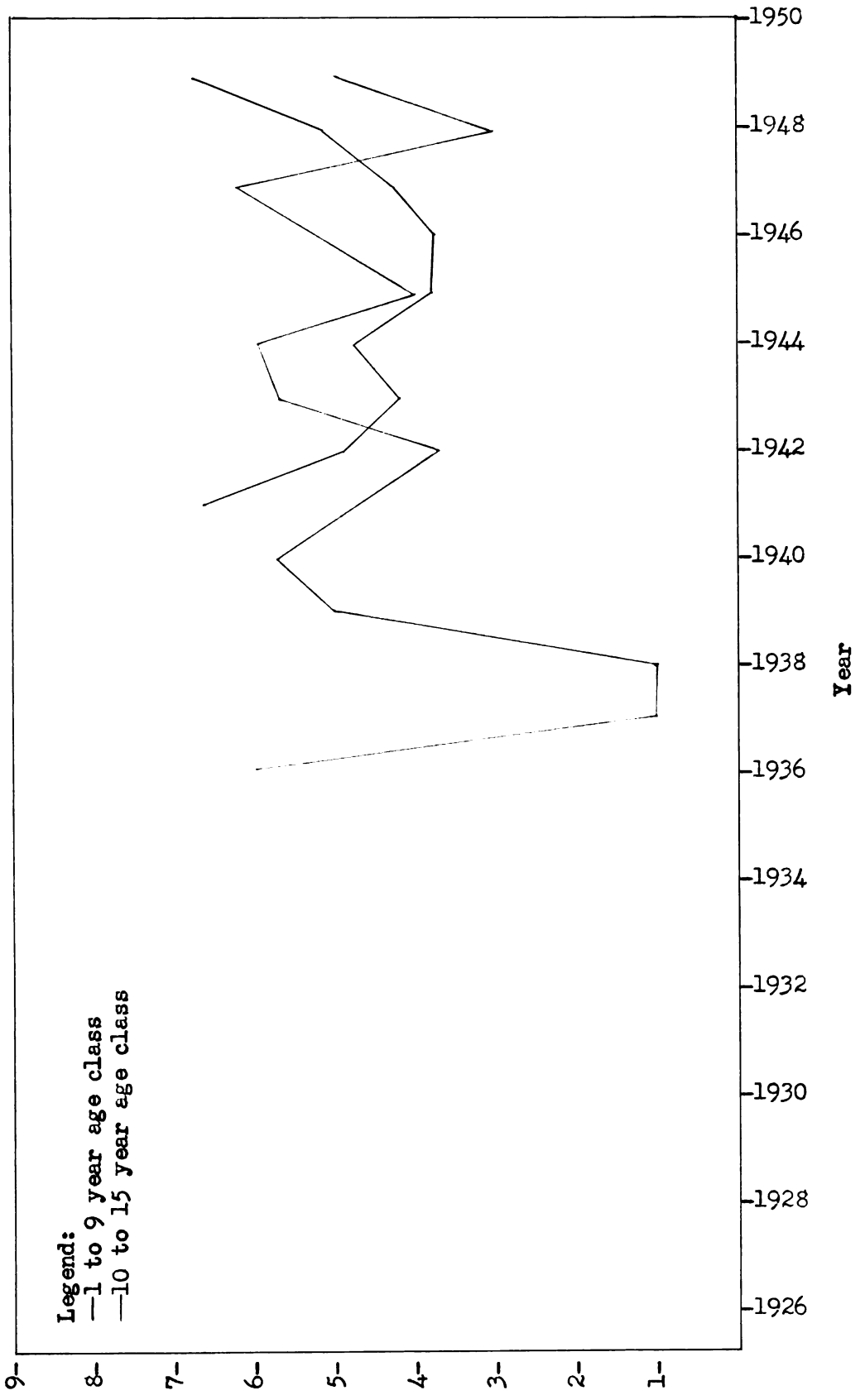


Figure 3.—Average annual height growth per stem, of white ash reproduction under large canopy openings.

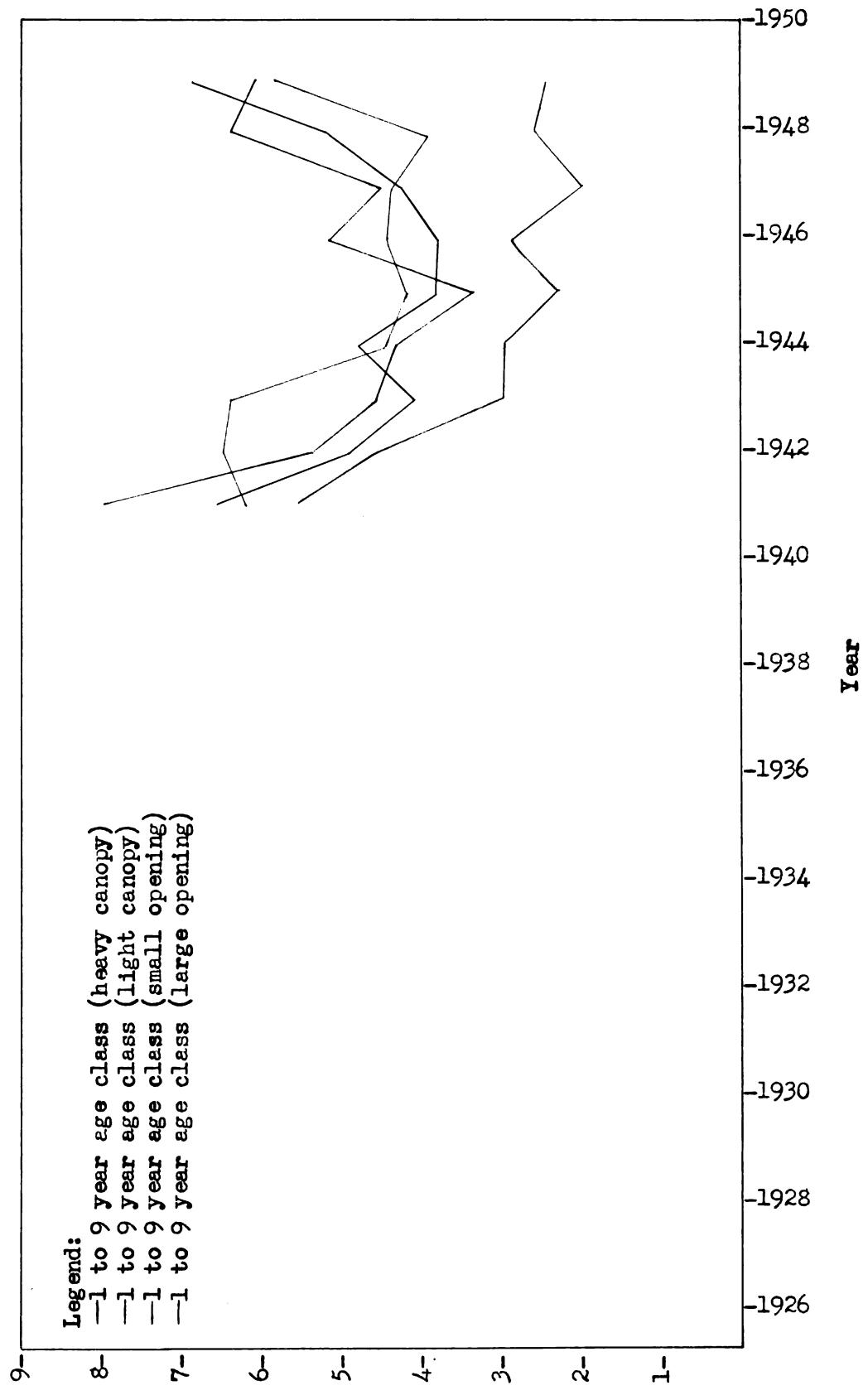


Figure 4.—Average annual height growth per stem, of white ash reproduction in the 1 to 9 year age class under all canopy condition classes.

Figure 5.—Average annual height growth per stem, of white ash reproduction in the 10 to 15 year age class under three canopy condition classes.

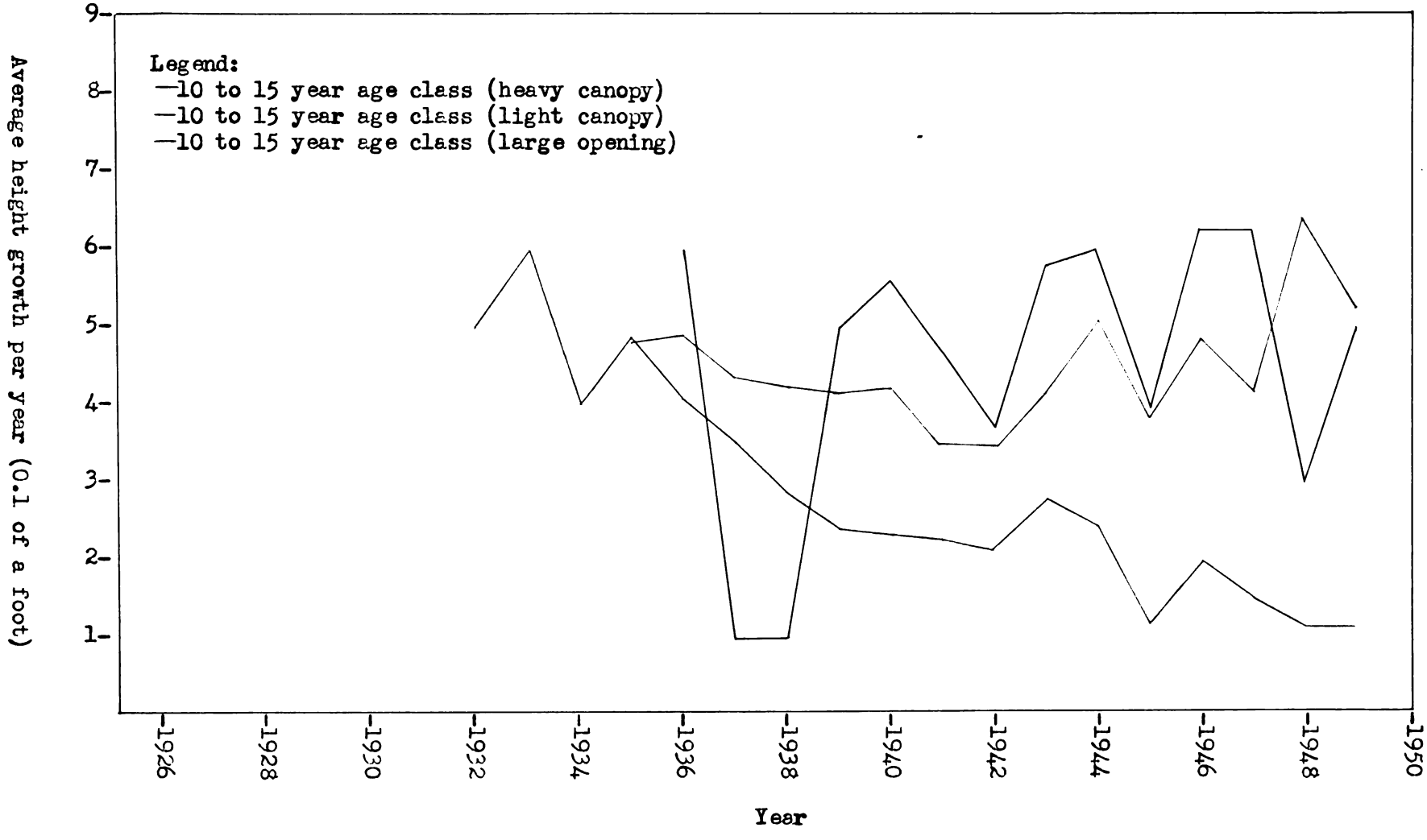


Figure 6.--Average annual height growth per stem, of white ash reproduction in the 16-plus-year age class under two canopy condition classes.

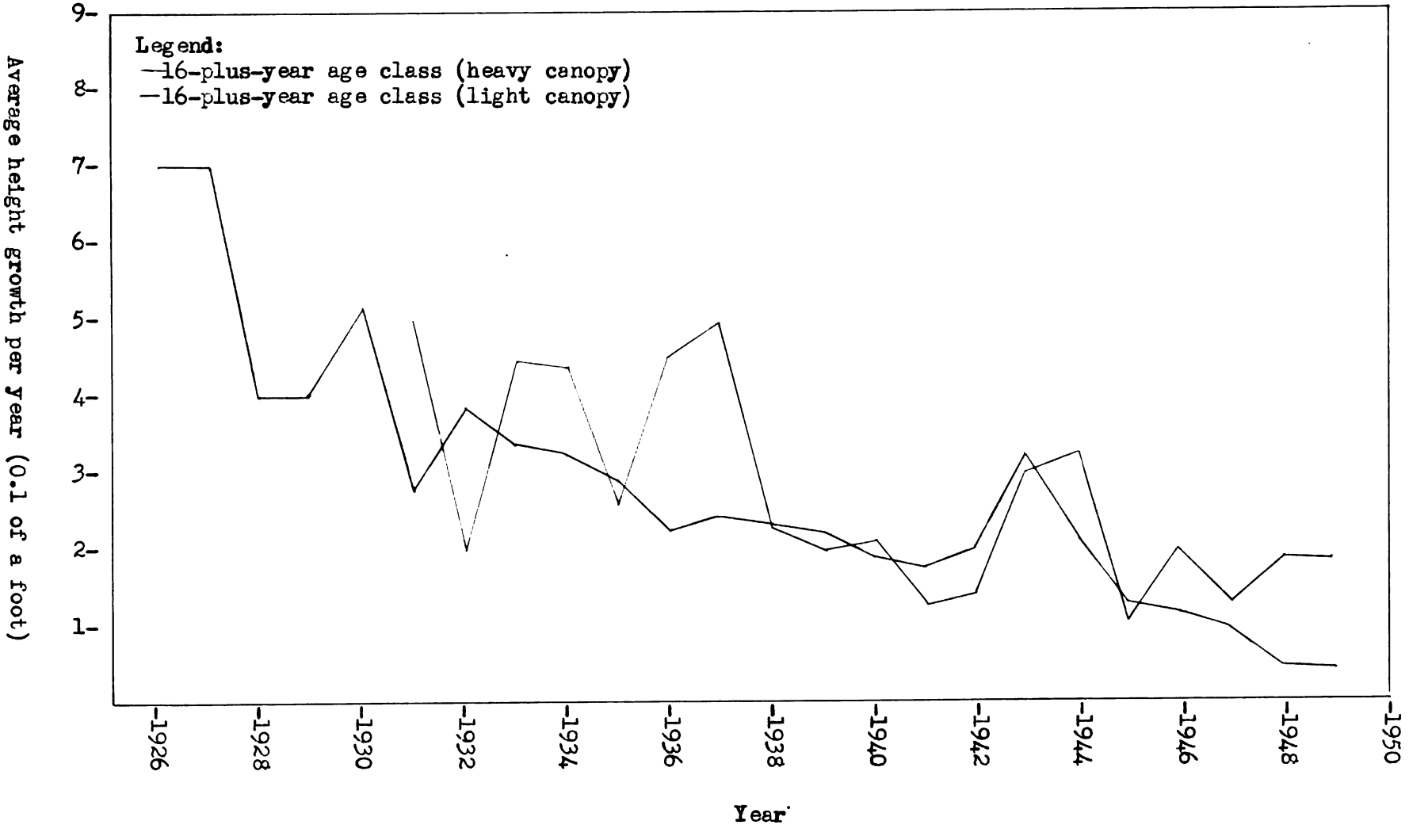


Figure 7.--Average cumulative height growth per stem, of white ash reproduction under all canopy condition classes.

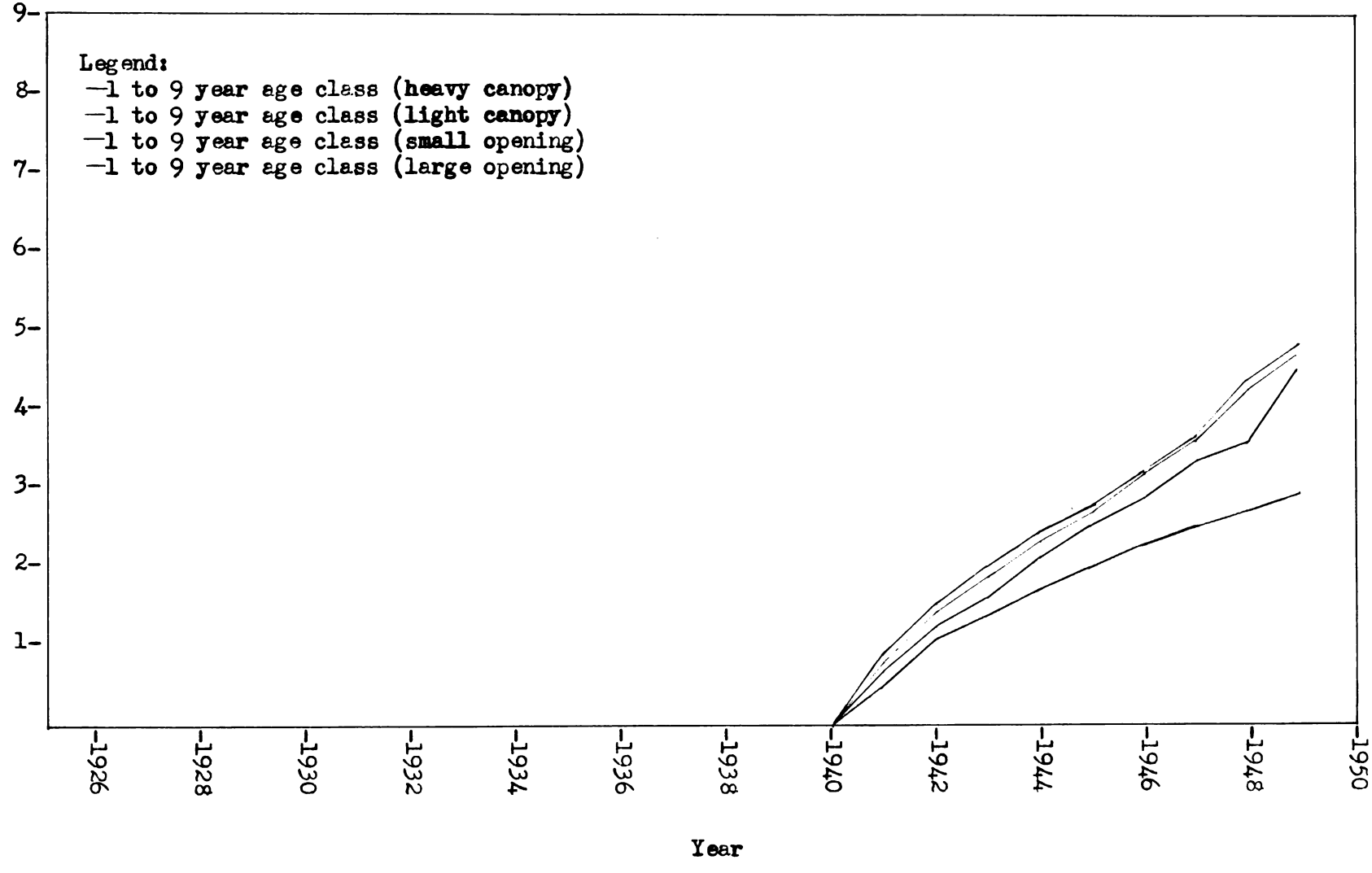


Figure 8.—Average cumulative height growth per stem, of white ash reproduction under three canopy condition classes.

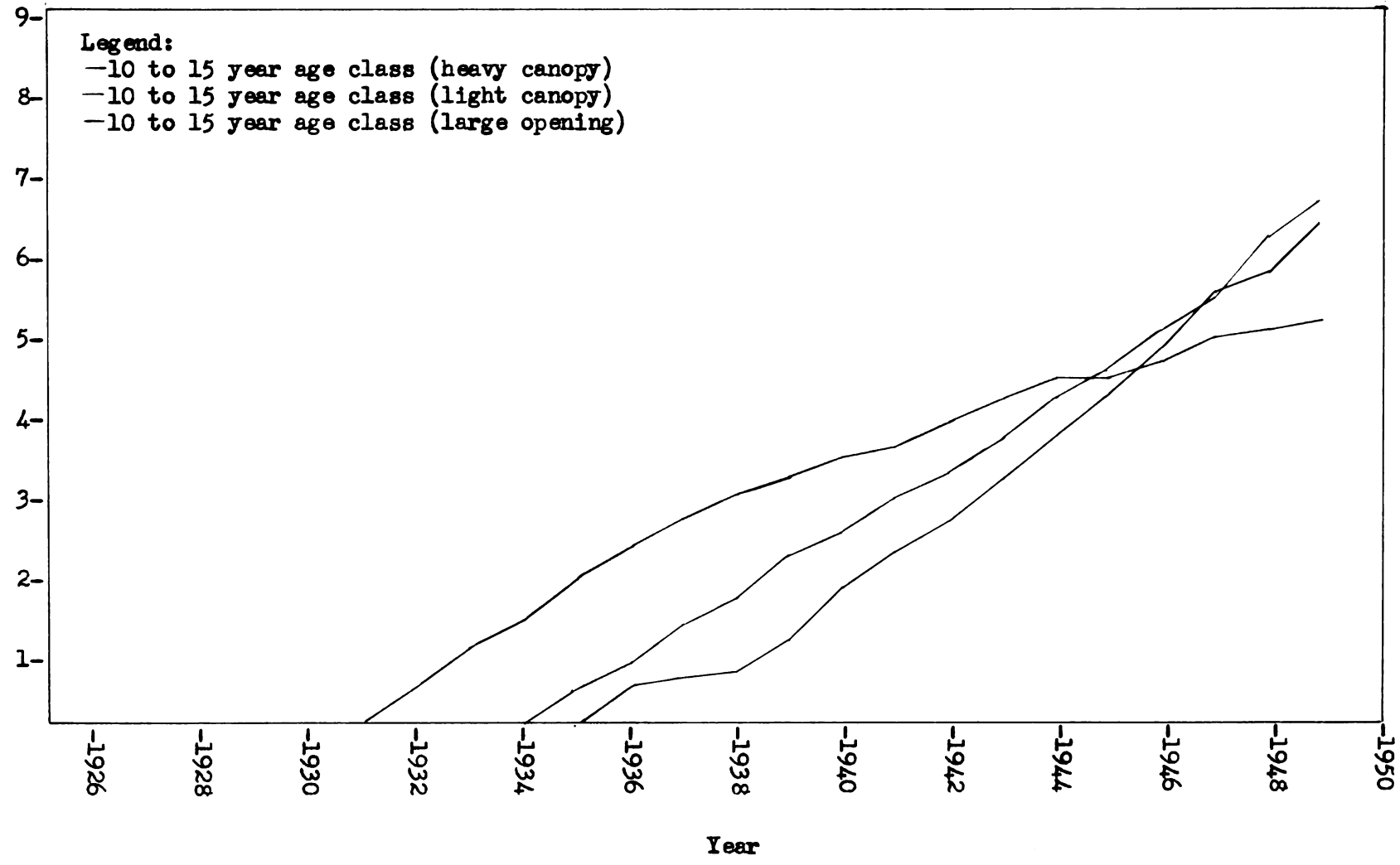


Figure 9.—Average cumulative height growth per stem, of white ash reproduction under two canopy condition classes.

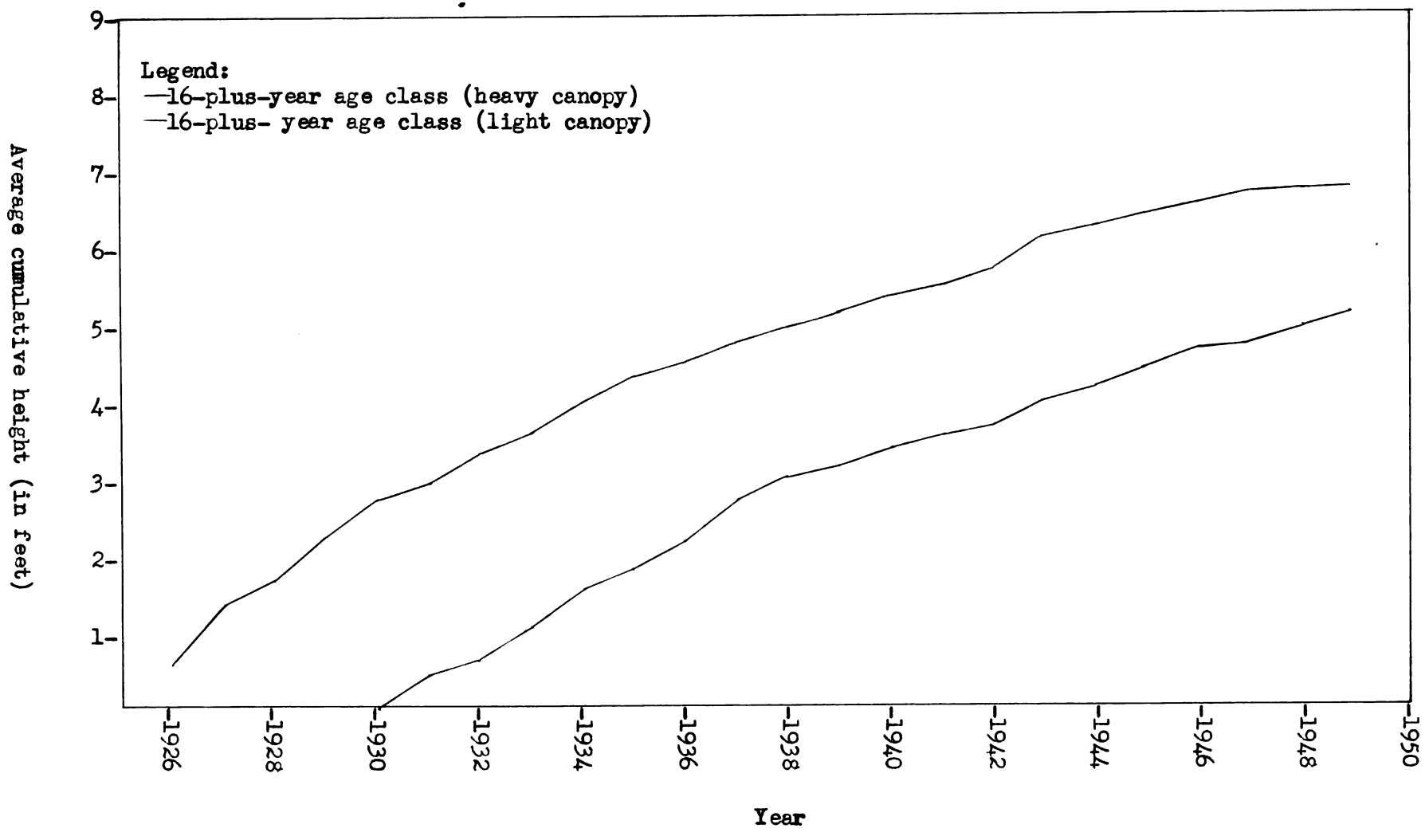


Figure 10.—Average cumulative height growth per stem, of white ash reproduction under three canopy condition classes. (Figure 8 based on the same origin for all age classes)

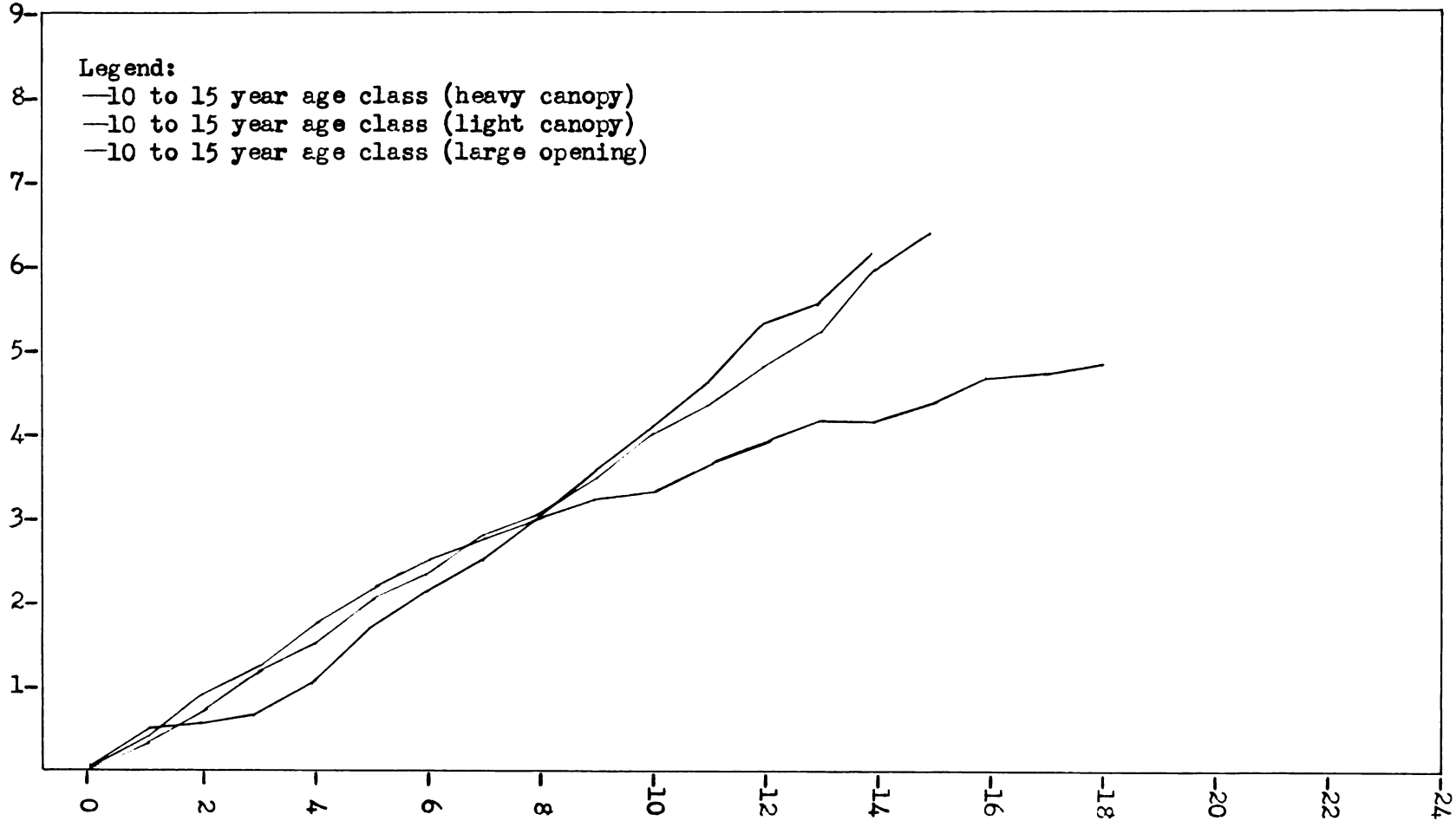


Figure 11.--Normal and actual monthly percentage of possible sunshine compared to the average annual height growth per stem for the 10 to 15 year age class, under a light canopy during the period of from 1944 to 1948 inclusive.

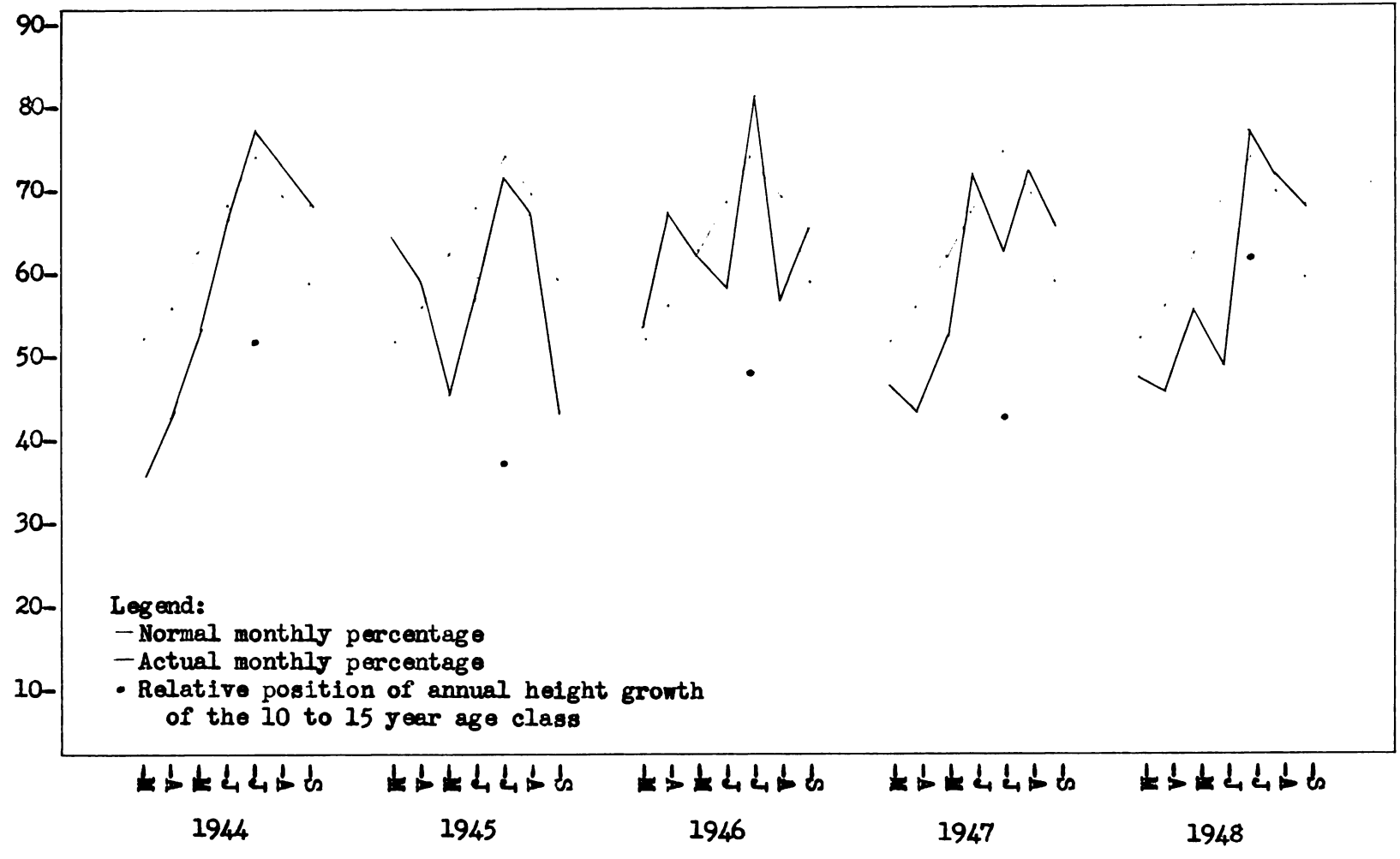
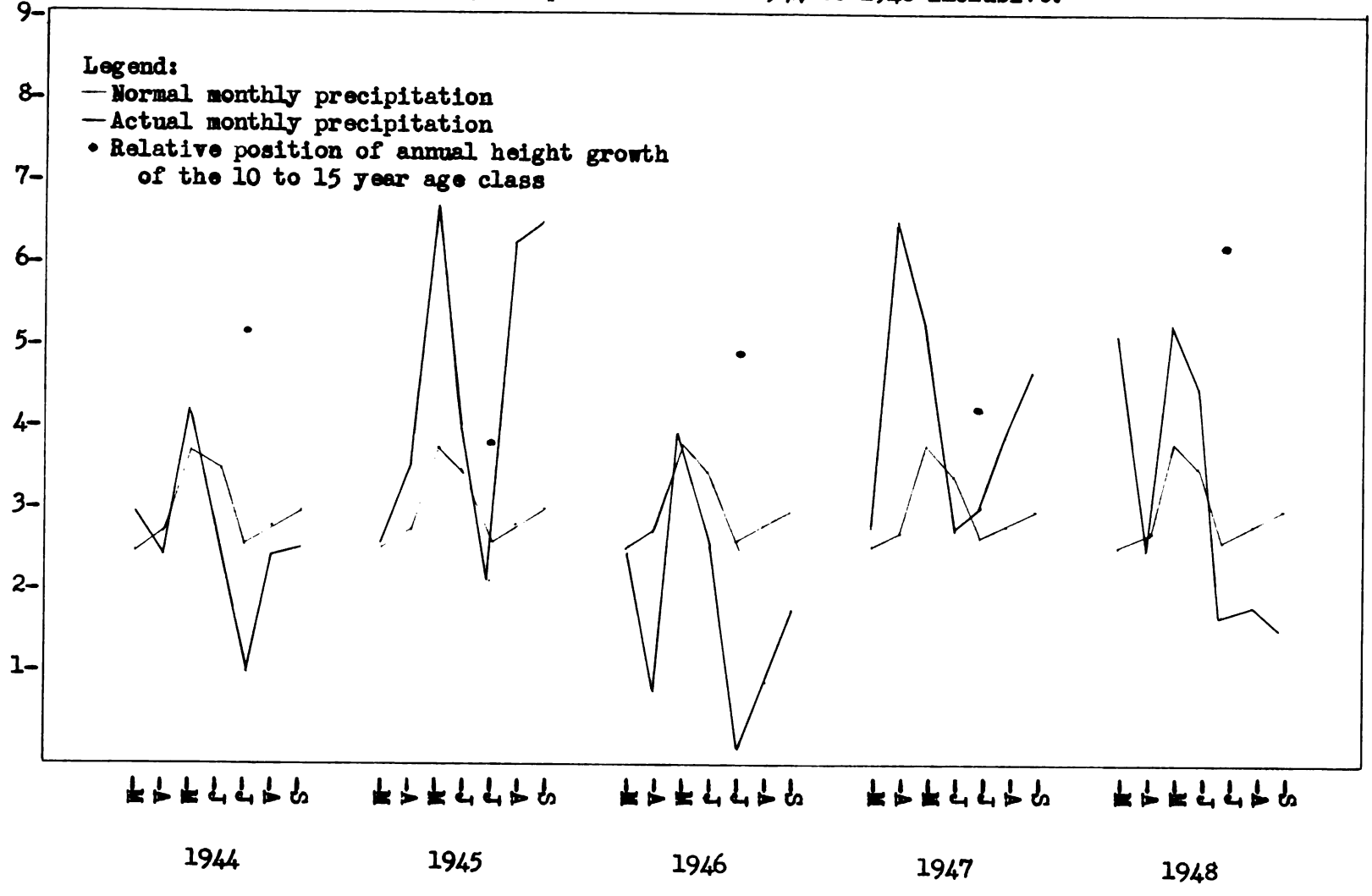


Figure 12.—Normal and actual monthly inches of precipitation compared to the average annual height growth per stem for the 10 to 15 year age class, under a light canopy during the period of from 1944 to 1948 inclusive.



SUMMARY

During the summer of 1949, a study was made of white ash seedlings under forest conditions. The objective of the study was to determine the tolerance of white ash reproduction under various canopy conditions, while attempting to hold other site factors constant. Conclusions that resulted from this study were:

(1.) White ash reproduction that was studied had progressively lower vigor and smaller annual height growth with age under heavy canopies that had either low height with thick density, low height with medium density, or medium height with medium density. The average light intensity under these canopy conditions was less than three per cent of full sunlight.

(2.) The decreasing vigor and height growth was believed to be due to the lack of sunlight, and possibly root competition, as other factors influencing the sites studied were quite uniform.

(3.) Steady reduction in vigor and height growth will eventually result in the mortality of the seedlings. This may be averted if release cuttings are made before the reproduction is 10 years old.

(4.) White ash reproduction that was studied maintained its vigor at least 15 years when growing under forest canopy-openings or under light canopies that have either high height with medium density or high height with thin density. The average light intensity under these canopy conditons was greater than three per cent of full sunlight.

(5.) Reproduction under these conditions will maintain itself or thrive for at least 15 years and will probably continue to maintain good vigor. Hence, release cuttings are less seriously needed than

under denser canopy conditions.

(6.) White ash reproduction was found to be more tolerant than generally believed. Specimens studied had existed for as long as 23 years under canopy conditions where the vigor of the tree was steadily declining owing to a lack of sunlight.

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A P P E N D I X

DESCRIPTION OF REPRESENTATIVE PLOTS

Representative plots were selected on the basis of how well they approximated average conditions within their canopy-condition class. Data listed is the actual field data taken on the plot.

HEAVY CANOPY

Represented by plot number 9.

1. Canopy opening - none.
2. Canopy height - saplings with overstory, approximating low height conditions.
3. Canopy density - medium.
4. Area of plot - 500 square feet.
5. Weston Foot-Candle Meter reading - the average of all readings was 100 foot-candles.
6. Soil type and litter layer conditions - Hillsdale sandy loam with a one-half inch thick litter layer.
7. Topography and exposure - level topography with slight downward slope to the north.
8. Distribution of ash reproduction and total number - even distribution of 25 stems.
9. Ground competition - mainly herbs with a few sugar maple seedlings; no serious competition.
10. Measurement of ash reproduction - see Table 6.

Table 6.—Representative plot under heavy canopy, plot number 9.

Year growth was made	Age Class 1 to 9 Years		Age Class 10 to 15 Years		Age Class 16-plus Years	
	Total annual growth, all stems (0.1 foot)	Number of stems	Total annual growth, all stems (0.1 foot)	Number of stems	Total annual growth, all stems (0.1 foot)	Number of stems
1934			17	3	21	4
1935					17	4
1936			33	7	16	4
1937			27	8	11	4
1938			21	8	18	4
1939			12	8	8	4
1940			9	8	5	4
1941	7	1	14	8	11	4
1942	4	1	19	8	10	4
1943	10	2	34	9	19	4
1944	5	2	23	9	14	4
1945	7	3	14	9	4	4
1946	7	3	10	9	2	4
1947	5	3	10	9	4	4
1948	6	3	12	9	4	4
1949	6	3	10	9	1	4

LIGHT CANOPY

Represented by plot number 17.

1. Canopy opening - none; small openings to south and west; west opening allows some direct light to reach plot in the late afternoon.
2. Canopy height - high.
3. Canopy density - medium.
4. Area of plot - 900 square feet.
5. Weston Foot-Candle Meter reading - the average of all readings was 150 foot-candles.
6. Soil type and litter layer conditions - Hillsdale sandy loam with a one-fourth inch thick litter layer.
7. Topography and exposure - level topography.
8. Distribution of ash reproduction and total number - even distribution of 100 stems.
9. Ground competition - a few herbs and sugar maple with some grass; much of the ash reproduction shaded other ash.
10. Measurement of ash reproduction - see Table 7.

Table 7.—Representative plot under light canopy, plot number 17.

Year growth was made	Age Class 1 to 9 Years		Age Class 10 to 15 Years	
	Total annual growth, all stems (0.1 foot)	Number of stems	Total annual growth, all stems (0.1 foot)	Number of stems
1935			6	1
1936			3	1
1937			11	2
1938			17	4
1939			10	5
1940			12	6
1941	4	1	14	6
1942	19	4	18	6
1943	17	5	22	6
1944	30	6	37	6
1945	19	6	28	6
1946	34	6	40	6
1947	16	6	29	6
1948	28	6	33	6
1949	37	6	35	6

SMALL CANOPY-OPENING

Represented by plot number 5.

1. Canopy opening - 600 square feet, circular in shape.
2. Canopy height - high with a few saplings.
3. Canopy density - medium, thin to the west.
4. Area of plot - 900 square feet.
5. Weston Foot-Candle Meter reading - the average for all readings was 210 foot-candles.
6. Soil type and litter layer conditions - Hillsdale sandy loam with one inch thick litter layer.
7. Topography and exposure - level topography.
8. Distribution of ash reproduction and total number - primarily on the southwest side of the plot; even distribution of 35 stems.
9. Ground competition - a few sugar maple and herbs; no serious competition.
10. Measurement of ash reproduction - see Table 8.

Table 8.—Representative plot under small canopy opening, plot number 5.

Year growth was made	Age Class 1 to 9 Years	
	Total annual growth, all stems (0.1 foot)	Number of stems
1943	7	1
1944	36	6
1945	30	9
1946	23	10
1947	38	13
1948	43	13
1949	98	13

LARGE CANOPY-OPENING

Represented by plot number 12.

1. Canopy opening - 900 square feet, irregular in shape.
2. Canopy height - high.
3. Canopy density - medium.
4. Area of plot - 1,100 square feet.
5. Weston Foot-Candle Meter reading - the average for all the readings was 313 foot-candles.
6. Soil type and litter layer conditions - Hillsdale sandy loam with a one inch thick litter layer.
7. Topography and exposure - level.
8. Distribution of ash reproduction and total number - even distribution of 100 stems.
9. Ground competition - much elderberry with some elm and herbs; much serious competition.
10. Measurement of ash reproduction - see Table 9.

Table 9.—Representative plot under large canopy opening, plot number 12.

Year growth was made	Age Class 1 to 9 Years		Age Class 10 to 15 Years	
	Total annual growth, all stems (0.1 foot)	Number of stems	Total annual growth, all stems (0.1 foot)	Number of stems
1939			9	1
1940			16	2
1941	14	2	11	2
1942	36	7	9	2
1943	39	10	13	2
1944	55	13	14	2
1945	85	16	11	2
1946	81	19	19	2
1947	63	19	13	2
1948	63	19	6	2
1949	90	19	8	2