INVESTMENT OPPORTUNITIES FOR BLACK WALNUT PRODUCTION IN IOWA

by

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INTRODUCTION

This is an economic study ranking alternative plantation management schemes for black walnut (Juglans nigra) in Iowa in terms of relative profitability. This information can assist Iowa landowners in making decisions regarding alternative land uses. Growth and yield data, experimental results, and current marketing information concerning black walnut have been combined into a set of models simulating actual conditions in Iowa. These models have been manipulated through a sequence of management decisions to determine the profitability of investment. This study is the first of its type in Iowa, but similar studies could be made using the techniques of this study for other tree species in Iowa.

Interest in black walnut is particularly high at this time, because of the recent competition for high quality black walnut logs and trees and the resulting high prices. Many owners have land which is either non-productive for agriculture or which has been removed from agricultural production as a result of governmental controls. This land availability, coupled with an increasing awareness of the benefits of holding forest resource land, has helped create a change in attitude toward these forests. If more information were available, many Iowa forest landowners might be willing to undertake an investment in timber production.

A study of this type is also timely because of a current national emphasis on increasing production from small timber holdings. One goal of the forestry profession has been the continual production of wood from forests to fulfill an increasing demand for wood and wood products. Where foresters have been directly involved in making forest management decisions, particularly on public and industrial lands, a sustained yield has almost become a reality. These forests represent only 41 percent of the commercial forest land in the United States (U. S. Forest Service, 1965). On the remaining 59 percent, most of which is in small holdings, the level of management has been significantly lower. As a result, in an attempt to increase the national aggregative production of wood, the owners of these small holdings have been encouraged to adopt a system of sustained yield forestry. The response of these owners has not been completely satisfactory to foresters.

Iowa woodlands are also owned primarily by small owners (Thornton and Morgan, 1959). These holdings average 40 acres in size. Intensive forest management has not become a reality despite the fact that: (1) Iowa State University has had a department of forestry since 1904, (2) professional technical assistance is available through the forestry section of the State Conservation Commission, and (3) favorable tax legislation has been provided (The Code of Iowa, 1958).

The substance of the "small owner problem" has been the forester attempting to persuade the small owner to practice more intensive forestry and the landowner reluctant to do so. Part of this problem may be traced to a lack of communication between the forester and the landowner. This is the hypothesis of Stoltenberg (1959). The forester may not have identified the landowners' objectives in owning land, or may have assumed that these objectives were identical to his own. One approach taken by foresters has been the economic motivation of the landowner, which is effective only if the objectives of owning land are economic in nature. For those landowners with economic objectives, a primary function of the forester is to supply adequate economic information.

This study provides economic information for one particularly promising investment alternative. The information obtained gives a basis, although only an estimate, for rational decision making regarding alternative land uses.

Information of interest to research also is provided by this study. The study enables the researcher to pin-point information gaps which may be important in black walnut management decisions. The study also tests and develops one method for evaluating and ranking investment alternatives. The simulation technique used here could be used for further study on other species and other products. This technique is particularly useful for sensitivity analysis and in determining the implications of specific variables.

In summary, the objectives of this study are threefold:

1. To provide information concerning investment opportunities in black walnut for Iowa forest landowners.
2. To determine information gaps for possible additional research.
3. To develop and test a technique for evaluating investment opportunities in Iowa hardwoods.

THE STUDY

The ranking of the black walnut investment alternatives is accomplished by simulating actual conditions with a model representing the important decisions and variables. The model is implemented with empirical data, primarily from an unpublished manuscript by Kellogg (1937). Where available, data from black walnut experiments have been used to improve the predictions of silvicultural response. Much of this information comes from experiments conducted outside the state of Iowa. For this reason, this information may not be identical with results from similar experiments if performed in Iowa. Still, such data are a fairly good estimate of what would happen under Iowa conditions.

Comparison of the investment opportunities in economic terms is the objective of the model design. In the analysis, the landowner is assumed to be attempting maximization of his return on his scarce resources. This assumption appears logical for landowners considering a high value species like black walnut as an investment alternative. This assumption is the basis for ranking the alternatives in economic terms.

Economic research for forest management decision making provides a guide for rational choice among management alternatives. The objective of the forest owner is defined as maximum return to scarce resources. The means to the objective are the alternative investment opportunities. Some of these are determined for black walnut based upon silvicultural predictions and presented in economic terms.

There are two broad classes of investment criteria--those determining the internal rate of return and those determining the present net worth--

which are applicable to this type of analysis. The choice of the most suitable criterion depends upon the nature of the underlying assumptions and the desired nature of the results (Hirschleifer, 1958; Webster, 1965). The internal rate of return criteria assume that the landowner has a fixed capital supply and has as his objective maximization of his return to this capital (Boulding, 1955). The present net worth criteria assume that land is the constraint and the landowner seeks to maximize his present net worth of land. The present net worth criterion seemed more applicable for the following reasons:

1. This method measures the absolute value of an investment opportunity where the rate of return does not.
2. The alternatives to be evaluated are mutually exclusive.[1]
3. The alternatives do not have a common time horizon which is essential for rate of return.

There are also several present net worth formulas in use for evaluating investments. The two most widely cited are the "financial maturity" method (Duerr, Fedkiw, and Guttenberg, 1956) and the soil rent or Faustmann method (Gaffney, 1960). These two differ slightly in their basic assumptions. Financial maturity does not consider the cost of inputs other than growing stock, while soil rent is more complete as both growing stock and land are treated as variable inputs. The soil rent approach, because it is more complete in that it takes into account the long-term outlook, is probably better for more situations encountered by foresters (Bentley and

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[1]A more complete discussion of mutually exclusive alternatives can be found in the article by Hirschleifer (1958).

Teeguarden, 1965). For that reason, the soil rent formula is used for this analysis.

The use of the soil rent formula requires selection of an interest rate for discounting. The analysis was made using a five percent rate of interest. Five percent was chosen because it is convenient to use, although is probably below the rate acceptable by most Iowa landowners. This is a deliberate attempt to have positive values in the final results. The actual rankings did not change significantly when the interest rate was changed. The absolute values did change due to the shortening of the rotation, timing of the inputs, and the higher discount rate.

The soil rent formula used for the analysis has the general form:

$$PNW = \frac{R_t + I(1+p)^{t-m} - C_i(1+p)^{t-c} - \left(C_j \frac{(1+p)^t - 1}{p} \right)}{(1+p)^t - 1}$$

where: PNW = Present net worth per acre.

R_t = Value of stand per acre at time t.

I = Value of intermediate harvest per acre at time m.

C_i = Cost per acre of silvicultural practice i at time c.

C_j = The annual cost per acre of owning land.

p = Rate of interest.

t = Rotation length in years.

m = Period of time until intermediate cut.

c = Period of time until treatment.

The silvicultural decisions considered in the model occur at different times in the production process. These decisions are interrelated. Any given decision is dependent upon previous decisions and directly affects subsequent decisions. This analysis does not evaluate decisions in sequence, but rather it is an evaluation of "packages" of alternative decisions. These packages are discussed in detail in the next chapter.

THE MODEL

The ranking of the alternative investment opportunities is developed through the use of an empirical model simulating actual decisions and silvicultural predictions. A model is an abstraction of reality which contains only those elements relevant to the solution of the problem of interest. Factors outside the model are considered fixed and, therefore, do not influence the results obtained with the model. This allows for testing endogenous variables against each other somewhat as is done with a controlled biological experiment. Particularly, price is assumed to be fixed throughout the analysis. This implicitly suggests that there will be no change in the relationship between the supply and demand for black walnut and its substitutes.

Difficulty arises in identifying the relevant variables for predicting silvicultural response necessary to give reasonably accurate results. No model can be entirely complete or realistic when compared to the real world. The model can be said to be valid if it predicts the real world with some determinate degree of accuracy (Friedman, 1953). However, if empirical data can be used to increase the accuracy of predictions, this data should be used wherever possible. Since this is a pilot study, the accuracy of the predictions cannot be compared to the real world. The use of empirical data hopefully improves the accuracy of the predictions.

In addition to the difficulty presented by the identification of the relevant variables, these must also be evaluated as to their influence on decision making. There is a time-jointness between decisions made at one time and the influence of these decisions on decisions made at another time. This interdependence between decisions at different periods of time reduces the accuracy of prediction by the model. The attempt is made to determine some "best" sequence of decisions based upon past decisions and expectations. A change in conditions would require that the decision sequence be reevaluated and modified in light of revised expectations.

The elements of the variables are discussed in the following sections. Before discussing the management decisions, the components of the problem to be solved here are defined as:

1. The decision maker, who may be either an Iowa forest landowner or manager.
2. The objective of the decision maker which is maximization of return to scarce resources of land and capital.
3. Alternative opportunities to investment and some doubt as to which is best in terms of the objective. One alternative under consideration is that of growing a black walnut plantation and selling the product as sawlogs or veneer logs.
4. The decision maker hires his labor, determines an opportunity cost for his own labor and buys or rents the specialized tools of forest management (i.e. pruning saws, chain saws, etc.).

The set of management decisions is presented in Figure 1. These represent the recommended sequence of possible management alternatives for hardwoods and are also the specific recommendations of the earlier black walnut researchers (Baker, 1921; Gibbs, 1927; and Kellogg, 1937). Each management decision is discussed in the following sections.

Site Selection

A determination of the productivity potential of an area should be made before a plantation is established. Foresters refer to this potential

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Invest in Black Walnut or Not Invest in Black Walnut

II

Site Selection

III

Site Preparation

IV

Planting

a. Seedlings vs Seeds

b. Mixed vs Pure Plantations

c. Spacing

V

Plantation Maintenance

a. Weed Control vs No Weed Control

b. Rodent Control vs No Rodent Control

VI

Pruning vs No Pruning

VII

Thinning vs No Thinning

VIII

Rotation

Figure 1. The set of decisions in sequence for the decision maker.

for growth on an area as "site." More specifically, site is defined by the Society of American Foresters' Committee on Forest Terminology (1958, p. 75) as: "an area, considered as to its ecological factors with reference to capacity to produce forests or other vegetation; the combination of biotic, climatic, and soil conditions of an area." A numerical site index is commonly used to express site quality. Site index is defined as the total height of the average dominant tree of a species at a standard age. For black walnut, the standard age is 50 years.

The selection of the proper site is particularly important when growing black walnut. According to Baker (1921, p. 32), black walnut requires "a deep, fertile soil, both well watered and well drained, permitting the free movement of soil moisture and, at the same time, the access of air to the roots." Baker assigned the major causes of plantation failure to the "poor" choice of planting sites, "wrong" management of the stands or both.[2]

The decision maker may not be able to choose the best site for the plantation. The objective is to maximize return to a scarce land resource. This land resource may not be the "best" for growing black walnut as defined by potential for growth. The decision maker will require information on possible expected returns for many site conditions. Therefore, a range of probable site indices representing Iowa conditions is investigated.

The best information available concerning the potential growth of black walnut on different site conditions has been provided by Kellogg (1937). He recorded data from black walnut plantations in six states in

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[2]Quotation marks mine. The author did not define either term.

the Central Hardwood Region.[3] His measurements of site index indicated a range from 35 to 83. The upper site index, site index 83, would appear to be the upper limit of black walnut sites since these measurements were made on the better bottomland sites of Ohio and Indiana.

The range determined by Kellogg needs some modification to include all Iowa sites. Three studies in Iowa lead to this conclusion. Gibbs (1927) recorded data from plantations in Central Iowa. By applying the curves developed by Kellogg (1939) for site indices of black walnut to this data, a range of site indices from 44 to 61 is obtained. Thomson (1956), working primarily with Southeastern Iowa sites, concluded that the site index curves of Kellogg were too high. He noted that sub-40 sites were not uncommon in this region. Hansen (1954) also noted low sites in this region. Applying the same curves to the data of Hansen, a range of site indices from 12 to 80 is indicated. Iowa forest landowners can be expected to have a large range of site conditions for potential planting sites.

The complete model should evaluate all possible site conditions and determine the consequences of choosing each possibility. The data provided by Kellogg is the most complete information available, but it is limited to five site classes--40, 50, 60, 70, and 80. This is probably not the entire range of conditions under which decisions might be made. Site indices greater than 80 are possible, although not probable. Site indices below 40 are not only possible, but probable. Available data precludes evaluations beyond these two limits.

Three site indices, therefore, are used to provide a representation of

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[3]His study was based upon 120 plots taken in Kentucky, Ohio, Indiana, Illinois, Missouri, and Iowa.

Iowa site conditions: the good site is represented by site index 80; the average site is represented by site index 60; the poor site is represented by site index 40. These three will provide enough of an indication to act as a guide for decision making.

The decision maker needs to determine the site index of his planting site to use the information obtained by analyzing these three site indices. Several methods have been suggested for doing this, and they are just mentioned here. The most accurate method of site determination and potential is by measuring black walnut already growing on the site. If no walnut is near by, other associated species such as Kentucky-coffee tree, yellow-poplar, or white ash are fairly reliable indicators of good black walnut site. Thomson (1956), Hansen (1954), Auten (1945a, 1945b), and Einspahr and McComb (1951) have suggested methods for site evaluation in the absence of indicator trees. These methods are not completely reliable as growth predictors (Hansen and McComb, 1958), but do provide some methods for evaluation of site in the absence of timber vegetation.

Site Preparation

Once the productivity potential of the site has been ascertained, the decision whether or not to plant is influenced by the cost of establishing the plantation compared to the values expected from production. The cost of establishment can be divided into the cost of site preparation, the cost of planting stock, and the cost of planting. Costs associated with the actual planting will be covered in the next section.

Site preparation is thought necessary for the establishment of a black walnut plantation. According to Limstrom (1963, p. 16), "some form of site preparation for planting will always be needed for planting in Iowa." This is true where grasses and annuals predominate (Lane and McComb, 1953). This would seem particularly true for black walnut since it is an intolerant species (Harlow and Harrar, 1958).

Site preparation costs depend upon the amount of vegetation to be removed, the topography, and the method of site preparation. An almost infinite number of conditions face potential decision makers in Iowa. To select one or two as representative would be impractical. Such a selection could represent only a few decision makers at most. For simplicity and convenience, the following assumptions have been made relative to cost of site preparation:

1. The site to be prepared consists of only an annual grass or weed cover.
2. Topography is level to gently rolling.
3. Treatment method is a chemical application shortly before planting.

The above assumptions would not apply to many Iowa forest lands. Typically, these lands are near rivers, and have steeper topography and some sort of woody vegetation growing on them. The cost evaluation is based upon the above assumptions only. Under more difficult conditions, site preparation costs would be expected to be higher. The amount of increase in costs is set by the level of the present net worth for each decision sequence, if a five percent rate of return is to be earned on the total investment. Site preparation is the only variable treated in this manner. All others have explicit costs attached to them.

A treatment of simazine is applied to the plantation shortly before planting.[4] This treatment could be applied to almost any site including bare ground as an insurance against the encroachment of weeds and grasses. A fixed cost of $10.00 per acre is applied to all site classes. This cost includes labor and materials.

Planting

The decision to establish a black walnut plantation also requires answering the following questions:

1. Should the plantation be established by planting nuts or seedlings?
2. Should the stock be planted in pure stands, or in mixture with some other species?
3. At what spacing should the stock be planted?

With the soil rent model, one can evaluate all alternative answers to the above set of questions. Lack of complete data and time required a less rigorous approach. The alternatives are analysed in the following subsections, and the alternative selected in each case is the one which apparently yields the highest increase in present net worth.

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[4]The decision to use simazine in hardwood plantations came from personal discussion with Gayne G. Erdmann, Research Forester, North Central States Forest Experiment Station. His results are in the publication, "How to use Simazine and Atrazine for weed control in hardwood plantations," North Central States Forest Experiment Station Tech. Note (In process).

Seeds versus seedlings

Black walnut plantations may be established from either nuts (seeds) or from natural or nursery-grown seedlings. Seidel (1961), in experiments in Kansas, found that the survival in the plantations was apparently the same whether the plantation had been established by nuts or carefully planted seedlings. Apparently, therefore, the choice of which is to be used can be made on the basis of establishment costs.

The disadvantage of planting seedlings is the possibility of root damage. The root system of black walnut is deep and wide-spreading, with a definite tap root early in life (Harlow and Harrar, 1958). This tap root can be injured in transplanting nursery seedlings (Thomson, 1956). Tap root injury was thought to be the reason for height differences between seeded black walnut and those established by seedlings in Kansas (Seidel, 1961). Cost per thousand of seedling stock is about $10.00 higher than for the same number of seeds.[5] The care which must be exercised in transplanting each seedling from the nursery adds an additional expense not incurred when working with seeds.

The primary disadvantage of seed planting is the susceptibility to rodent damage. Losses due to rodents may be quite high if precautions are not taken (Krajicek, 1960). Physical measures, such as screening, may be of some value, but chemical repellents are not effective (Engle and Clark, 1959). Rodent losses are correlated with the presence of other nut-producing trees and plant species. For example, if red oak is available,

[5] Prices obtained from the published list of the State Conservation Commission for Spring 1965.

black walnut nuts are not taken. Losses also may be reduced by the careful selection of the planting season (Baker, 1921; Engle and Clark, 1959). Rodent damage appears to be least on those plantations established in the Spring following a good mast year of red oak and other species. Losses can be further reduced by planting stratified seeds which germinate sooner. Unless severe losses from rodents are expected, Limstrom (1963) feels that control measures are too expensive to be warranted.

The study will evaluate only those plantations established by seeds and requiring no rodent control. The losses due to rodents are considered as normal stand losses in the model.

Pure versus mixed

Black walnut may be planted in pure stands or in mixture with other species. Planting recommendations in the literature generally favor planting walnut in mixed plantations. Some of the reasons given are:

1. Plantation is less likely to be destroyed completely by disease or insects (Limstrom, 1963).
2. Better growth and form due to shading by faster growing species (Chapman, 1961).
3. Site improvement (Kellogg, 1937).
4. Early marketing of alternate products (Seidel and Brinkman, 1962).

A mixed plantation requires the careful selection of the companion species. Conifers in mixture with black walnut are not as satisfactory as hardwoods (Deitschman, 1956). Black walnut apparently grows well with northern red oak, white oak, green ash, and sweet gum. The American Walnut Association (1963) adds black locust, sugar maple, basswood, and yellow poplar to the list of good associated species.

Experimentation with mixed plantations, however, has not completely established their superiority over pure plantations. Experiments in Kansas with black walnut in both pure and mixed plantations indicated that there may be few real differences between them (Seidel and Brinkman, 1962). Several plantations were established with black walnut planted purely and in mixture with other hardwoods. Survival of black walnut was best in the pure stands, but, with one exception, not significantly better than survival in mixed stands. Stands containing black locust had significantly lower survival than stands without locust. Height growth also was greater in the pure stands, but again not significantly so. Form was found to be better in the pure stands. Seidel and Brinkman recommended mixed plantations, however, providing that some products could be marketed from the companion species before the black walnut was marketable.

One disadvantage of a mixed plantation could be the crowding from faster growing species. Hansen (1954) noted a plantation in which the black walnut had been planted with ash. The taller ash had reduced growth of the black walnut by rubbing the buds off the walnut branches. Other advantages associated with pure plantations are the ease of establishment and ease of subsequent management.

The arguments presented above for establishing mixed plantations are not completely substantiated by the literature. Limstrom argues for mixed plantations on the basis of reducing losses by insects and disease. Black walnut, however, has few important insect enemies and trees seldom die from insect damage alone (Brinkman, 1957). Damaged trees are susceptible to European canker. Even though the infected trees eventually die, the rate of spread of disease is quite slow. Chapman's argument that mixed plantations produce better form and growth was not borne out by Seidel and Brinkman. Kellogg's argument on the basis of site improvement may be quite valid, but not enough is known about the interaction of tree species and soil fertility to provide a guide to planting mixtures. The argument for early marketing of alternative products presents an unexplored area for study. This opportunity could be significant in some marketing areas, but is probably not generally found in the Midwest.

The arguments that mixed plantations are superior to pure may be valid, but its not substantiated by the present knowledge. Consequently, not enough data is available to choose the "best" combination of species, so only pure plantations are considered.

Spacing

The final decision regarding planting is the proper spacing of the planting stock. Spacing is important because of its interaction with later decisions. A close spacing might raise the value of individual trees through the amount of bole cleared by self-pruning. The same spacing, however, might commit the decision maker to more thinnings in order to maintain a faster rate of growth. A wider spacing might reduce the number of thinnings, but lower the value of the tree through reduced self-pruning. The decision maker would prefer to plant at some "optimum" spacing; that is where his return would be highest considering thinnings and final harvest in terms of present net worth.

The spacings selected for consideration are those recommended for black walnut planting. The American Walnut Association (1963) recommends that the trees be planted at least ten feet apart. Baker (1921) recommends two spacings based upon anticipated management intensity--a close spacing of four feet by four feet for "managed" stands and a wider spacing, six feet by sixteen feet for "unmanaged" stands.[6] Kellogg (1937) observed black walnut plantations which had been established with original spacings of from three feet by three feet to twenty feet by twenty feet. He recommended that the spacing should be between seven feet by seven feet to ten feet by ten feet, but that pruning and thinning would also be necessary. Hansen (1954) concluded that walnut needed space to maintain adequate crown development. He reasoned that walnut was a good self-pruner, so a wide spacing (greater than six feet by six feet) would result in less thinning. Limstrom (1963) recommends a spacing of six feet by twelve feet to ten feet by ten feet where thinnings are planned and eight feet by twelve feet to ten feet by ten feet where no thinnings are planned.

From the above range of spacings, three were chosen for the analysis. These represent the extremes of the recommendations and take full advantage of the data supplied by Kellogg (1937). A spacing of four feet by four feet is chosen to represent a close spacing to test the effect of natural pruning as opposed to the cost of more frequent thinnings. A spacing of seven feet by seven feet represents the average or medium spacing. Ten feet by ten feet represents the wide spacing. Square spacings are used for computational convenience.

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[6]The author was not explicit in the meaning of the terms "managed" and "unmanaged."

Planting costs

Planting costs are determined per acre and are shown in Table 1. Two methods of planting were tested to provide an indication of the probable extremes of costs. The two methods are as follows:

1. Two men and a farm tractor with a plow. The tractor and plow loosen the soil to facilitate the planting by the second man. Two hundred nuts per hour are planted in this manner.
2. One man and a planting tool. The tool is used to open a hole large enough for the nut. The hole is covered in the same operation. One hundred and twenty-five nuts per hour are planted in this manner.

Both methods were evaluated in the analysis. Cost of planting stock was established from the current prices published by the State Conservation Commission. Labor costs were determined at the current minimum wage of $1.25 per hour.

Plantation Maintenance

The establishment of a plantation commits the owner or manager to certain ownership costs. These are classified generally as maintenance or overhead costs. A managed stand requires a certain amount of attention, the cost of which must be included in the model. These costs can be thought of in two ways--those which will occur and those occurring with some degree of uncertainty.

These costs occurring with some degree of uncertainty can be further refined into risk or those costs occurring with a determinable probability

Table 1. Determination of planting costs per acre by method of planting and spacing of seed.

Planting Method	Spacing	Number of Nuts per Acre	Costs Per Acre				Total Costs Per Acre
			Tractor[a]	Fixed Labor[b]	Variable Labor	Planting Stock	
			$	$	$	$	$
Tractor-2 men	10' x 10'	436	1.85	.94	2.73[c]	2.62	8.14
	7' x 7'	889	1.85	.94	5.56	5.33	13.68
	4' x 4'	2723	1.85	.94	17.03	16.34	36.16
One man-tool	10' x 10'	436			4.36[d]	2.62	6.98
	7' x 7'	889			8.89	5.33	14.22
	4' x 4'	2723			27.23	16.34	43.57

[a]Tractor costs computed from James C. Frisby and Dale O. Hull. 1965. 1965 Costs for field work. Iowa Farm Science, Vol. 19, No. 7; pages 8 and 9. Costs are for tractor and 3-bottom plow.

[b]Labor costs computed at $1.25 per hour.

[c]Planter is able to plant 200 nuts per hour.

[d]Planter is able to plant 125 nuts per hour.

and uncertainty or those costs whose occurrence has an undeterminable probability. In the analysis, risk and uncertainty costs occur when the trees are either killed or damaged. Risk is implicit in the analysis for the stands in which no thinning occurs through the use of the trees per acre curves of Kellogg (1937). This reduction in the number of trees as the stand matures is a cost which is reflected in a reduced final total stand value. Uncertainty costs are those which occur as a result of an unexpected event such as fire, severe insect or disease attack, or unusual weather conditions. While the probability of any one of these events occurring is low, the cost to the decision maker if the event occurs is high. A common business practice is to reduce the impact of such an occurrence by the purchasing of insurance. This adds a smaller fixed cost to the operation instead of the higher variable cost occurring by chance. A forest owner, however, cannot purchase insurance on a long-term timber investment. The occurrence of such an event, therefore, would probably erase the value of the investment, so an implicit assumption in the analysis is that such an event will not happen. This is not illogical when the low probability of the occurrence of such an event is considered.

The other costs which will occur are certain. In a managed stand, these could include protection, weed control, taxes, and overhead resulting from periodic plantation inspections. Some of these costs would occur if the owner or manager did no more than minimal management. These costs need to be included in a pragmatic evaluation. Some costs, such as pruning and thinning costs, have special problems associated with them and are covered in separate sections.

Initial plantation maintenance costs are primarily those for the control of weeds. The need for weed control in hardwood plantations has already been discussed in the section on site preparation. An application of simazine at the time of establishment will sufficiently control weeds for one year. Another application is necessary at the beginning of the second year to guarantee the survival of the plantation. Beyond two years, black walnut has grown tall enough to compete with other species (Green and Green, 1959). An additional $10.00 per acre cost for weed control in the second year is included in the analysis.

Taxes and overhead costs occur annually. Overhead denotes costs arising from minimum protection measures and periodic inspections of the plantation to determine the additional management needs. An average of these costs is included in the analysis. This is determined to be $1.25 for each year of the operation of the plantation. One dollar of the cost can be considered to be the average yearly cost of maintenance and protection. The remaining $.25 is the allowance for yearly land taxes.[7]

Pruning

The purpose of pruning a stand of timber is to attempt to increase the value of the trees by reducing the amount of defect. The decision maker should also consider the alternative of pruning in his investment. The criterion for judging whether or not pruning is worthwhile is the additional net value added to the final product by the pruning operation. If

[7]These figures were obtained from personal discussion with James H. Gottsacker, Extension Forester, Iowa State University. These are average and are not necessarily the cost to any one landowner and are assumed to be those applicable under the Iowa Forest Law.

pruning increases the present net worth of the investment, it is considered worthwhile. The analysis will compare the productivity of the pruning investment to a similar stand without pruning.

The difficulty encountered in analysing the pruning investment is the lack of information. Although pruning has been recommended as a management alternative by most authors beginning with Baker (1921), only one pruning experiment was found in the literature. Black walnut planted on Kansas spoilbanks was pruned by diameter classes and intensity (Clark, 1955; Clark and Seidel, 1961). The emphasis of the experiment was on the determining of the earliest practical pruning time and the interaction of intensity with growth and sprouting. Only trees of three small diameter classes--three, four, and five inches diameter breast height--were pruned and these to only three crown intensities--twenty-five, fifty, and seventy-five percent of the live crown. The fifty percent intensity gave the best results in terms of subsequent height and diameter growth. The twenty-five percent intensity had the advantage of the fewest sprouts occurring. "Sprouting may well be the limiting factor in pruning black walnut" (Clark, 1955). The tree could be pruned as soon as it had reached three inches diameter breast height without ill effect.

The pruning alternatives in the analysis were developed around the results of Clark's research. Present market standards indicate that the more clear wood which can be produced on the tree the higher the subsequent price. Pruning apparently should be initiated early in the tree's development. The initial pruning, therefore, occurs when the tree reaches three inches diameter breast height.

Since the intensity of pruning might adversely effect the final value of the tree, the decision maker will want to choose that intensity which will apparently minimize the loss in value. This would appear to be the twenty-five percent pruning intensity. Fewest sprouts or epicormic branches resulted with this intensity. This would not, however, guarantee that sprouts will not occur. The incidence of sprouting could possibly be reduced by other methods such as covering the wounds with motor oil (Boyce and Neebe, 1963), or by careful selection of dominant and co-dominant trees as the ones to be pruned (Skilling, 1957). The latter method would be particularly applicable in a managed stand where these trees would be chosen most likely as the final "crop." These methods do not give a positive guarantee against the occurrence of sprouts. Skilling (1957) also found that the effect of thinning on the occurrence of epicormic branches to be minor.

An underlying assumption of the analysis is that the final product is not changed by the occurrence of epicormic branches or sprouts. This assumption is made because there is no way to predict the incidence of branching, when they would occur, or what the effect of their presence would have on the final product. Conceivably, if the branches occurred early enough in the life of the tree, they could be removed in the pruning process. The assumption of no effect is used because complete information is not available. Hopefully, the occurrence will be infrequent due to the pruning intensity used.

A pruning alternative was developed for each site and original spacing combination using the data of Kellogg (1937). The initial pruning occurs when the tree reaches a three inch diameter breast height. At that time all of the bole is cleared to include twenty-five percent of the live crown.

Subsequent prunings occur whenever an additional eight feet of bole can be cleared. The eight foot minimum is arbitrarily selected. This would be typically the minimum salable log and would, therefore, represent the operation of pruning an additional salable log. The pruning process is repeated, eight feet at a pruning, until the desired height is reached.

These pruning alternatives are presented as a package of pruning decisions for each site and spacing combination. No attempt has been made to evaluate each pruning alternative in sequence regarding the effect on net worth of pruning each log of the tree. Time and lack of complete information do not permit this evaluation. These packages are presented in Tables 2 to 4.

The costs of pruning are a function of the overhead, type of equipment used, number of trees pruned, size of trees pruned, and height of tree cleared. Clark (1953) recorded the time to prune black walnut by three, four, and five inch diameter classes and total height cleared to eighteen feet. His results were used as a guide to the determination of the pruning costs in the analysis. His costs were used directly for the cost of the initial pruning, and extrapolated to give an estimate of the costs of later and higher prunings. This data was combined with the techniques employed by Hopkins (1959).

Labor costs were determined at the rate of the present minimum wage, \$1.25 per hour, for a paid six hour working day. A six hour working day allows for a landowner to accomplish other jobs in the same day. This would be typical of a farmer-landowner. This working day was reduced to an effective day of four hours to allow for paid travel and "down" time. The number of trees pruned per day was determined using Clark's pruning

Table 2. Pruning models by site index for original spacing 4 feet x 4 feet. (rounded to whole integers)

Site Index	Pruning	Age	Average D.B.H.	Total Height	Height to base of crown	Crown Height	25% of Crown	Cleared Height
		yrs.	ins.	ft.	ft.	ft.	ft.	ft.
40	1	21[a]	3.0[b]	25[c]	9	16	4	13
	2	36	4.8	33	17	16	4	21
60	1	13[a]	3.0[b]	27[c]	11	16	4	15
	2	23	5.0	38	18	20	5	23
	3	35	7.2	52	24	28	7	31
80	1	9[a]	3.0[b]	26[c]	14	12	3	17
	2	15	4.8	40	20	20	5	25
	3	23	6.8	51	27	24	6	33
	4	34	8.9	65	33	32	8	41

[a] Kellogg, Table 75

[b] Kellogg, Table 49

[c] Kellogg, Figure 25

Table 3. Pruning models by site index for original spacing 7 feet x 7 feet. (rounded to whole integers)

Site Index	Pruning	Age	Average D.B.H.	Total Height	Height to base of crown	Crown Height	25% of Crown	Cleared Height
		yrs.	ins.	ft.	ft.	ft.	ft.	ft.
40	1	20	3.0[a]	25[b]	9[c]	16	4	13
	2	34	5.0	33	17	16	4	21
60	1	12	3.0[a]	25[b]	9[c]	16	4	13
	2	21	5.2	36	16	20	5	21
	3	34	7.6	47	23	24	6	29
80	1	7	3.0[a]	20[b]	8[c]	12	3	11
	2	12	4.9	31	15	16	4	19
	3	19	6.7	45	21	24	6	27
	4	28	8.6	56	28	28	7	35

[a] Kellogg, Table 78

[b] Kellogg, Table 49

[c] Kelloggs, Figure 25

Table 4. Pruning models by site index for original spacing 10 feet x 10 feet. (rounded to whole integers)

Site Index	Pruning	Age	Average D.B.H.	Total Height	Height to base of crown	Crown Height	25% of Crown	Cleared Height
		yrs.	ins.	ft.	ft.	ft.	ft.	ft.
40	1	15	3.0[a]	21[b]	5[c]	16	4	9
	2	27	4.7	32	12	20	5	17
60	1	11	3.0[a]	23[b]	7[c]	16	4	11
	2	20	5.4	34	14	20	5	19
	3	33	8.1	48	20	28	7	27
	4	50	10.7	59	27	32	8	35
80	1	8	3.0[a]	25[b]	9[c]	16	4	13
	2	14	5.1	36	16	20	5	21
	3	21	7.4	47	23	24	6	29
	4	31	10.0	58	30	28	7	37
	5	45	12.6	75	35	40	10	45

[a] Kellogg, Table 81

[b] Kellogg, Table 49

[c] Kellogg, Figure 25

times per tree and adding an additional minute per tree in the first pruning for selection and adding one-half minute per tree in the second pruning for the same reason. No additional time was added in subsequent prunings. Ascent and descent time for the higher prunings was computed at the rate of four-one hundreths (.04) of a minute per climbing foot.

The equipment costs were determined by developing a typical method of pruning. In this case, the pruning is accomplished by using a pole saw with a sectional handle. The equipment requirements vary with height and are assumed to be as follows:

1. One man can clear 9 feet with the saw and no handle.
2. One man can clear 13 feet with the saw and 4 feet of handle.
3. One man can clear 17 feet with the saw and 8 feet of handle.
4. One man can clear 21 feet with the saw and 12 feet of handle.
5. One man can clear 25 feet with the saw and 16 feet of handle.

At heights greater than twenty-five feet, the pruning method is changed to pruning with a set of climbers. The initial cost of the climbers is incurred when it becomes necessary to go above twenty-five feet. Subsequent heights can be cleared without any additional equipment costs. Costs of pruning per acre are summarized in Table 5. The number of trees pruned in the analysis of each alternative is the same as the number of trees finally harvested.[8]

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[8]The decision to prune only this many trees was a result of discussion with members of the Forestry Department. Conceivably, a landowner might want to be safe and prune extra trees or he might consider pruning only his largest trees.

Table 5. Pruning costs per tree by site index and original spacing

Site Index	Spacing	Pruning	Cleared Height	Labor Cost	Equipment Cost	Pruning time per tree: Ascent	Pruning time per tree: Pruning	Pruning time per tree: Descent	Cost Per Tree
		no.	ft.	$	$	min.	min.	min.	$
40	4' x 4'	1	13	15.00	.75	0	5.25	0	.1750
		2	21	15.00	.60	0	3.50	0	.1138
	7' x 7'	1	13	15.00	.75	0	5.25	0	.1750
		2	21	15.00	.60	0	3.50	0	.1138
	10' x 10'	1	9	15.00	.45	0	3.50	0	.1128
		2	17	15.00	.60	0	3.50	0	.1138
60	4' x 4'	1	15	15.00	1.05	0	6.00	0	.2006
		2	23	15.00	.60	0	3.50	0	.1138
		3	31	15.00	3.36	.92	3.00	1.24	.1974
	7' x 7'	1	13	15.00	.75	0	5.25	0	.1750
		2	21	15.00	.60	0	3.50	0	.1138
		3	29	15.00	3.36	.84	3.00	1.16	.1912
	10' x 10'	1	11	15.00	.75	0	4.50	0	.1472
		2	19	15.00	.60	0	3.50	0	.1138
		3	27	15.00	3.36	.76	3.00	1.08	.1855
		4	35	15.00	0	1.08	3.00	1.40	.1705

Table 5. Pruning costs per tree by site index and original spacing (continued).

Site Index	Spacing	Pruning	Cleared Height	Labor Cost	Equipment Cost	Pruning time per tree: Ascent	Pruning time per tree: Pruning	Pruning time per tree: Descent	Cost Per Tree
		no.	ft.	$	$	min.	min.	min.	$
80	4' x 4'	1	17	15.00	1.05	0	6.70	0	.2229
		2	25	15.00	.60	0	3.50	0	.1138
		3	33	15.00	3.36	1.00	3.00	1.32	.2040
		4	41	15.00	0	1.32	3.00	1.64	.1852
	7' x 7'	1	11	15.00	.75	0	4.50	0	.1472
		2	19	15.00	.60	0	3.50	0	.1138
		3	27	15.00	3.36	.76	3.00	1.08	.1855
		4	35	15.00	0	1.08	3.00	1.40	.1705
	10' x 10'	1	13	15.00	.75	0	5.25	0	.1750
		2	21	15.00	.60	0	3.50	0	.1138
		3	29	15.00	3.36	.84	3.00	1.16	.1912
		4	37	15.00	0	1.16	3.00	1.48	.1765
		5	45	15.00	0	1.48	3.00	1.80	.1974

Thinning

The need for thinning

The decision maker contemplating management of a plantation should also consider the alternative of thinning. "It is by thinning, more than any other operation, that a forester can control the destiny of a plantation and contribute to its financial success" (Hiley, 1956, p. 99). Properly timed thinnings influence the final value of the stand by (Davis, 1954):

1. Decreasing the proportion of cull material in the species.
2. Increasing the total volume per acre to some extent through better spacing and reduced mortality of desired trees.
3. Increasing unit value somewhat by concentrating growth on the better and faster growing trees.

The need for thinning in black walnut plantations was indicated by Baker (1921, p. 19), "In plantations, the interlocking of crowns soon causes a decided reduction of diameter growth; and after the tree has attained a height of 30 to 40 feet, height growth is no longer stimulated by crowding, the effect of which is, rather, to cut down on all increment." Kellogg (1937) found that without marked expression of dominance and segregation of crown classes, black walnut stands have reduced growth rates almost to the point of stagnation. His data showed that growth in volume represented by the periodic annual board foot growth had a decided tendency to "peak" early and then decrease. This condition would indicate that thinning should be considered as an alternative.

The analysis compares the returns to the investment for both the alternatives of thinning and not thinning. Thinning adds a certainty cost to the investment which has to be considered in appraising the alternatives. In some cases, the material removed may be marketed to defray all or a part of the cost of thinning. These are also included regarding their influence on the net worths.

The decision to thin a stand includes the decisions of how often should thinning be accomplished and to what residual density. These decisions interact with the site index and original spacing. A site of high productivity can be expected to produce a more rapid growth per tree thereby requiring that the stand be thinned more frequently. Similarly, a close spacing would cause earlier crown closure and result in a need for early thinning. The decision maker should, therefore, have some sort of guide as to which combination of site index and spacing will produce the highest present net worth.

The difficulty of determining thinning alternatives is a lack of data regarding responses to thinning. Kellogg (1937) observed stands which had been thinned, but he was unable to obtain information regarding costs and amount of material removed. No experiments involving thinning black walnut were found in the literature. A prediction of response to thinning is necessary for the evaluation, so it was necessary to simulate this response information.

Predicting response

The data of Kellogg (1937) and the recommendations of the Central States Forest Experiment Station (1962) were combined for predictions. Certain assumptions had to be made and are as follows:

1. Plantation growth is related to original spacing and site index.

A different prediction had to be developed for each site index-original spacing combination.

2. Diameter growth is affected by thinning, but not height growth. The data of Kellogg indicated that this was probably true for black walnut.

3. Response to thinning of the plantation is a function of the basal area of the residual stand. Basal area would appear to be a fairly reliable indicator of growth and yield of a stand when compared with the independent variables of site index and stand density (Buckman, 1962).

4. A stand of a certain basal area will be growing at a particular diameter growth rate on the average. If the same stand is thinned at a later time to that same basal area, then it will again grow at the same rate.

This last assumption, it should be noted, is the weakest of the four, but also the most important of the four. Implicitly, it says that there is no difference in the vigor of an old stand when compared to the vigor of a younger stand. If this assumption is optimistic, then the predictions would tend to be optimistic as to growth rates. Equally probable is the fact that these predictions may be pessimistic. Actual experiment would be the only way to test the validity of the predictions. The predictions as developed are as accurate as the data from which they were determined in light of the assumptions used. This is one area of information on black walnut which is particularly sparse.

Determination of frequency and intensity

To be effective, thinnings must be properly timed. Particular attention should be given to the initial thinning and subsequent thinnings should be accomplished when the stand growth rate has been significantly reduced. The purpose of thinning is to maintain stand growth at a high rate. The periodic annual volume growth tends to culminate or "peak" with walnut. Up to this point, volume growth per acre is the highest possible. If the stand is thinned at this point, the volume growth should continue at the same high rate. This peak is related to site index and original spacing and is different for each combination. This peak time is selected as the time for the initial thinning.

Subsequent thinnings are accomplished using the guides of the Central States Forest Experiment Station (1962) as being the "best" information. The recommendations were rigidly followed as being the "true" guides for hardwood management. These were combined with the data of Kellogg to create the thinning alternatives presented in Tables 6 to 8. Some further assumptions are implied in these alternatives and are listed as follows:

1. The objective of management of hardwood timber should be to maintain a fully stocked stand as defined in the guide. A fully stocked stand is one in which the stocking percentage is between 60 and 100. This is computed in the management guide as a percentage determined by number of trees per acre and basal area using an arbitrary standard.

2. The stand should be thinned when the stocking percentage reaches 100.

Table 6. Thinning models by site index, original spacing 10' x 10'.

Thinning Number	Site Index	Age of Stand	Average D.B.H.	Basal Area per Acre Before	Basal Area per Acre After	Trees per Acre Before	Trees per Acre After	Stocking Before	Stocking After
		yrs.	ins.	sq.ft.	sq.ft.	no.	no.	%	%
1st	40	45[a]	6.7[b]	62.5[c]		252[d]		62[e]	
1st	60	30[a]	7.6[b]	89.5[c]	63.0	282[d]	200	85	60
2nd	60	44	10.3	116.5	70.0	200	121	100	60
3rd	60	62	13.8	126.0	76.0	121	73	100	60
1st	80	25[a]	8.6[b]	92.5[c]	66.0	228[d]	164	84	60
2nd	80	35	11.6	120.0	72.0	164	99	100	60
3rd	80	51	15.5	129.0	78.0	99	60	100	60

[a] Kellogg, Figure 127.

[b] Kellogg, Table 81. Reproduced in Appendix C.

[c] Kellogg, Table 57. Reproduced in Appendix C.

[d] Kellogg, Table 65. Reproduced in Appendix B.

[e] Spacing precludes any thinning. At no time during the stand life does the stocking reach a level requiring thinning.

Table 7. Thinning models by site index, original spacing 7' x 7'.

Thinning Number	Site Index	Age of Stand	Average D.B.H.	Basal Area per Acre		Trees per Acre		Stocking	
				Before	After	Before	After	Before	After
		yrs.	ins.	sq.ft.	sq.ft.	no.	no.	%	%
1st	40	48[a]	6.5[b]	68[c]	59	295[d]	258	69	60
2nd	40	72	8.9	111	66	258	153	100	60
1st	60	32[a]	7.3[b]	97[c]	62	335[d]	213	93	60
2nd	60	43	9.9	115	69	213	129	100	60
3rd	60	60	13.3	125	75	129	78	100	60
1st	80	25[a]	8.0[b]	100[c]	64	288[d]	185	94	60
2nd	80	36	10.8	118	71	185	112	100	60
3rd	80	52	14.4	127	77	112	68	100	60

[a] Kellogg, Figure 124.

[b] Kellogg, Table 78. Reproduced in Appendix C.

[c] Kellogg, Table 54. Reproduced in Appendix C.

[d] Kellogg, Table 62. Reproduced in Appendix B.

Table 8. Thinning models by site index, original spacing 4' x 4'.

Thinning Number	Site Index	Age of Stand	Average D.B.H.	Basal Area per Acre Before	Basal Area per Acre After	Trees per Acre Before	Trees per Acre After	Stocking Before	Stocking After
		yrs.	ins.	sq.ft.	sq.ft.	no.	no.	%	%
1st	40	55[a]	6.6[b]	76[c]	60	323[d]	253	76	60
2nd	40	80	9.0	112	67	253	152	100	60
1st	60	33[a]	6.9[b]	103[c]	61	397[d]	235	101	60
2nd	60	46	9.4	113	68	235	141	100	60
3rd	60	65	12.6	123	74	141	85	100	60
1st	80	25[a]	7.3[b]	101[c]	62	353[d]	213	96	60
2nd	80	36	9.9	115	69	213	129	100	60
3rd	80	52	13.3	125	75	129	78	100	60

[a] Kellogg, Figure 121.

[b] Kellogg, Table 75. Reproduced in Appendix C.

[c] Kellogg, Table 51. Reproduced in Appendix C.

[d] Kellogg, Table 59. Reproduced in Appendix B.

3. Thinning should remove basal area until the residual stand is at the 60 percent stocking level.

4. No mortality will result among the residuals between thinnings or between the last thinning and harvest.

5. Increase in growth is assumed to be a function of diameter increment which in turn is a function of basal area.

The exact procedure used for determining the thinning models is outlined in Appendix A.

Determining thinning costs

Each time a stand is thinned, certain costs are incurred. These costs are a function of tree size and number of trees removed. The basis for cost determination is the diameter of the average tree. This cost multiplied by the number of trees removed per acre will give the average thinning cost per acre. These were determined for the average tree using cost data from a study by R. L. Schnell in the Tennessee Valley (1964). His costs were for hardwood pulpwood, but the similarity of pulpwood to the material being removed indicates that similar costs would be expected for thinning. The average tree was converted to cordwood using the Lake States Forest Experiment Station Note Number 185 (1942). Included in the costs are allowances for felling, bucking, and removal of the timber from the plantation site. No allowances are made for removal beyond the plantation site. Timber considered merchantable is removed using the costs of conversion developed in the next section.[9] These costs are summarized in Table 9 for the unmerchantable material.

Rotation

The final decision is when to harvest the plantation. Timber is held as capital until that time when the present net value of the original investment is highest. The analysis will provide to guide to the decision maker regarding the time when this highest present net worth will occur. If the decision is made to harvest the plantation before it has reached this point, the decision maker will lose an opportunity to obtain a higher net worth. If the timber is carried beyond this point, the decision maker will have a lower present net worth.

The determination of the length of rotation is a result of manipulating the model. The previous variables have been determined outside the model and then treated as variables in the model. The length of rotation is determined within the model as a result of iterating the soil rent formula at several possible rotation lengths. The highest present net worth indicates the length of rotation.

The value of a tree given a particular log market situation is a function of its diameter breast height, merchantable height, and amount of defect. In the analysis, defects other than knots and dead branches are assumed not to occur. This assumption is made in the absence of complete

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[9] Merchantable timber will be discussed in more detail in the section on harvesting. It is defined as a black walnut tree with a minimum diameter breast height of 12.5 inches.

Table 9. Thinning costs per tree by tree diameter breast height

Diameter breast height	Volume per tree	Costs Per Cord			Cost per tree
		Felling	Skidding[a]	Total	
in.	cd.	$	$	$	$
6	.04	2.46	1.92	4.38	.18
7	.06	1.93	1.92	3.85	.23
8	.09	1.72	1.92	3.64	.33
9	.12	1.56	1.92	3.48	.42
10	.17	1.41	1.92	3.33	.57
11	.21	1.40	1.92	3.32	.70
12	.26	1.37	1.92	3.29	.86

a. These costs were included as an indication of costs incurred in the removal of down material to insure against losses from fire and insects. This would appear logical in a high-valued stand.

information. Even in a managed stand, some defect would be expected. Intensive management could reduce the incidence of defects resulting from fire, insects, disease, or weather, but could not guarantee against them. The assumption is used rather than attempt to establish probabilities of occurrence in the absence of data.

Knots and branches are defects which could be expected to occur and, therefore, must be considered. If a tree is pruned, these would be removed and the bole could be considered clear. Where the stand is not pruned, the tree could be expected to remove some of its branches through self-pruning. The data of Kellogg (1937) provided some guides regarding how much clear length could be expected. This is reproduced in Appendix D. Other defects on the bole are assumed to not occur.

The prices used for the evaluation of the final product are shown in Table 10. These are for both sawlogs and veneer logs and are f.o.b. mill. The price per thousand board feet moves in discrete jumps as the minimum diameter specifications change. These values and specifications are assumed rigid. A log is valued at the lower price until it changes in size and moves to a higher value class. These prices, however, are from only one buyer and, consequently, may not reflect the range of prices encountered by all Iowa sellers.

The prices shown in Table 10 are also fixed over the length of the rotation. Some of the investment alternatives involved rotations as long as 200 years. Obviously, prices will change in that length of time. Gansner (1963) indicates that the annual cut of black walnut is exceeding growth. If this trend continues without the substitution of some other species for black walnut, the reduced supply should generate a higher price and revised

Table 10. Value and specifications for black walnut logs per board foot Doyle log rule.

Grade[b]	Length	Diameter	Specifications	Price
AA[c]	8'6" & longer	15" and larger	BUTT-CUT, clear, straight logs, free of all defects.	1.40
A+	8'6" & longer	14"	BUTT-CUT, clear, straight logs, free of all defects.	1.00
		15" and larger	SECOND-CUT, clear, straight logs, free of all defects.	
A	6'[a] & 7'	14" and larger	BUTT-CUT, clear, straight logs, free of all defects.	.80
B	8'6" & longer	14" and larger	Straight logs with at least one-half the log clear and free of all defects.	.60
	6' & 7'	14" and larger	SECOND-CUT, clear, straight logs, free of all defects.	
C	8'6" & longer	13"	BUTT-CUT, clear, straight logs free of all defects.	.40
	6' & 7'	15" and larger	Straight logs with at least one-half the log clear.	
D	8'6" & longer	13"	SECOND-CUT, clear, straight logs free of all defects.	.30
	6' & 7'	14"	Straight logs with at least one-half the log clear.	
LBR.	6' & longer	11" and larger	Must be reasonably straight with at least two clear sides.	.15
CULL	6' & longer	11" and larger	Must be reasonably straight with at least one clear side.	.03

[a]Add 4 inches to all lengths other than 8 foot and 6 inch lengths for trim allowance.

[b]Grades and prices adapted from information received courtesy of Bacon Veneer Co. Prices are f.o.b. mill.

[c]Grades AA to D are for veneer logs.

log grade standards. The analysis, consequently, has a conservative bias regarding the absolute prices of the final product.

To determine the volume and characteristics of the final product based upon the average diameter breast height, the trees had to be constructed by simulation. These simulated trees are shown in Table 11. Each tree is constructed from a pre-determined diameter breast height using a form class of 78 and taper tables from Mesavage and Girard (1946). The minimum top diameter inside the bark is eleven inches corresponding to the minimum specifications in Table 10. Total height is increased to a limit of 48 feet of merchantable length including allowances for stump and trim. This restriction was imposed because Kellogg's volume tables (1948) for Iowa went to only that height. Forty-eight feet may be the maximum merchantable height of Iowa black walnut.

The trees were converted to logs as might be done by an experienced logger. Where value of the tree could be increased by the log bucking process, the trees were so divided. For example, a tree with 18 feet of merchantable length can be divided into two-nine foot logs or three-six foot logs. Total volume can be increased by cutting into three logs, and, therefore, the tree would be worth a higher value. If the specifications were such that the value of the tree could be increased by retaining a larger portion of the tree in a higher value log class even though total volume would be reduced, the tree was left in the higher log class. Fourteen feet is arbitrarily selected as the length of the longest log for reasons of ease of handling for the logger.

Conversion costs were determined from the Tennessee Valley Authority Technical Note Number 16 (1953). The costs determined are assumed to

Table 11. Volume by diameter breast height and log length to a merchantable top of 11.0 inches in board feet, Doyle log rule complete.

Diameter Breast Height	Butt Log										2nd Log					3rd Log								4th Log					5th Log					6th Log	
	6	7	8	9	10	11	12	13	14	D.I.B.	6	7	8	9	D.I.B.	6	7	8	9	10	11	12	D.I.B.	6	7	8	9	D.I.B.	6	7	8	9	D.I.B.	6	D.I.B.
in.	bd. ft.									in.	bd. ft.				in.	bd. ft.							in.	bd. ft.				in.	bd. ft.				in.	bd. ft.	in.
12.5	18									11.0																									
12.7		21								11.0																									
12.9			24							11.0																									
13.0				28						11.0																									
13.2					31					11.0																									
13.4	21									11.5	18				11.0																				
13.6		23								11.8	18				11.0																				
13.8			30							11.8	18				11.0																				
14.0			31							11.9		21			11.0																				
14.2				37						12.1			25		11.1																				
14.4	27									12.5	22				11.7	18							11.0												
14.6			35							12.4	22				11.6	18							11.0												
14.8			36							12.5		25			11.6	18							11.0												
15.0			38							12.7			29		11.7		21						11.0												
15.2	31									13.1	26				12.4	22							11.7	18				11.0							
15.4			40							13.0	25				12.2	23							11.8	18				11.0							
15.6				46						13.0	26				12.3	22							11.6	18				11.0							
15.8				47						13.1	26				12.4	22							11.6	18				11.0							
16.0							61			13.0		32			12.0			24					11.0												
16.2								66		13.0		32			12.0			24					11.0												
16.4	37									14.0		40			13.0				36				12.0			24		11.0							
16.6		44								14.0		40			13.0				36				12.0			24		11.0							
16.8			51							14.1		40			13.0				36				12.0			24		11.0							
17.0					62					14.0		40			13.0			32					12.0			24		11.0							
17.2					63					14.1			46		13.0				36				12.0			24		11.0							
17.4		50								14.7	37				14.0			40					13.0				34	11.7			24		11.0		
17.6			57							14.7	37				14.0			40					13.0	26				12.4	22				11.7	18	11.0
17.8			59							14.9	44				14.0				46				13.0	26				12.4	22				11.7	18	11.0
18.0			60							15.0		50			14.0					51			13.0	26				12.4	22				11.7	18	11.0
18.2				68						15.0			56		14.0				46				13.0	26				12.4	22				11.7	18	11.0
18.4						83				15.0			56		14.0					51			13.0			33		12.1			24		11.0		
18.6							91			15.0		50			14.0					51			13.0				35	11.9			24		11.0		
18.8									106	15.0		50			14.0					51			13.0			33		12.1			25		11.2		
19.0									108	15.1			56		14.0			40					13.0				37	12.1			27		11.3		
19.2			72							16.0		60			15.0				56				14.0				46	13.0			32		12.0	19	11.4
19.4				81						16.0		60			15.0				56				14.0				46	13.0		29			12.2	21	11.5
19.6				84						16.2			68		15.0					62			14.0		35			13.0		30			12.3	22	11.7
19.8					93					16.2			68		15.0						69		14.0				46	13.0				34	11.8		
20.0					95					16.3			68		15.0							75	14.0			40		13.0				36	12.0		

be representative of Iowa costs. The crew times for each operation are converted to dollar costs under the following conditions:

1. Felling is done by three men with a saw. The crew rate is based on $1.25 per hour per man plus $1.00 per hour equipment cost.
2. Skidding is accomplished by two methods. For small logs, one man and one animal do the skidding at a rate of $1.75 per hour. Larger logs are skidded by a man with two animals at a rate of $2.25 per hour.
3. Loading is done by a crew of 2.5 men at $1.25 per man per hour.
4. Hauling is done with an average crew of 2.3 men at the rate of $1.25 per man per hour using a truck at the rate of $.25 per mile.

Table 12 summarizes the time requirements of conversion and Table 13 summarizes costs. These are the costs of conversion based on the tree of average diameter breast height. These costs were converted from the International one-quarter inch log rule to the Doyle log rule for ease in comparison with the buyers rates. It is presumed that the costs determined here would not differ substantially from costs in Iowa in which other methods might be used.

Table 12. Log conversion time requirements by tree diameter breast height per thousand board feet for logging hardwoods under average conditions in the Tennessee Valley. Converted from Int. ¼ log rule to Doyle log rule.

D.B.H.	Average Volume	Felling & Bucking, Power Saw 3 men	Skidding: Distance	Skidding: 1 Animal 1 Man	Skidding: 2 Animals 1 Man	Load & Unload, Hand 2.5 men	Haul 10 miles on improved rds. 2.3 men	Haul 50 miles on paved rds. 2.3 men
	b.f.	crew hrs.	ft.	crew hrs.	crew hrs.	crew hrs.	crew hrs.	crew hrs.
12	16	3.39	200	6.10		1.69	5.98	7.76
13	28	2.92	200	5.88		1.51	5.26	6.84
14	52	2.53	250		5.22	1.33	4.65	6.05
15	88	2.21	250		5.16	1.20	4.13	5.37
16	117	1.97	300		6.12	1.09	3.73	4.84
17	158	1.79	300		5.72	1.01	3.28	4.25
18	227	1.63	350		6.19	.94	2.87	3.71
19	268	1.48	350		6.02	.88	2.65	3.42
20	314	1.36	400		6.75	.83	2.48	3.20

Table 13. Costs of conversion to logs per thousand board feet, Doyle log rule.

D.B.H.	Average Volume Per Tree	Felling & Bucking	Skidding	Loading & Unloading	Hauling Improved Roads	Hauling Paved Roads	Total	Cost Per Tree
	b.f.	$	$	$	$	$	$	$
12	16	16.10	10.68	5.28	19.69	34.81	86.56	1.38
13	28	13.87	10.29	4.72	17.62	32.17	78.67	2.20
14	52	12.02	11.74	4.16	15.87	29.89	73.68	3.83
15	88	10.50	11.61	3.75	14.37	27.94	68.17	6.00
16	117	9.36	13.77	3.41	13.22	26.42	66.17	7.74
17	158	8.50	12.87	3.16	11.93	24.72	61.18	9.67
18	227	7.74	13.93	2.94	10.75	23.17	58.53	13.29
19	268	7.03	13.55	2.75	10.12	22.33	55.78	14.95
20	314	6.46	15.19	2.59	9.63	21.70	55.57	17.45

ANALYSIS AND RESULTS

The complete model consists of 72 "packages" of decision alternatives based upon three site index variables, three original spacings, two planting methods, and four sets of management decisions. All revenues and costs are compounded to the rotation age on a per acre basis and the net result is discounted to the present. The procedure is as follows:

1. A particular rotation is selected for trial and the diameter breast height is determined.
2. The tree value is determined by combining the logs as shown in Table 11 with the respective prices shown in Table 10. The defect characteristics are determined for the unpruned trees using the curves in Appendix D and for the pruned trees using the heights pruned from Tables 2, 3, and 4. These tree values are converted to per acre costs utilizing the curves of number of trees per acre shown in Appendix B.
3. Intermediate revenues, where applicable, are treated similarly and are compounded to the rotation age.
4. The conversion costs are determined for the average diameter breast height from Table 13. These are converted to per acre costs using the number of trees determined for Step 2 above.
5. The planting cost is determined from Table 1 and is compounded for the full period of the rotation.
6. Plantation maintenance costs ot $10.00 per acre are compounded for the full period of rotation and a second time for the full period less one year.

7. Thinning costs, where applicable, are determined per acre with the alternatives shown in Tables 6, 7, and 8. These are converted to per tree costs utilizing the costs by diameter breast height shown in Table 9 and converted to per acre costs by multiplying by the number of trees removed in the thinning. These costs are compounded for the period of the rotation less the age at which the thinning occurred.
8. Pruning costs are determined using the alternatives shown in Tables 2, 3, and 4. These are converted to costs per tree using the values in Table 5 and are converted to per acre costs by multiplying by the number of trees per acre determined in Step 2 above. These are compounded for the period of rotation less the age at which the pruning occurred.
9. Costs of protection and taxes are included as a fixed cost of $1.25 per acre occurring annually for the period of the rotation.
10. All costs are subtracted from the total revenues at the rotation age and the net result is discounted to the present.
11. The process is repeated until the highest present net worth value is determined.

The results of the analysis are presented in Table 14. Each alternative is ranked by present net worth per acre from highest to lowest. The rotation lengths and diameter breast height of the average tree are presented in Table 15.

Table 14. The present net worth values per acre of each production alternative ranked from highest to lowest (continued).

Ranking	Spacing	Site Index	Method of Planting	Thinning	Pruning	Present Net Worth
						$
1	10 x 10	80	Hand	Yes	Yes	+437.65
2	10 x 10	80	Tractor	Yes	Yes	+436.38
3	10 x 10	80	Hand	Yes	No	+398.14
4	10 x 10	80	Tractor	Yes	No	+396.91
5	7 x 7	80	Tractor	Yes	Yes	+320.70
6	7 x 7	80	Hand	Yes	Yes	+320.01
7	7 x 7	80	Tractor	Yes	No	+310.21
8	7 x 7	80	Hand	Yes	No	+309.65
9	4 x 4	80	Tractor	Yes	No	+174.21
10	4 x 4	80	Hand	Yes	No	+166.66
11	4 x 4	80	Tractor	Yes	Yes	+165.83
12	4 x 4	80	Hand	Yes	Yes	+158.28
13	10 x 10	60	Hand	Yes	No	+100.20
14	10 x 10	60	Tractor	Yes	No	+ 99.02
15	10 x 10	60	Hand	Yes	Yes	+ 95.97
16	10 x 10	60	Tractor	Yes	Yes	+ 94.80
17	7 x 7	60	Tractor	Yes	No	+ 64.12
18	7 x 7	60	Hand	Yes	No	+ 63.58
19	7 x 7	60	Tractor	Yes	Yes	+ 56.81
20	7 x 7	60	Hand	Yes	Yes	+ 56.27
21	10 x 10	80	Hand	No	No	+ 6.31
22	10 x 10	80	Tractor	No	No	+ 5.11
23	10 x 10	80	Hand	No	Yes	- 4.71
24	10 x 10	80	Tractor	No	Yes	- 5.91
25	4 x 4	60	Tractor	Yes	No	- 30.32
26	4 x 4	60	Tractor	Yes	Yes	- 35.98
27	4 x 4	60	Hand	Yes	No	- 37.80
28	7 x 7	80	Tractor	No	No	- 38.96
29	7 x 7	80	Hand	No	No	- 39.51
30	4 x 4	60	Hand	Yes	Yes	- 43.99
31	10 x 10	60	Hand	No	No	- 46.91
32	10 x 10	60	Tractor	No	No	- 48.09
33	7 x 7	80	Tractor	No	Yes	- 49.95
34	7 x 7	80	Hand	No	Yes	- 50.50
35	10 x 10	40	Hand	No	No	- 51.45

Table 14. The present net worth values per acre of each production alternative ranked from highest to lowest (continued).

Ranking	Spacing	Site Index	Method of Planting	Thinning	Pruning	Present Net Worth
						$
36	10 x 10	40	Hand	Yes	No	- 51.45
37	10 x 10	40	Tractor	No	No	- 52.61
38	10 x 10	40	Tractor	Yes	No	- 52.61
39	10 x 10	40	Hand	No	Yes	- 54.97
40	10 x 10	40	Hand	Yes	Yes	- 54.97
41	7 x 7	60	Tractor	No	No	- 55.64
42	10 x 10	40	Tractor	No	Yes	- 56.13
43	10 x 10	40	Tractor	Yes	Yes	- 56.13
44	7 x 7	60	Hand	No	No	- 56.18
45	10 x 10	60	Hand	No	Yes	- 56.87
46	10 x 10	60	Tractor	No	Yes	- 57.52
47	7 x 7	40	Tractor	No	No	- 58.09
48	7 x 7	40	Hand	No	No	- 58.73
49	7 x 7	40	Tractor	Yes	No	- 59.63
50	7 x 7	40	Hand	Yes	No	- 60.17
51	7 x 7	40	Tractor	No	Yes	- 67.00
52	7 x 7	40	Hand	No	Yes	- 67.63
53	7 x 7	60	Tractor	No	Yes	- 67.83
54	7 x 7	60	Hand	No	Yes	- 68.38
55	7 x 7	40	Tractor	Yes	Yes	- 68.80
56	7 x 7	40	Hand	Yes	Yes	- 69.33
57	4 x 4	80	Tractor	No	No	- 77.14
58	4 x 4	60	Tractor	No	No	- 79.22
59	4 x 4	40	Tractor	No	No	- 80.68
60	4 x 4	40	Tractor	Yes	No	- 82.46
61	4 x 4	80	Hand	No	No	- 84.62
62	4 x 4	60	Hand	No	No	- 86.64
63	4 x 4	40	Hand	No	No	- 88.09
64	4 x 4	40	Hand	Yes	No	- 89.88
65	4 x 4	40	Tractor	Yes	Yes	- 92.02
66	4 x 4	40	Tractor	No	Yes	- 94.21
67	4 x 4	80	Tractor	No	Yes	- 97.31
68	4 x 4	60	Tractor	No	Yes	- 98.61
69	4 x 4	40	Hand	Yes	Yes	- 99.44
70	4 x 4	40	Hand	No	Yes	-101.55

Table 14. The present net worth values per acre of each production alternative ranked from highest to lowest (continued).

Ranking	Spacing	Site Index	Method of Planting	Thinning	Pruning	Present Net Worth
						$
71	4 x 4	80	Hand	No	Yes	-104.79
72	4 x 4	60	Hand	No	Yes	-106.04

Table 15. Rotation length and diameter breast height of the average tree for each ranked alternative.

Ranked Alternative	Rotation	Diameter Breast Height	Ranked Alternative	Rotation	Diameter Breast Height
	yrs.	ins.		yrs.	ins.
1	70	19.6	37	140	12.7
2	70	19.6	38	140	12.7
3	67	19.0	39	160	13.4
4	67	19.0	40	160	13.4
5	72	19.0	41	140	15.4
6	72	19.0	42	160	13.4
7	69	18.4	43	160	13.4
8	69	18.4	44	87	13.4
9	81	18.8	45	140	15.4
10	81	18.8	46	87	13.4
11	81	18.8	47	190	12.7
12	81	18.8	48	190	12.7
13	85	18.2	49	144	12.7
14	85	18.2	50	144	12.7
15	85	18.2	51	190	12.7
16	85	18.2	52	190	12.7
17	93	18.4	53	140	15.4
18	93	18.4	54	140	15.4
19	93	18.4	55	144	12.7
20	93	18.4	56	144	12.7
21	70	15.4	57	95	13.4
22	70	15.4	58	130	12.7
23	70	15.4	59	195	12.5
24	70	15.4	60	152	12.7
25	95	17.0	61	95	13.4
26	95	17.0	62	130	12.7
27	95	17.0	63	195	12.5
28	95	15.4	64	152	12.7
29	95	15.4	65	152	12.7
30	95	17.0	66	195	12.5
31	87	13.4	67	95	13.4
32	87	13.4	68	130	12.7
33	95	15.4	69	152	12.7
34	95	15.4	70	195	12.5
35	140	12.7	71	95	13.4
36	140	12.7	72	130	12.7

CONCLUSIONS

The results presented in Table 14 are obtained by manipulation of a simulation model and are not obtained by an actual experiment. The model is based upon empirical data which in many instances had to be extrapolated or combined in order to derive predictions. Consequently, there is no way of expressing a statistical confidence in the value predictions obtained. The values predicted may not be correct in an absolute sense, but should indicate the relative values of each alternative. Despite this limitation, some generalities may be made from the results.

The rankings do indicate the importance of proper site selection for a black walnut plantation. By comparing alternatives in which site was the only variable, site index 80 gave consistently higher net worth values and site index 40 gave the lowest. The exceptions are worth noting because they indicate a bias deliberately included in the analysis. Exceptions are the alternatives with a four by four original spacing with pruning and no thinning. In these instances, the site index 40 is higher than the other two site indices. This apparent inconsistency is a result of over-predicting the growth on black walnut for rotations longer than 100 years. Growth is assumed to be a constant rate beyond 100 years when, in fact, it would be expected to decrease. As a result, the stand actually was found to mature sooner than one would expect. Since all values were negative at the five percent discount rate, the absolute values are not that important. This bias is included to provide a more conservative estimate.

The results also indicate that additional site preparation cost beyond those already assumed may not be economical. Twenty-two alternatives have positive present net worths. Additional preparation costs on sites 60 and 80 may be incurred up to the expected present net worth and still achieve at least a five percent rate of return on the total investment. Thus, up to a $437.65 additional expenditure could be made on site 80 for preparation and up to a $100.20 additional expenditure on site 60 assuming a five percent interest rate.

The spacing decision is an important decision. The widest spacing--ten feet by ten feet--gave consistently higher results when compared to other spacing alternatives with the same site index and silvicultural system. Probably this is a result of faster initial growth and the later thinnings. Since only three spacings were evaluated, further experimentation might prove that the ten by ten spacing is not the most efficient economically. This analysis does indicate that the wide spacings are apparently more efficient, and that there is little justification for planting the stock close together.

As could be expected from a silvicultural standpoint, the thinning alternatives indicated higher net worths than did the same alternatives without thinning. While this is an economic argument for thinning, the thinning predictions are completely simulated and may be overly optimistic. Also the thinning was presented as a "package" in which all thinning was accomplished instead of each thinning in succession being evaluated separately. Perhaps thinning should be evaluated in a sequential decision model.

Pruning could be expected from a silvicultural point of view to add value to the original investment. In only a few cases did the pruning-thinning alternative give a higher net worth than did the no-pruning-thinning alternative. The highest present net worths did result from the combination of pruning and thinning which indicates that pruning would add to the investment.

The fact that pruning is not economical in all other alternatives results from the black walnut log market structure. The present standards for log buying are based on soundness of log and outside defect. As long as the log shows certain external characteristics, then the log is priced accordingly. A pruned log will sell for the same price on the market as one which has no visible defect regardless of whether it has been pruned or not. For the vertically integrated firm, pruning will have a different influence. Where the log is sold as lumber, grade of boards would be effected by the amount of clear lumber produced (Freeman, 1954; King, 1958). This is more reflected in the resale of lumber than in the purchase of logs. The value of pruning might also enter as a market guarantee of getting the higher price for logs. This guarantee is made as an assumption in the analysis.

In summary, the results indicate that the alternative of timber management in black walnut is not exceedingly lucrative as many people expected. The long rotation lengths in hardwood timber production involve a time-cost which reduced the present net worth considerably. With some management inputs, particularly thinning, profits apparently can be expected by investing in a black walnut plantation given a five percent interest rate.

LIMITATIONS AND INFORMATION GAPS

Induction from the results of this analysis to real or actual conditions can be made provided that the limitations inherent in the simulation are recognized. Because this is a simulation model, any generalizations made should be within the framework of the assumptions used. These assumptions may be relaxed only with caution.

Rate of interest

The guiding rate of interest used for the present net worth discounting was five percent. As was stated at the beginning, this rate was chosen arbitrarily to guarantee that positive net worths will appear in the results. The choice of interest rate does not affect the ranking of the better alternatives in this particular case study. Ranking of intermediate alternatives changed slightly. By applying other rates of interest, it was found that this choice obtained the stated objectives. The five percent rate resulted in twenty-two positive values (Table 14). If the rate is changed to six percent, only sixteen values are positive. At the rate of nine percent, the only positive present net worth is the first (ten feet by ten feet spacing on site index 80 with thinning and pruning), and this is approximately zero. Thus for the decision maker with a guiding rate of interest higher than nine percent, an investment in black walnut production is not an available alternative.

Bias

The evaluation contains intentional biases in an attempt to err on the side of conservatism except on low sites. These biases are introduced in three ways.

First, the model is static in that no change in the price of walnut logs is allowed. If the future can be predicted by the past, the expectation of price changes would be upward. Thus, the price obtained for the final product may be greater 70 years from today than it would be today. This is price in an absolute sense. Price of walnut logs relative to the prices of other commodities might remain constant or even decline. There would be no way to actually predict which would be the case. In an absolute sense, the static price assumption should make the projected estimates conservative.

Bias is further introduced by the method of extrapolation for growth on low quality sites. As mentioned, the growth estimates are overpredicted for rotations longer than 100 years. The bias increases as the rotation becomes longer. Thus, the site index 40 estimates are higher than they should be. This estimate system was used because growth rates for this site were such that expected rotations would be greater than 200 years. One attempt to fit a curvilinear estimate produced an expected rotation of 509 years to produce a minimum merchantable tree. The low quality site alternatives, however, all have negative present net worths. Thus, the absolute differences between these alternatives and the positive alternatives should be greater than the differences indicated in Table 14; that is, the negative values should be even more negative.

Conservative bias is further guaranteed by the use of the "average" tree as the basis for predictions and value determinations. A stand of timber would not be expected to contain all trees of a similar size and diameter. Instead, the stand structure would resemble a normal distribution of diameters around an average diameter. The data of Kellogg (1937) contained estimates of such distributions, but these were not projected beyond 55 years for spacing ten feet by ten feet on site index 80. Since rotations longer than this are obtained, the "average" tree is used. It is more convenient to project a single value into the future than a distribution of values. Computation is easier also.

The consequences of this type of projection is a conservative estimate of the final product value. This is indicated in Table 16. The distribution compared is the one for a stand on site index 80 established by an original spacing of ten feet by ten feet at an age of 55 years. This, incidently, represents the limit of the distributions recorded by Kellogg. As Table 16 indicates, the predicted returns are much lower using the average tree compared to the actual distribution. Other costs for each stand can be expected to be the same. Thinning would change this distribution such that the variance around the average tree would be less and the average diameter is greater.

<u>Errors due to ommission</u>

The evaluation should also be judged on the basis of what is not included in the model. Particularly, the results could be expected to be in error if the highest present net worth possible for each alternative is not determined or if a relevant variable is ommitted from the model.

In theory, to test for the maximum net worth by trial and error, the present net worth for each year should be determined for each alternative. In practice, this is not necessary. The product specifications used caused

Table 16. Comparison of the values per acre of an average tree stand to a normally distributed stand.

Stand	Diameter Breast Height	Trees Per Acre	Stand Value	Conversion Cost	Net Value
	ins.	no.	$	$	$
Average	13.5	112	672.00	338.24	333.76
Distributed	9.0	3	0.0	0.0	0.0
	10.0	5	0.0	0.0	0.0
	11.0	10	0.0	0.0	0.0
	12.0	16	0.0	0.0	0.0
	13.0	18	75.60	39.60	36.00
	14.0	19	148.20	72.77	75.43
	15.0	15	198.00	90.00	108.00
	16.0	11	293.70	85.14	208.56
	17.0	8	460.80	77.36	383.44
	18.0	4	526.20	53.16	473.04
	19.0	3	601.20	44.85	556.35
		112			1840.82

a condition which made the iteration process easier. The minimum specifications provided a starting point for discounting. The trees were not merchantable below these minimum specifications. As the minimum requirements changed, the tree "jumped" in present net worth. For example, at 15.4 inches diameter breast height, the butt log "jumped" in value from $.15 per board foot to $.40 per board foot as the diameter inside the bark increased to 13.0 inches. Similar "jumps" occurred at 16.4 inches and 18.0 inches. It was only necessary to test these "peaks" and determine which was highest to locate the neighborhood of the highest present net worth. In this manner, the iterative process was assured of finding the highest present net worth and is, therefore, reasonably accurate in this respect.

The possibility of error through the ommission of a relevant variable is more serious. This possibility is always present in a study which predates actual experimentation in the field. The results of the analysis, therefore, are valid only for the assumptions and relationships tested. The actual returns to investment can only be tested by an actual experiment and until then are subjective. This indicates areas in which more information is needed.

If a realistic program for investing in black walnut is to be initiated, more information is needed regarding the silviculture of black walnut. Response estimates are needed for thinning and pruning. At the same time, these should be studied as to the proper timing of each and the frequency and intensity. The frequencies and intensities used may be accurate only by chance. These two treatments combined in the analysis to give high results. Cost data should be incorporated in the same studies. Hopefully, the cost data used is very near the actual costs. Changes do occur and cost data based upon dollars alone is unrealistic. Coinciding with the response studies should be time studies.

The area of mixed and pure plantations should be explored more fully. The concept of multi-products from different species as proposed by Seidel and Brinkman (1962) offers some possibility.

Finally, a study should be initiated regarding the effect of pruning on the final product for the log producer. As shown in the analysis, the log producer does not derive the full benefit from pruning because of present grading rules. He is producing more clear wood in his product compared to the unpruned product, and the market should yield more benefit than the analysis indicated. This might be an argument for a "tree pedigree" system wherein the buyer is assured of getting a product with certain desirable internal characteristics. The grading institution represents a condition which could greatly effect the final product and, therefore, completely change the analysis.

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APPENDIX A

Procedure for determining time of pruning and number of trees to be removed using the example of site index 60, original spacing seven feet by seven feet.

Since response data for thinning was not available, it was necessary to create thinning models and predict the response to thinning. The basic assumptions are outlined in the section on thinning. The exact procedure used to determine the models in Tables 6, 7, and 8 is as follows:

1. Determine the age at which the highest periodic annual growth occurs (Kellogg, 1937, Figure 124). (Age 32)
2. At this age, determine the average diameter breast height (Kellogg, Table 78, reproduced as Figure 9 in Appendix C), basal area per acre (Kellogg, Table 54, reproduced as Figure 9 in Appendix C), and number of trees per acre (Kellogg, Table 62, reproduced as Figure 3 in Appendix B). (7.3 inches, 97 square feet, and 335 trees respectively)
3. Calculate the stocking percentage (Central States Forest Experiment Station, 1962, pp. 16 and 17). (93 percent)
4. With average diameter breast height held constant, read from the guide the basal area corresponding to a 60 percent stocking. (62 square feet)
5. Calculate the number of trees per acre from the formula: basal area per tree = $.005454150D^2$ where D is the average diameter breast height. (213 trees) The difference between this number and the number found in step 2 is the number of trees removed in thinning. (335 - 313 = 122)

6. With the number of trees fixed, read from the stocking guide the basal area equivalent to 100 percent stocking. (115 square feet)
7. Determine the average diameter of the stand with the above number of trees and basal area using the formula in step 5 above. (9.9 inches)
8. Subtract this diameter from that determined in step 2. (9.9 - 7.3 = 2.6) This is the diameter increment which must be added to each tree as the basal area increases from 62 to 115 square feet per acre.
9. Using the curves in Figure 9, determine the age and diameter breast height corresponding to the basal area of 62. (16 years and 4.1 inches)
10. Add to the diameter determined in step 9 the difference in diameter determined in step 8. (4.1 + 2.6 = 6.7) Determine from Figure 9 the age at which this diameter occurs. (27 years)
11. The difference in the ages determined in steps 9 and 10 is the length of time in which the stand went from a basal area of 62 to a basal area of 115. (27 - 16 = 11) Add this number of years to the original time of thinning and this represents the time when the stand is again ready to be thinned. (32 + 11 = 43)
12. Repeat steps 3 through 11 for subsequent thinnings.

APPENDIX B

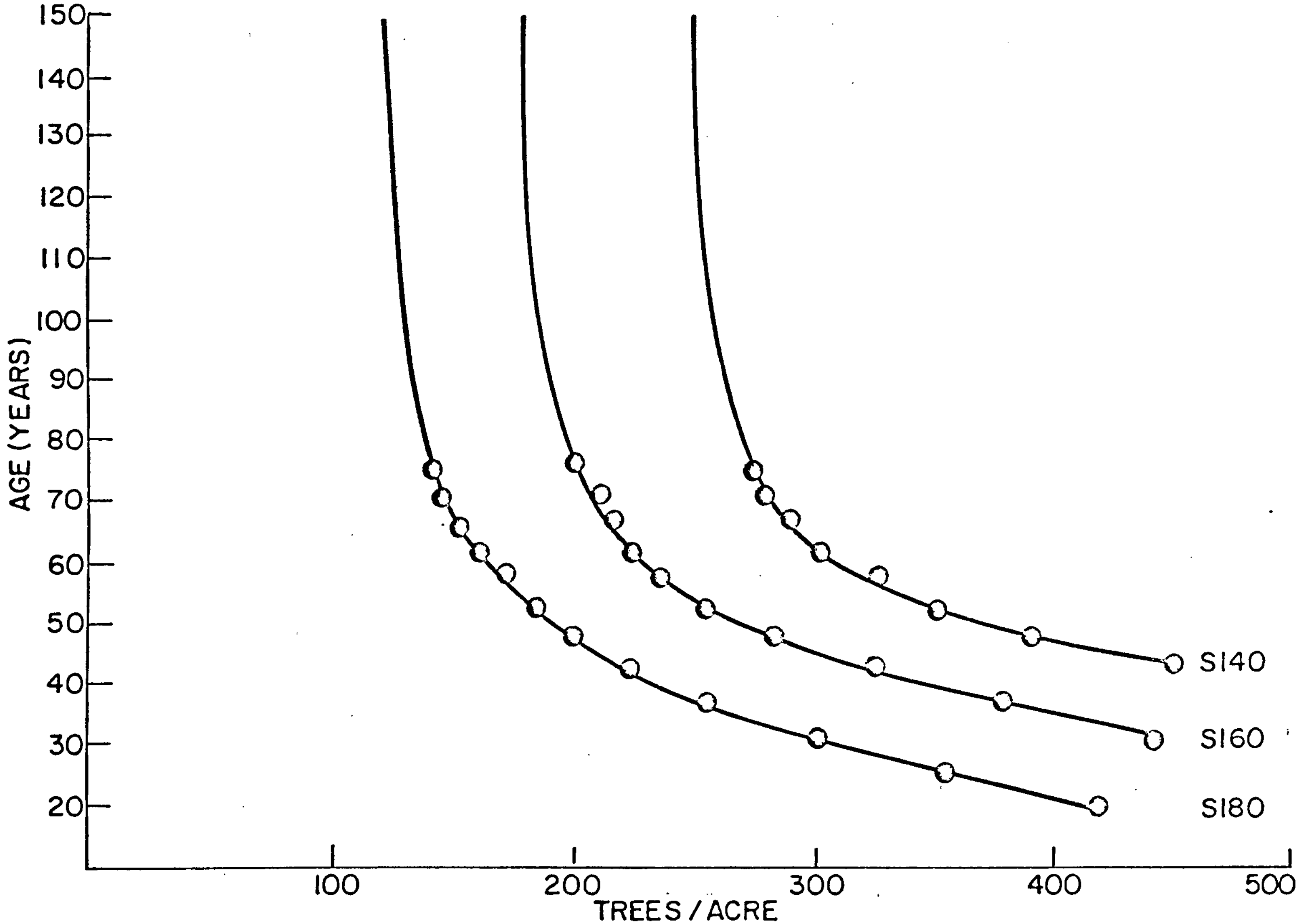

Figure 2. Number of trees per acre by site index, original spacing 4 feet by 4 feet.

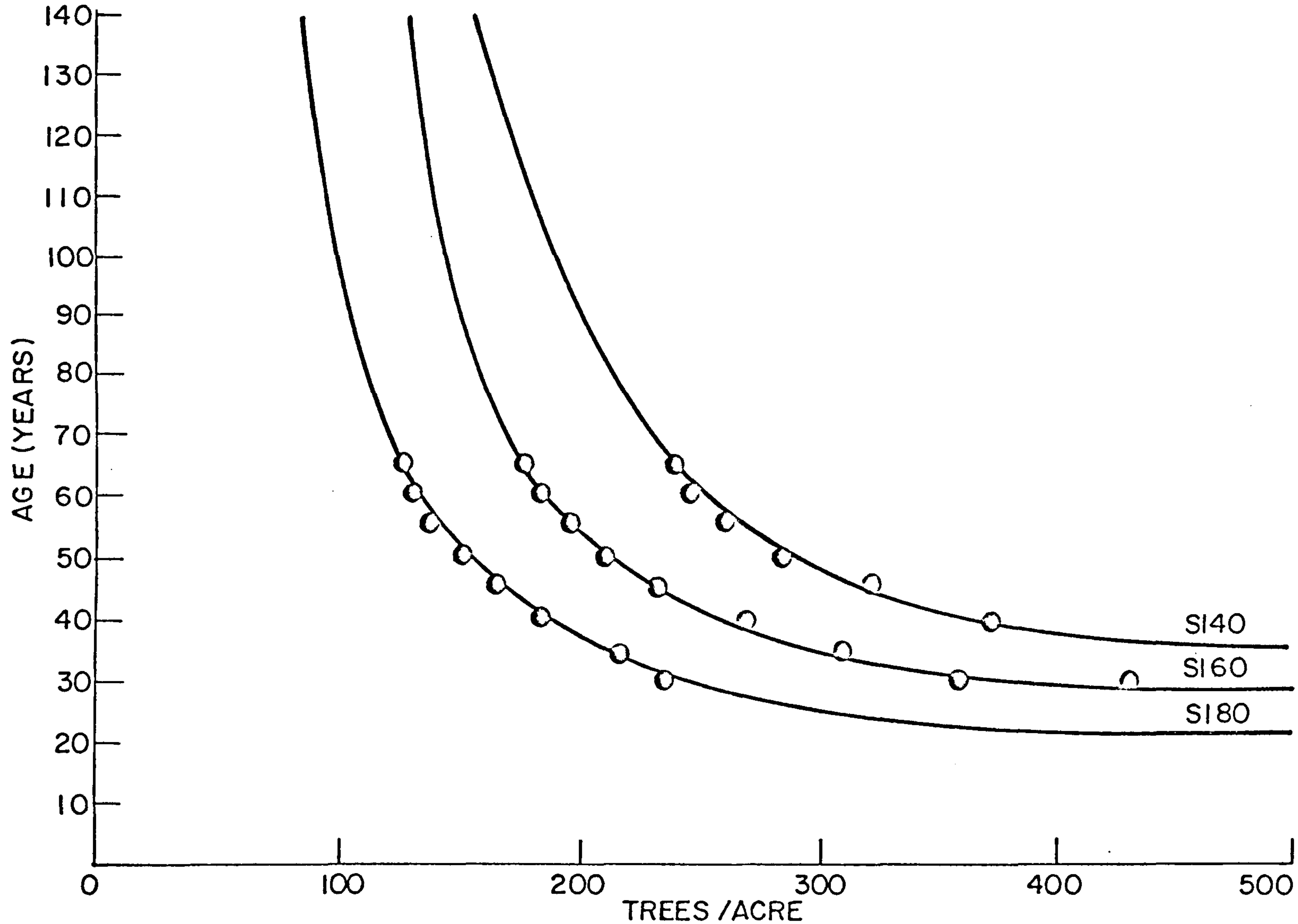

Figure 3. Number of trees per acre by site index, original spacing 7 feet by 7 feet.

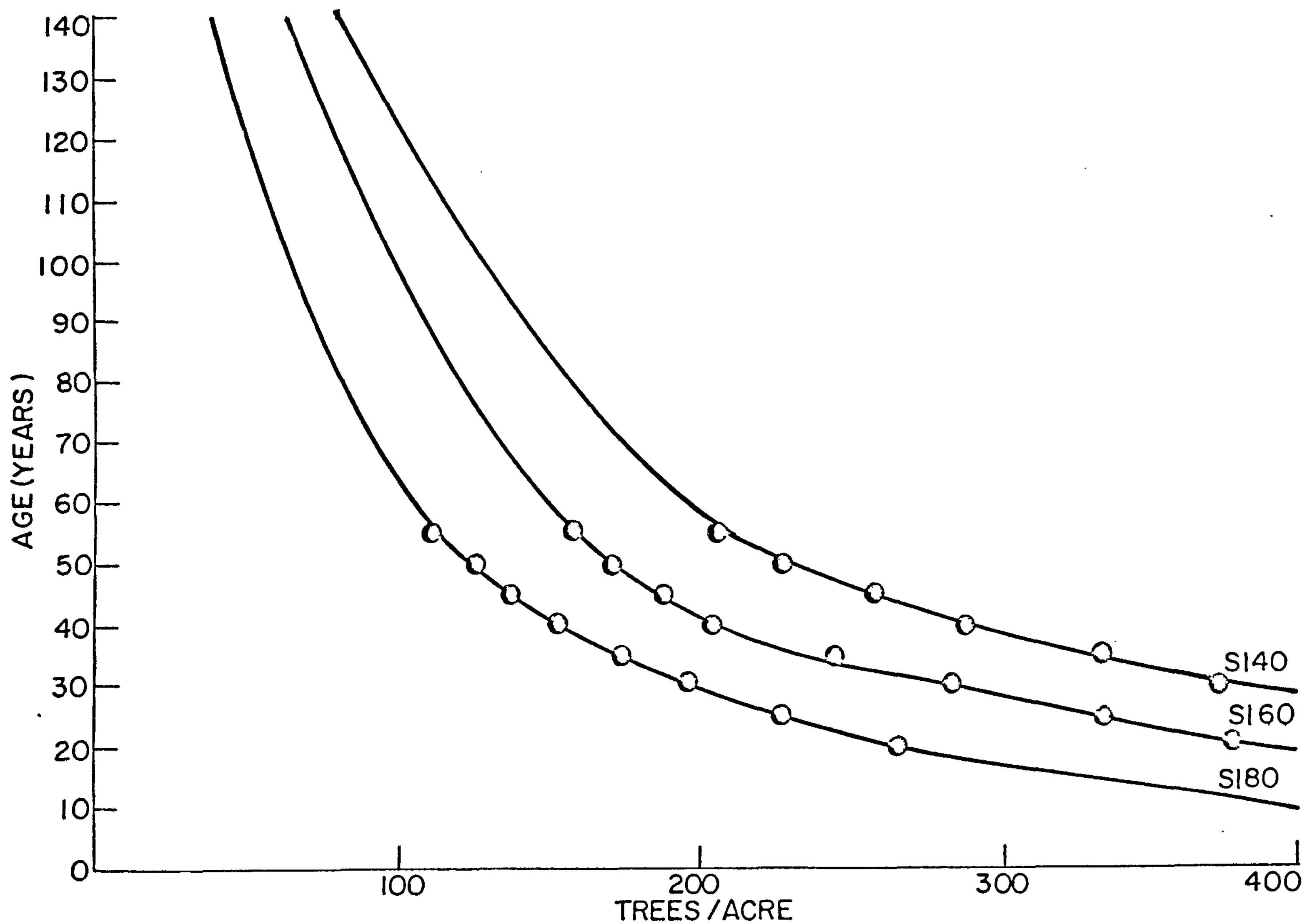

Figure 4. Number of trees per acre by site index, original spacing 10 feet by 10 feet.

APPENDIX C

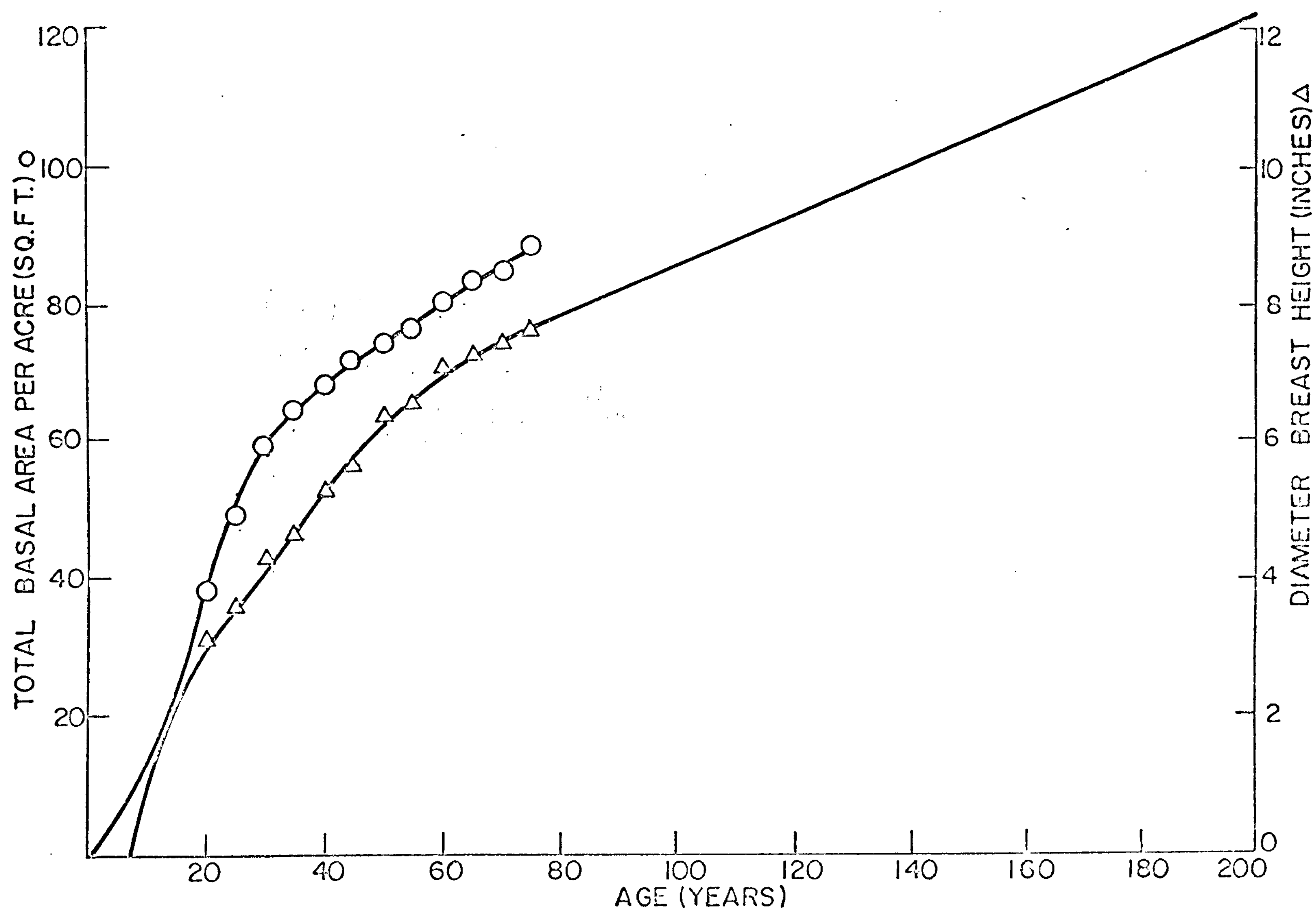

Figure 5. Basal area per acre and diameter breast height, site index 40, original spacing 4 feet by 4 feet.

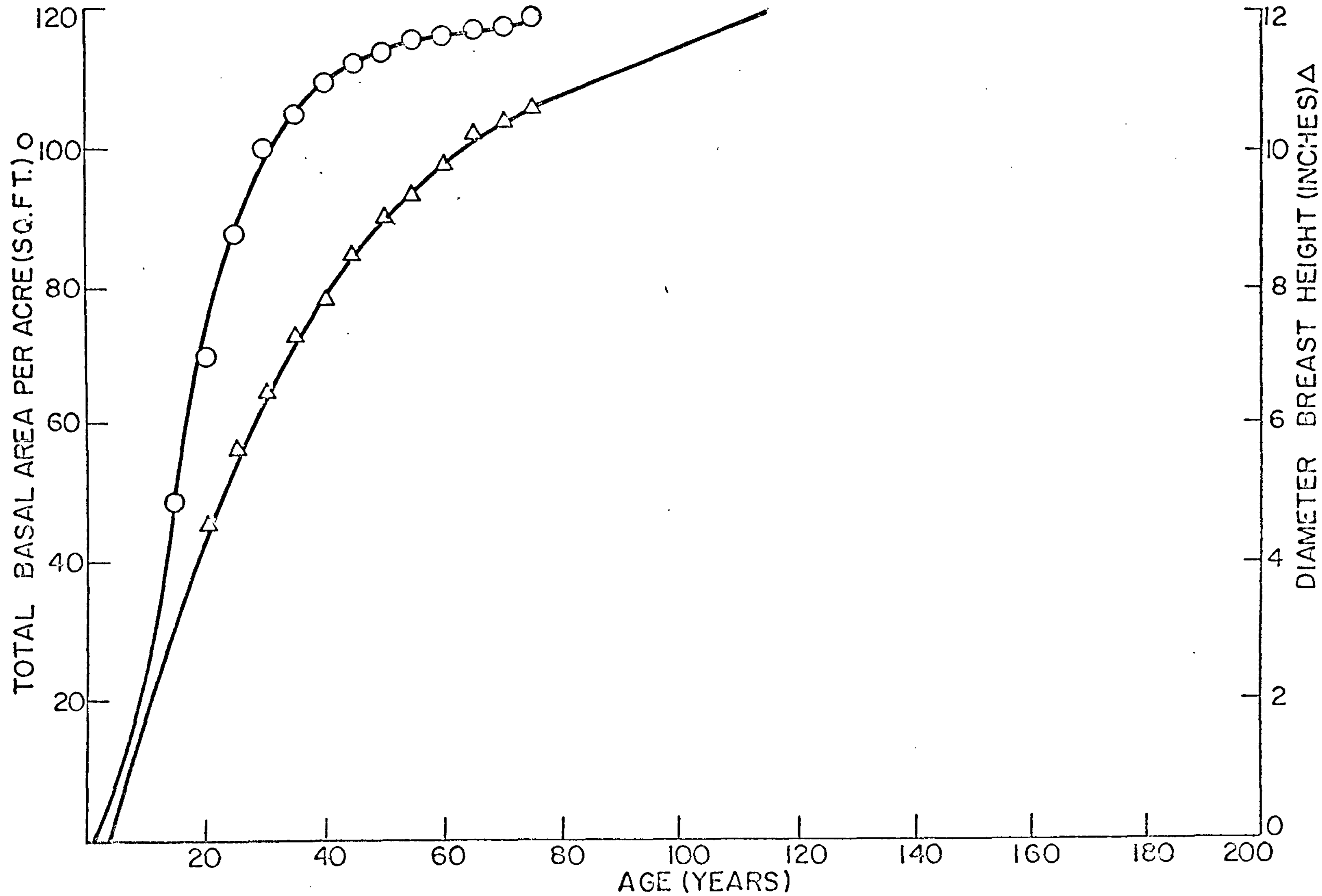

Figure 6. Basal area per acre and diameter breast height, site index 60, original spacing 4 feet by 4 feet.

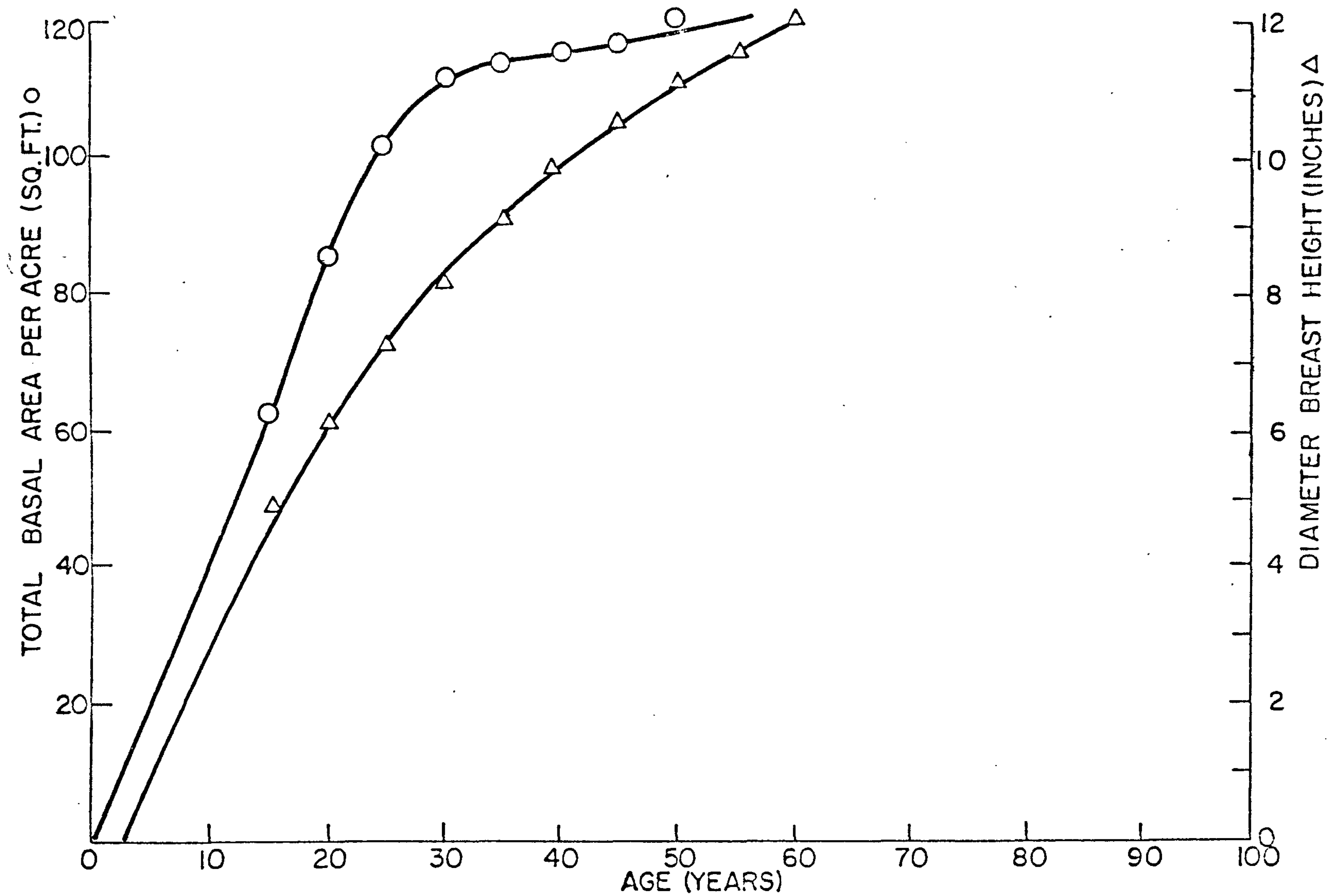

Figure 7. Basal area per acre and diameter breast height, site index 80, original spacing 4 feet by 4 feet.

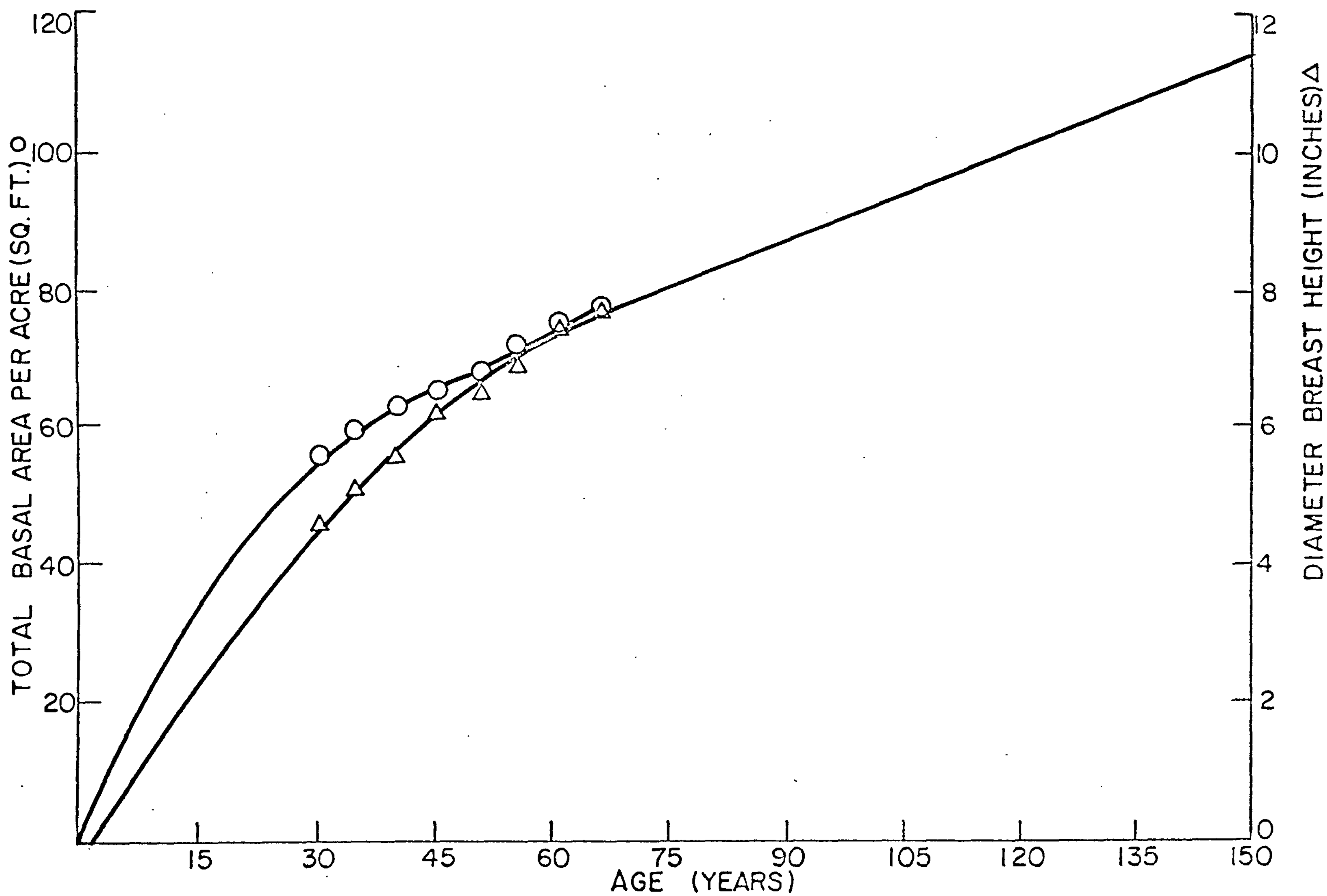

Figure 8. Basal area per acre and diameter breast height, site index 40, original spacing 7 feet by 7 feet.

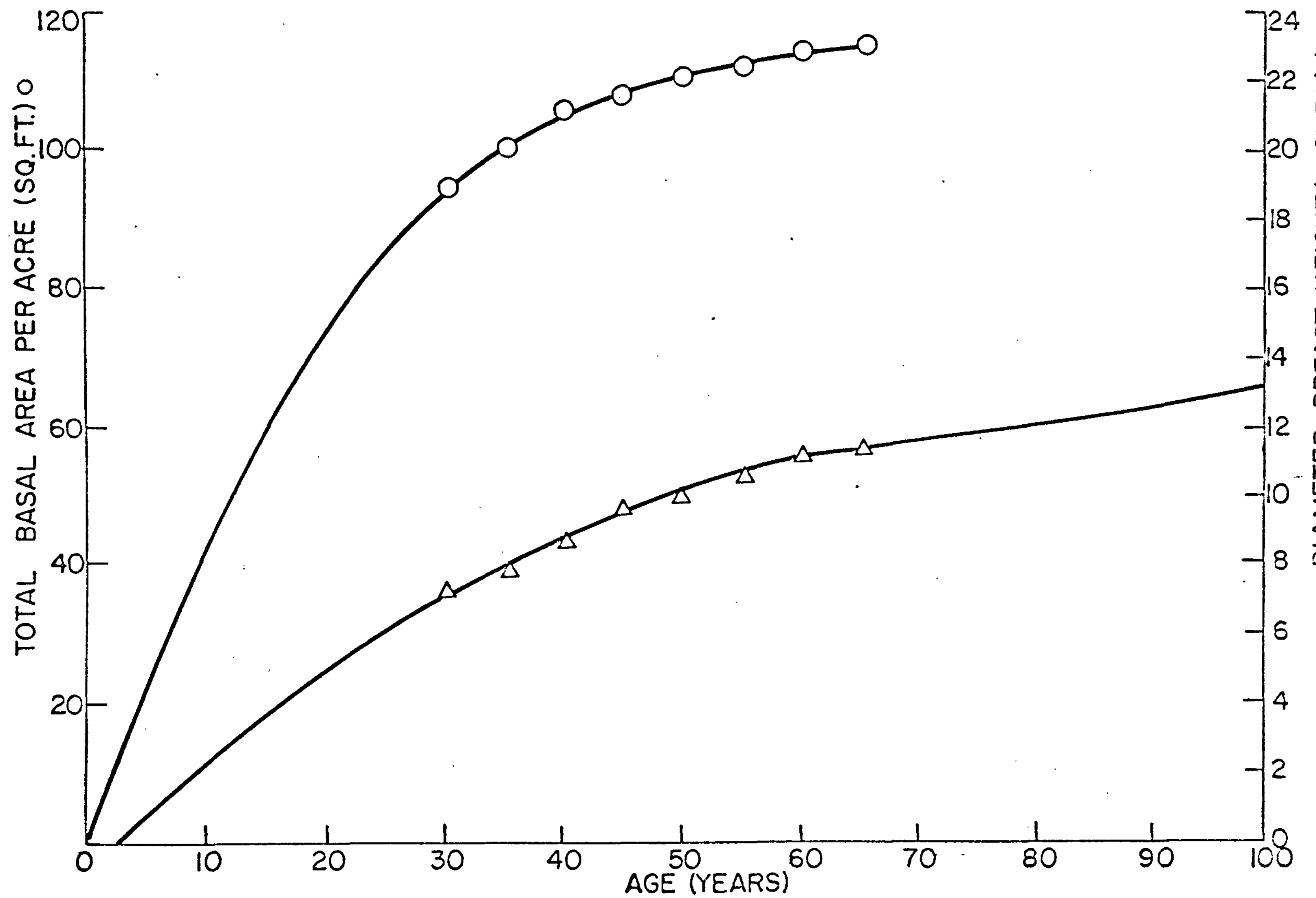

Figure 9. Basal area per acre and diameter breast height, site index 60, original spacing 7 feet by 7 feet.

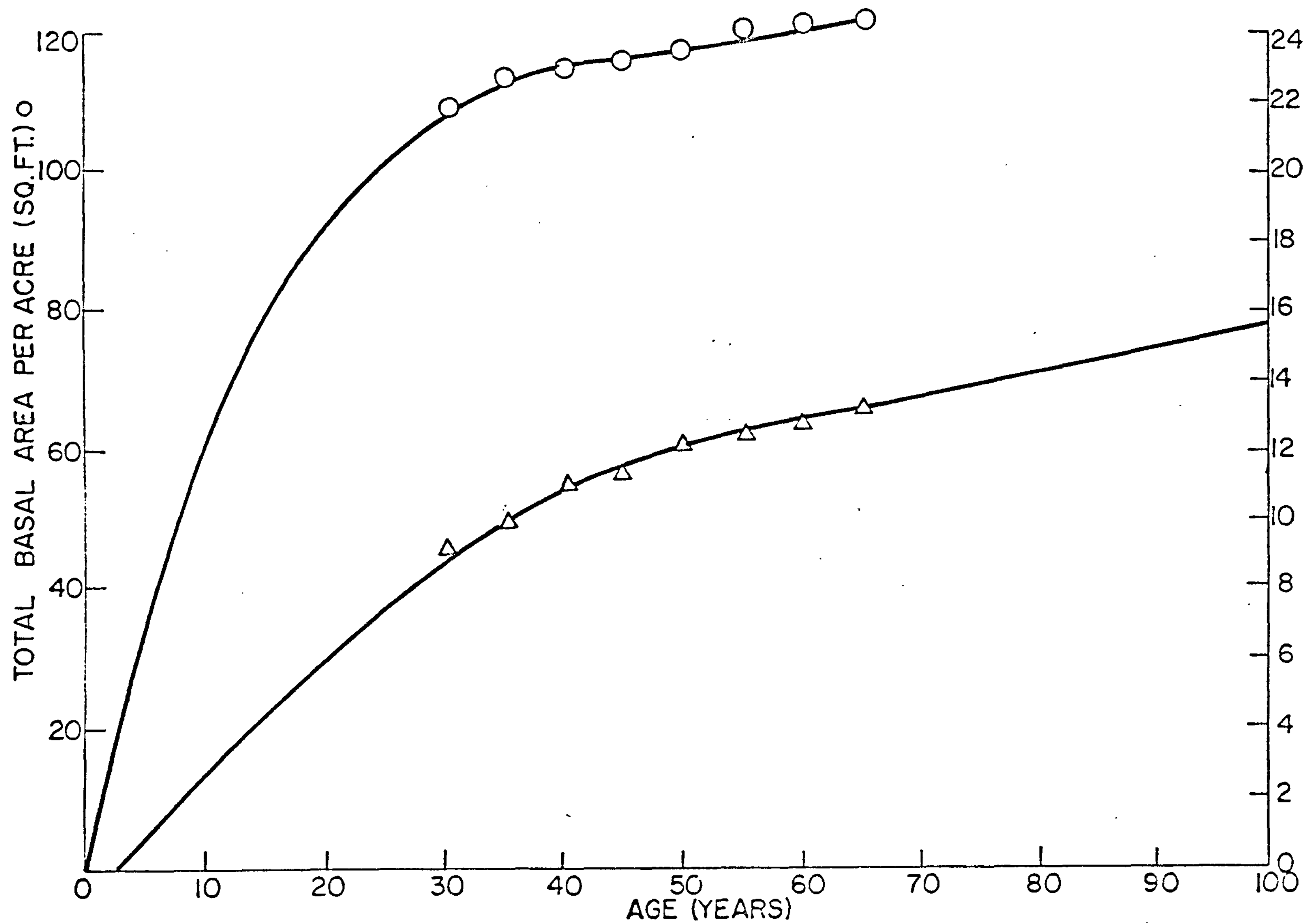

Figure 10. Basal area per acre and diameter breast height, site index 80, original spacing 7 feet by 7 feet.

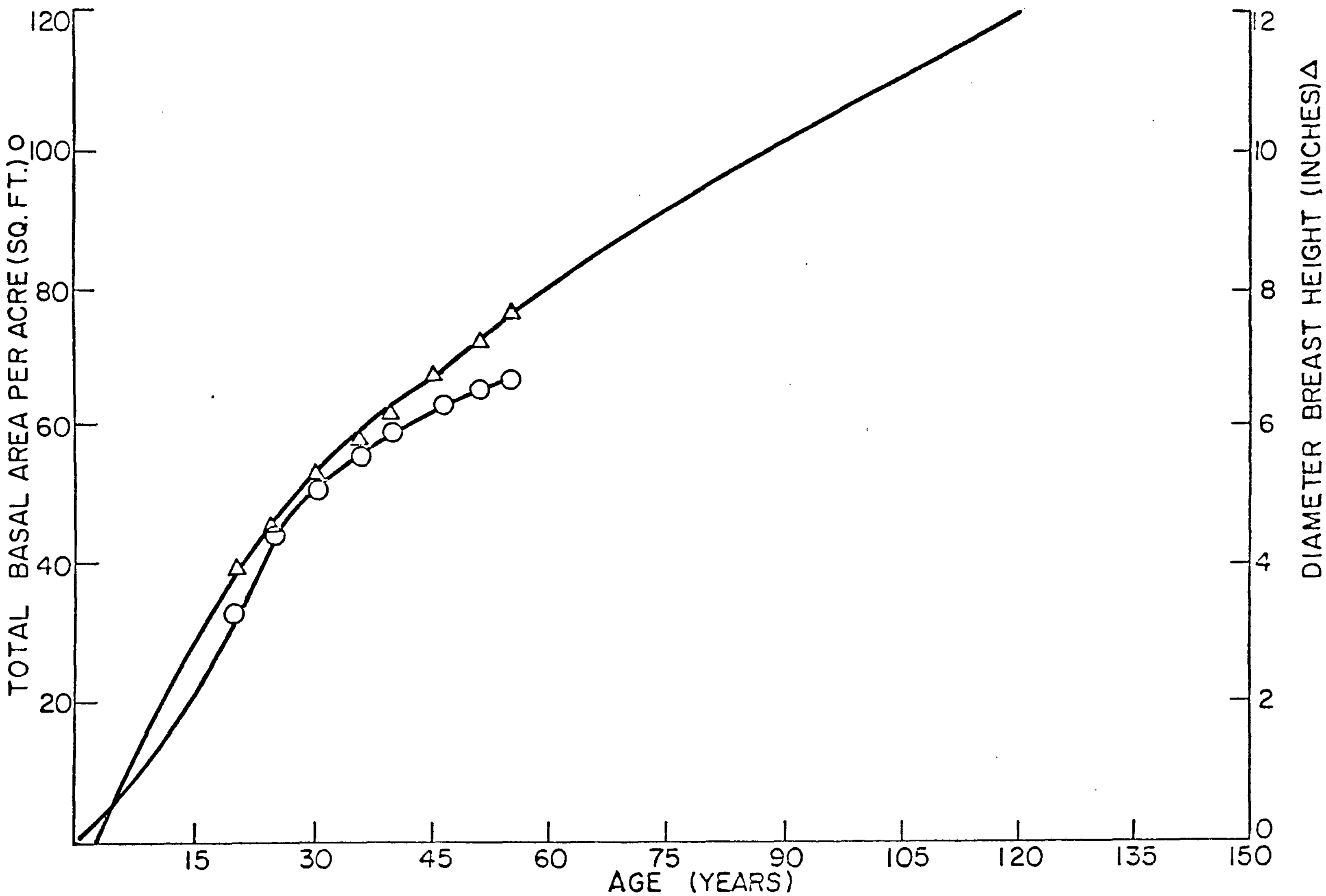

Figure 11. Basal area per acre and diameter breast height, site index 40, original spacing 10 feet by 10 feet.

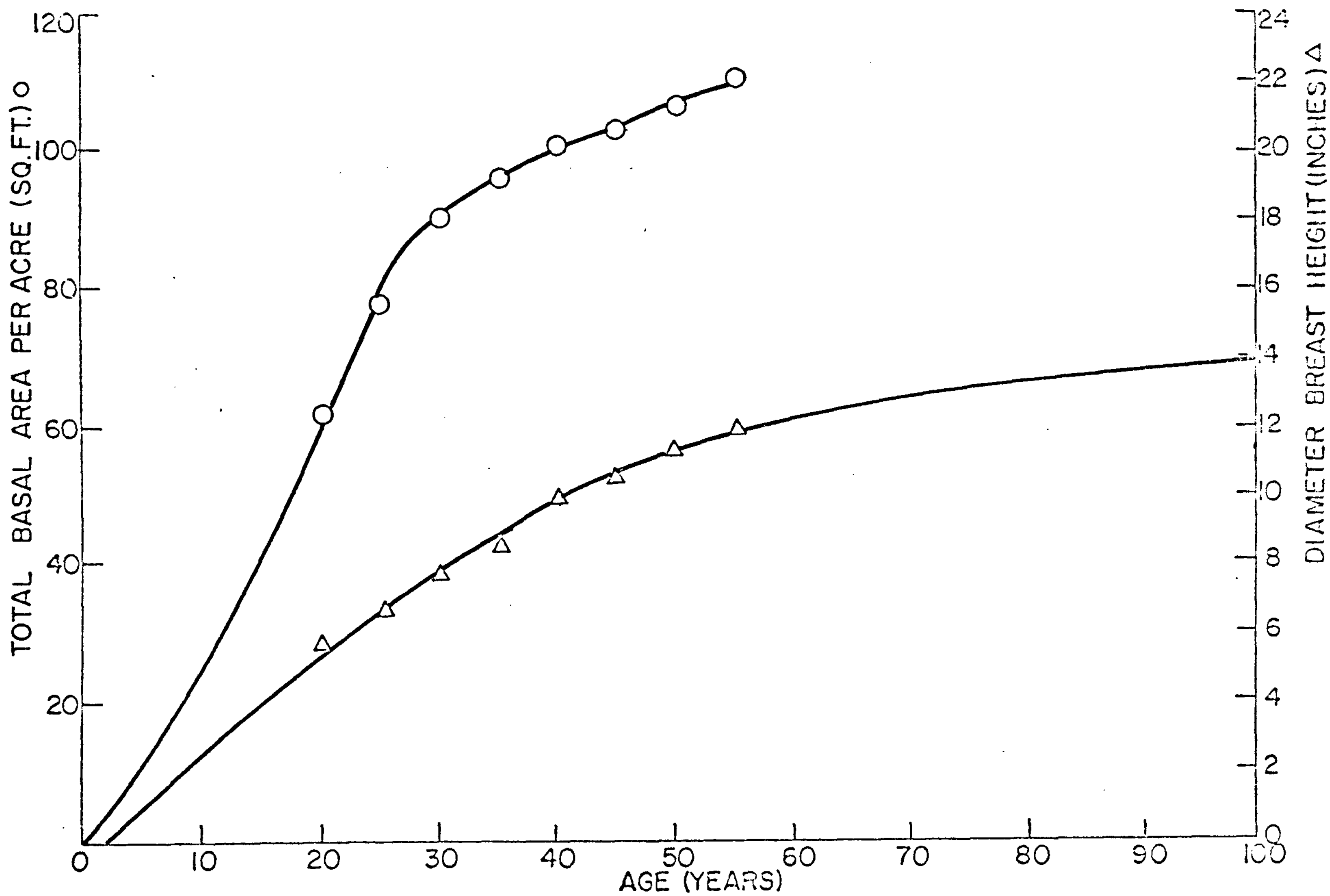

Figure 12. Basal area per acre and diameter breast height, site index 60, original spacing 10 feet by 10 feet.

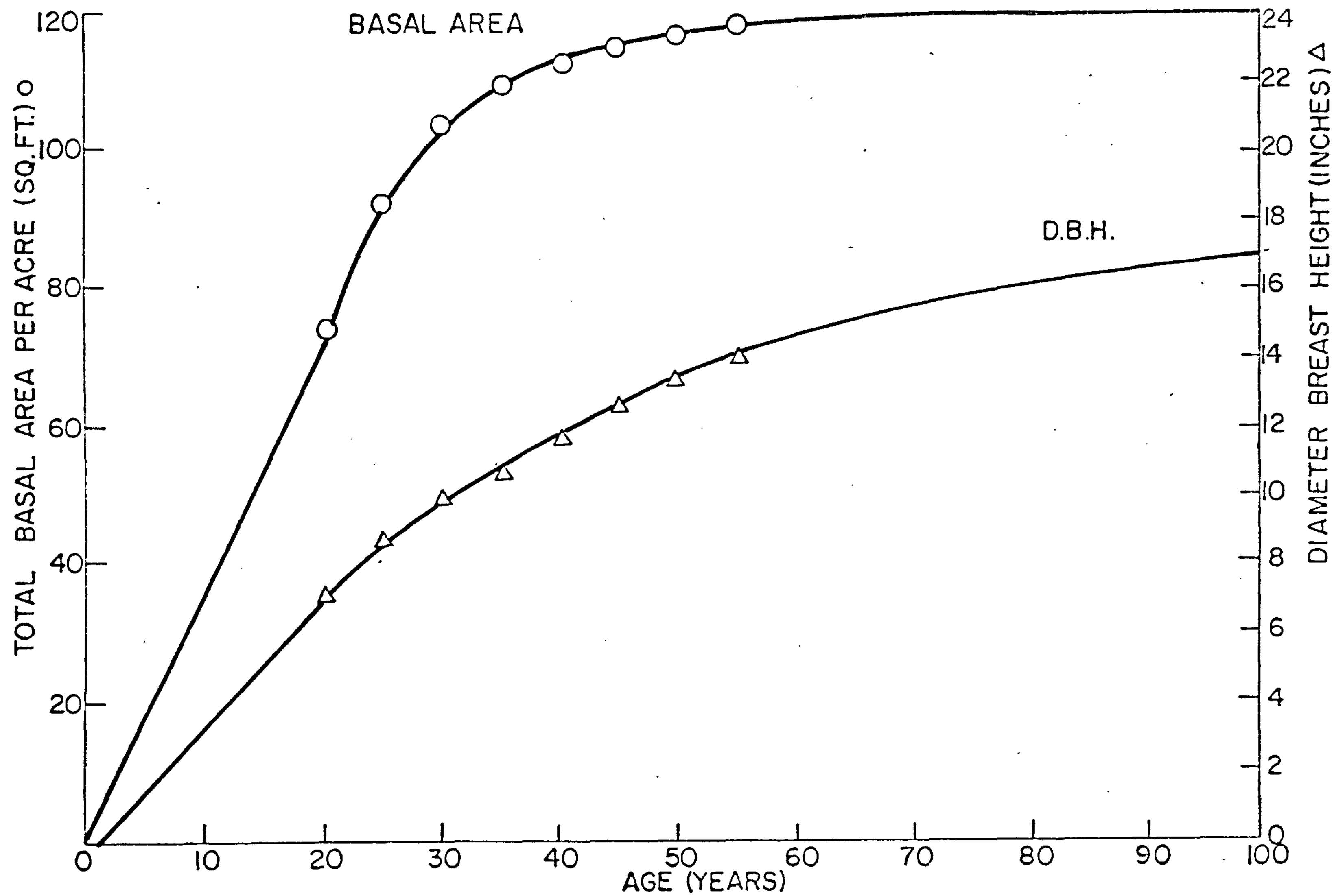

Figure 13. Average diameter breast height and total basal area per acre, original spacing 10 feet by 10 feet, site index 80.

APPENDIX D

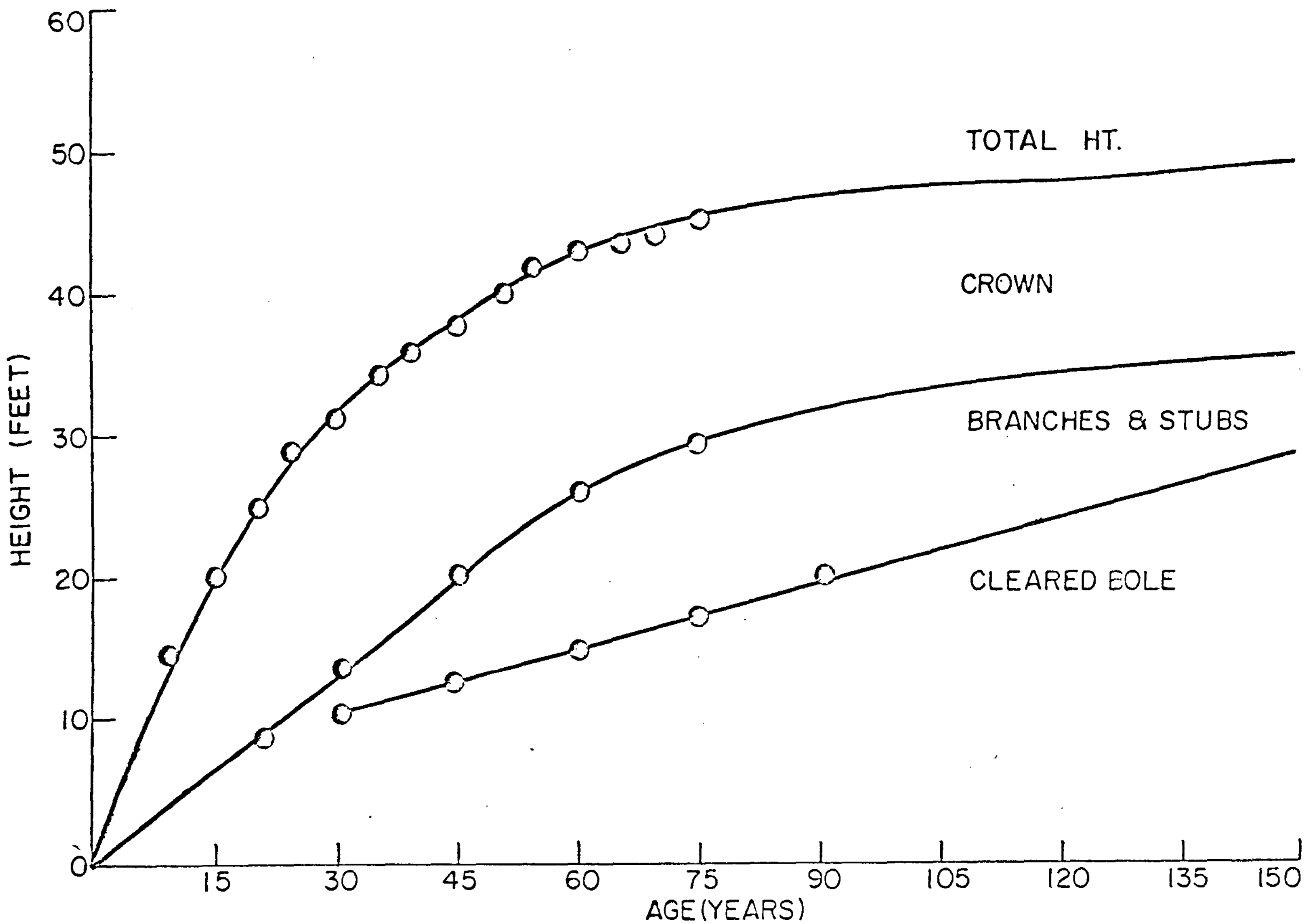

Figure 14. Total height, height to base of crown and cleared height for site index 40, original spacing 4 feet by 4 feet.

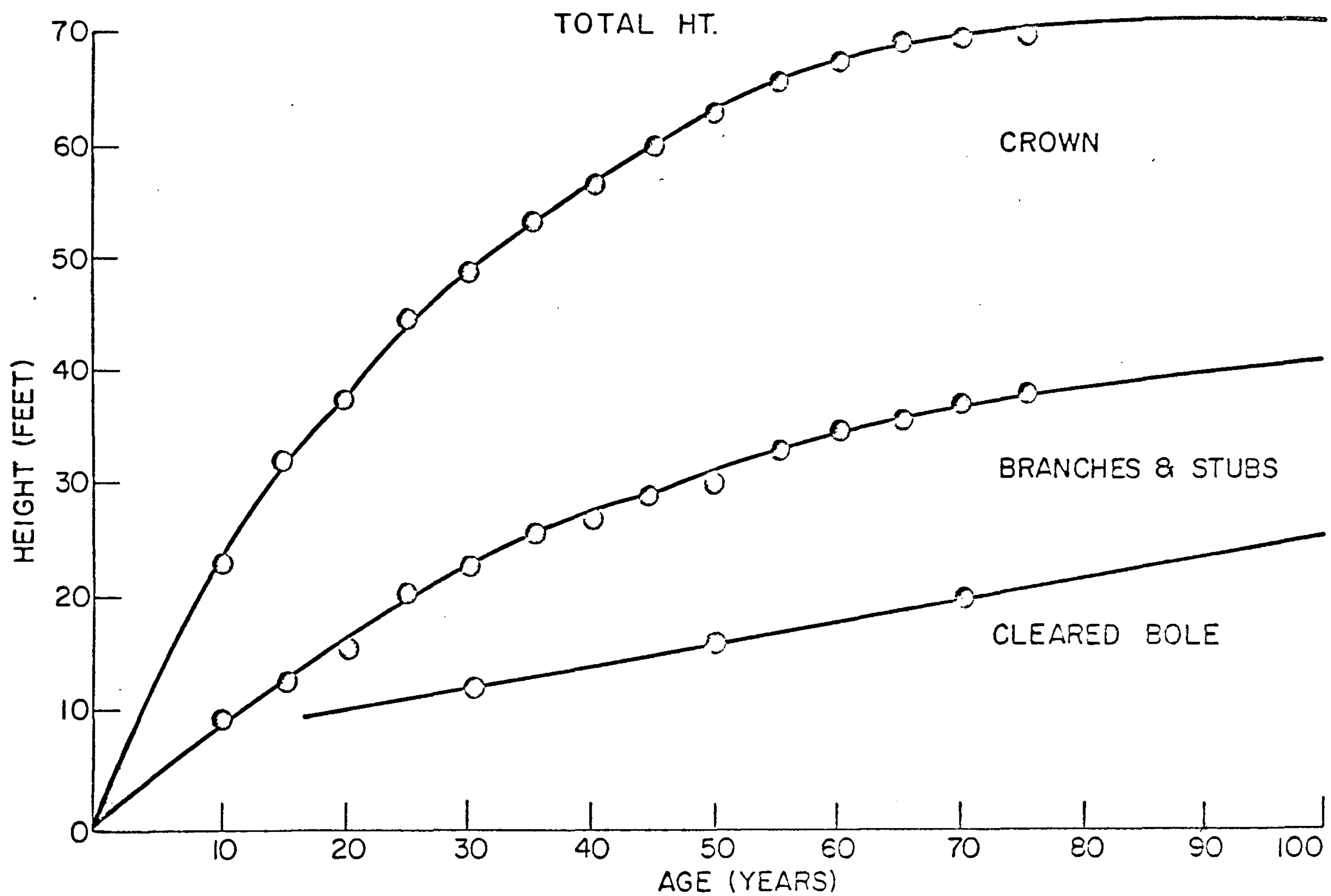

Figure 15. Total height, height to base of crown and cleared height for site index 60, original spacing 4 feet by 4 feet.

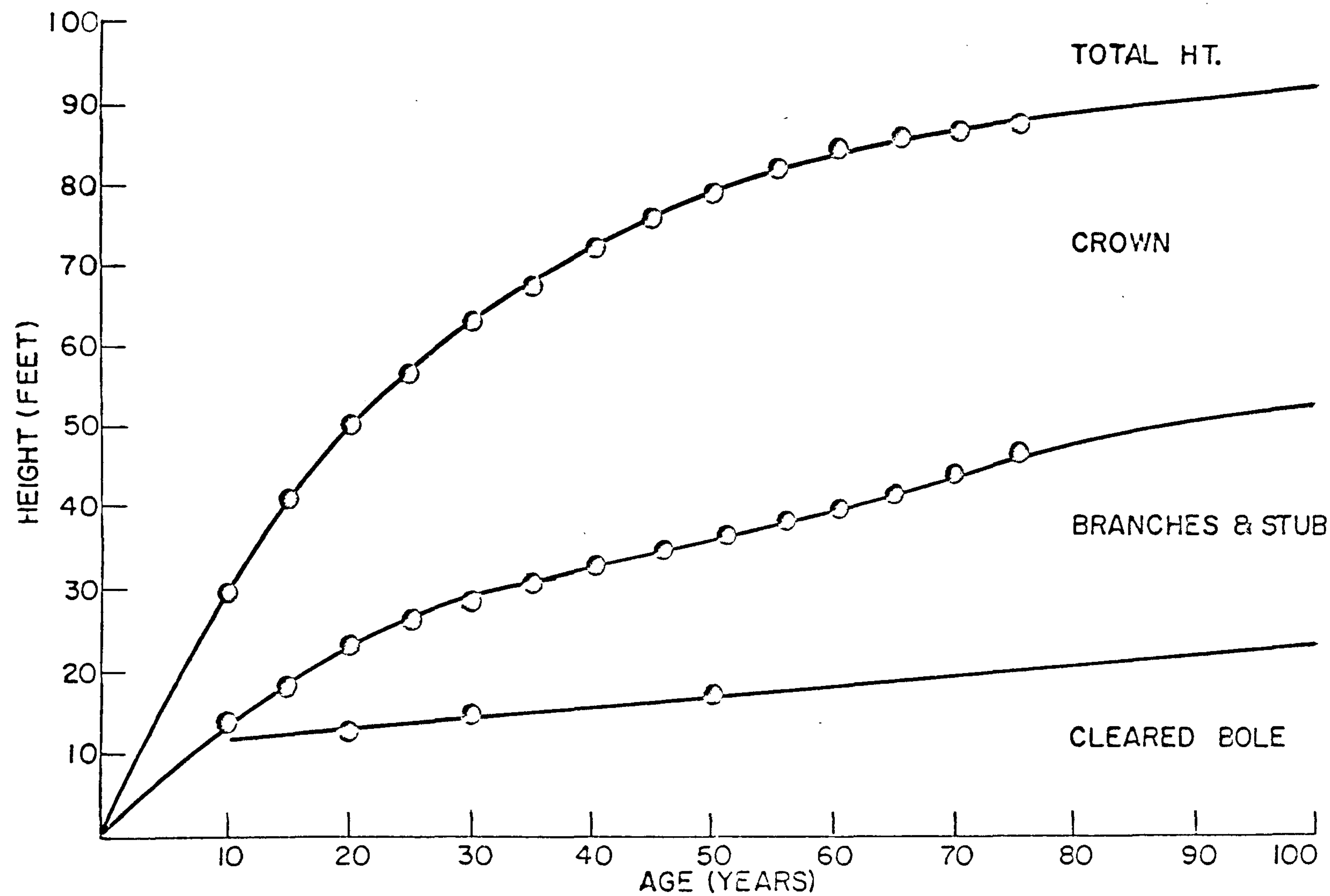

Figure 16. Total height, height to base of crown and cleared height for site index 80, original spacing 4 feet by 4 feet.

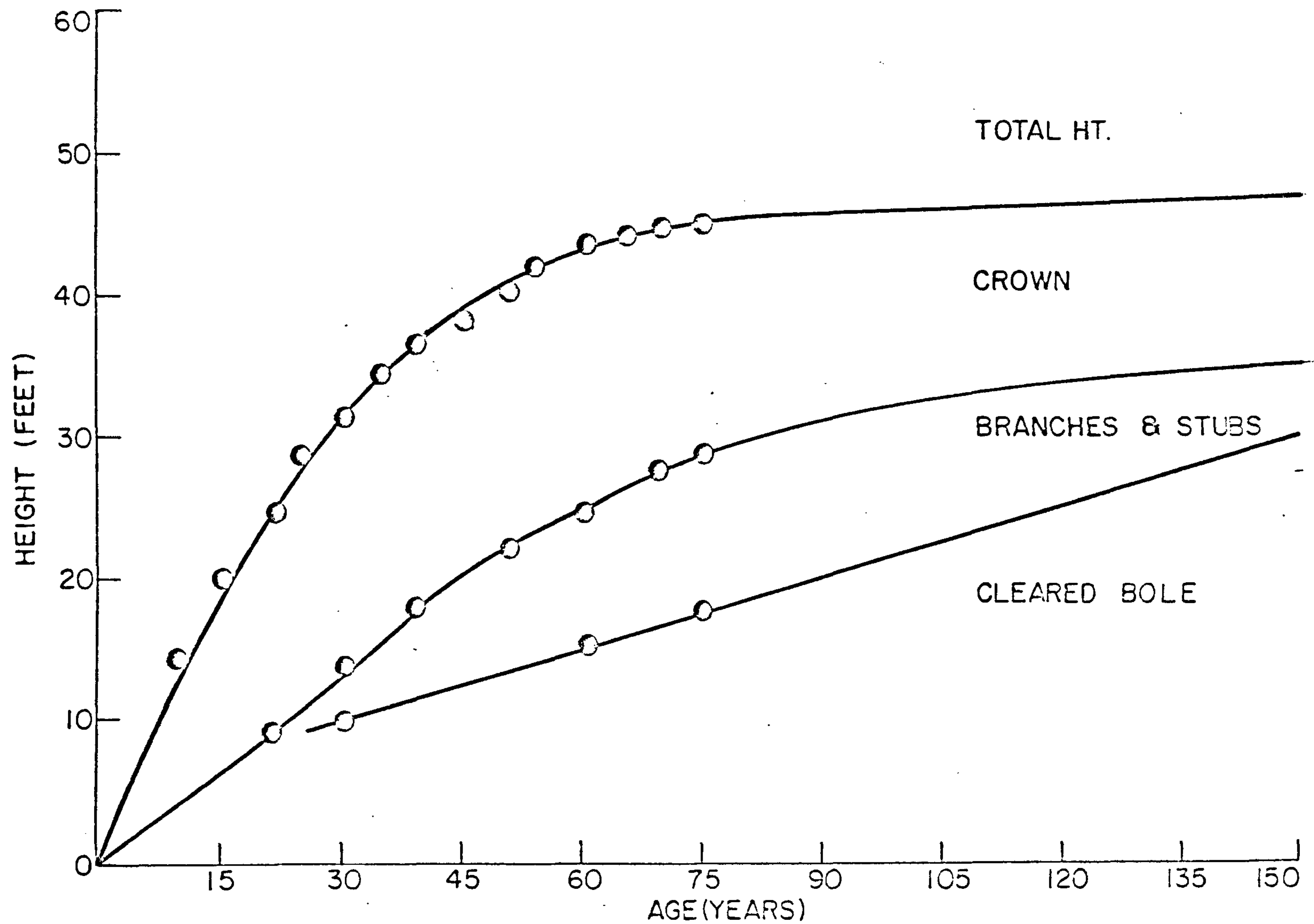

Figure 17. **Total height, height to base of crown and cleared height for site index 40, original spacing 7 feet by 7 feet.**

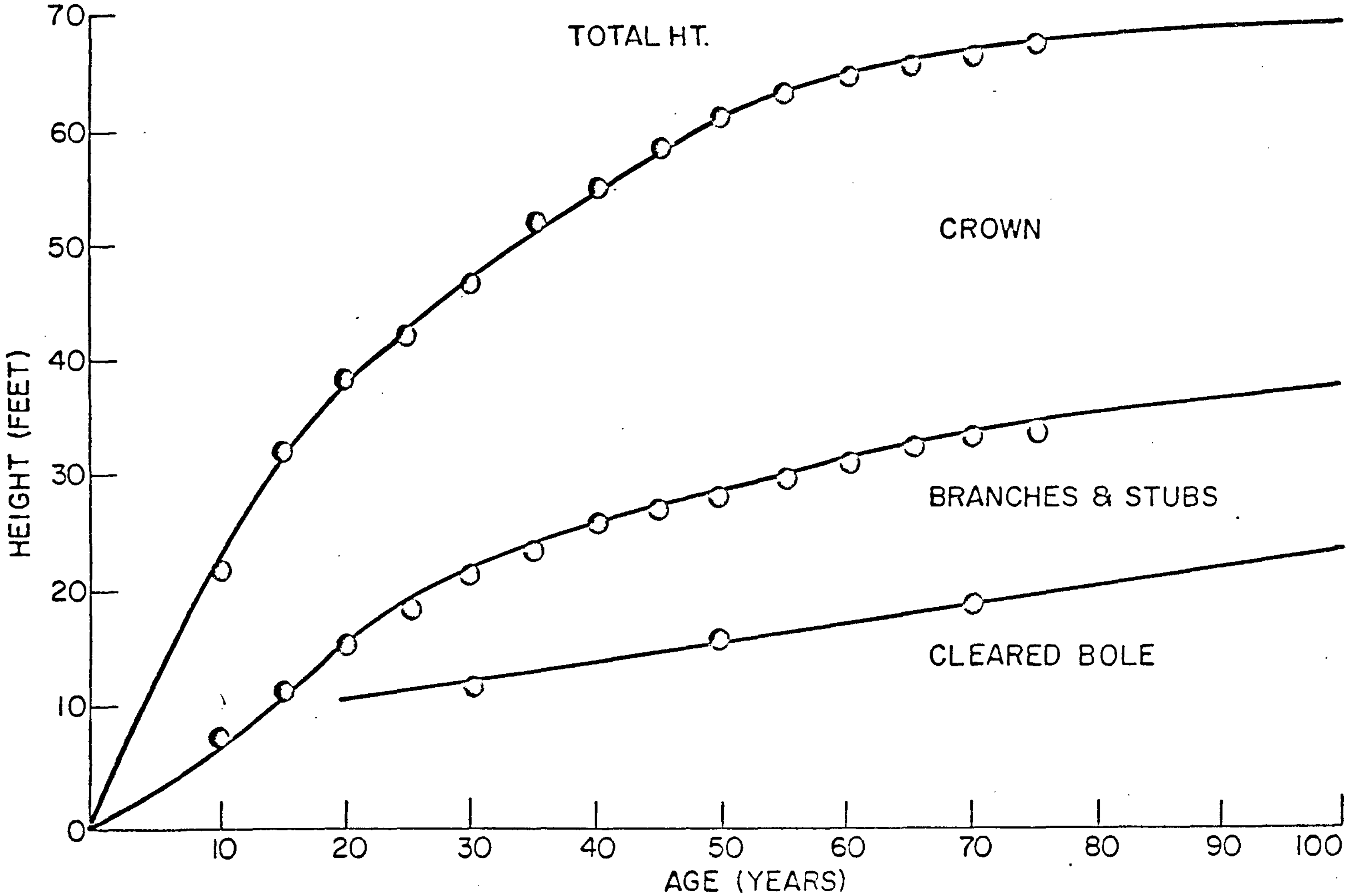

Figure 18. **Total height, height to base of crown and cleared height for site index 60, original spacing 7 feet by 7 feet.**

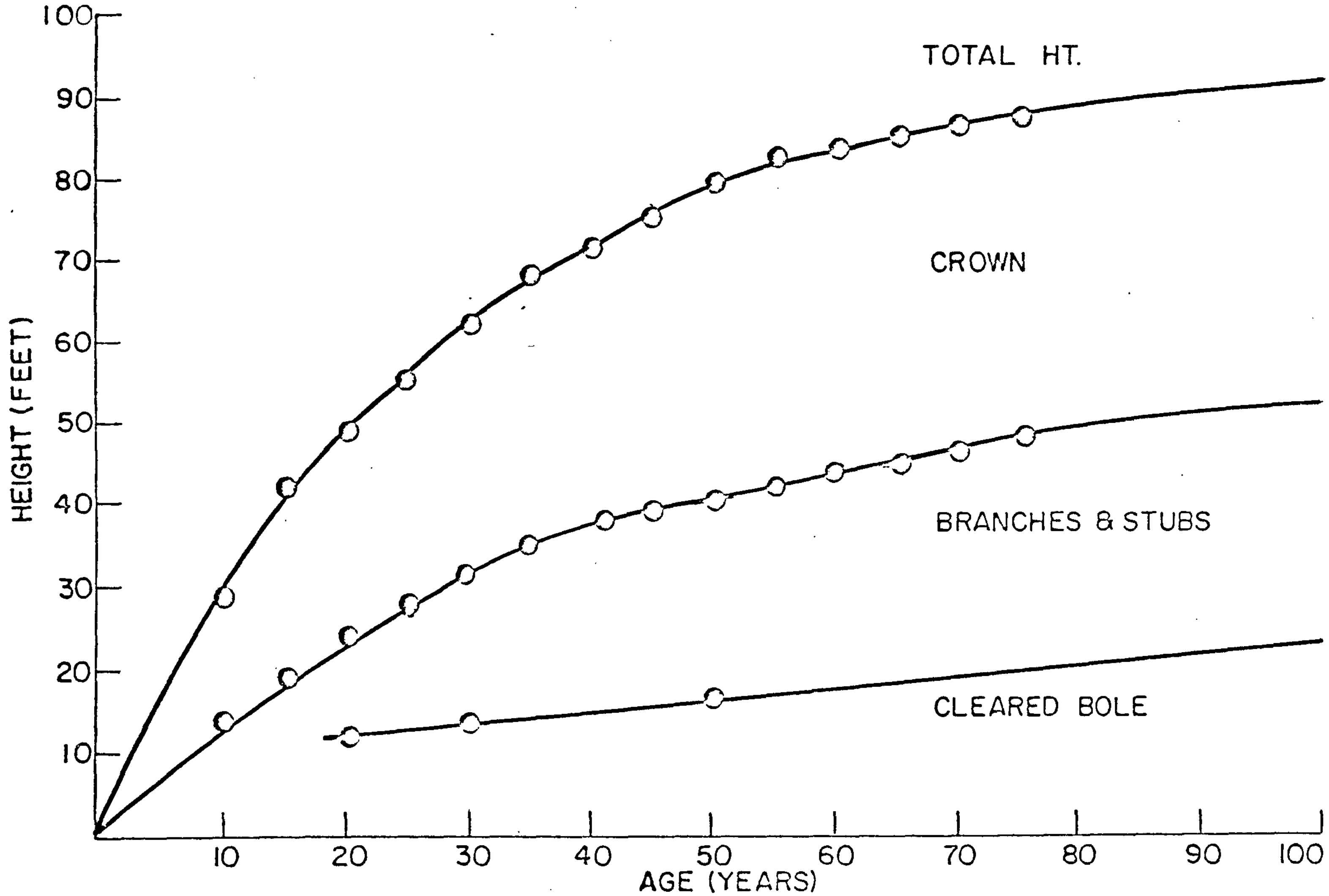

Figure 19. Total height, height to base of crown and cleared height for site index 80, original spacing 7 feet by 7 feet.

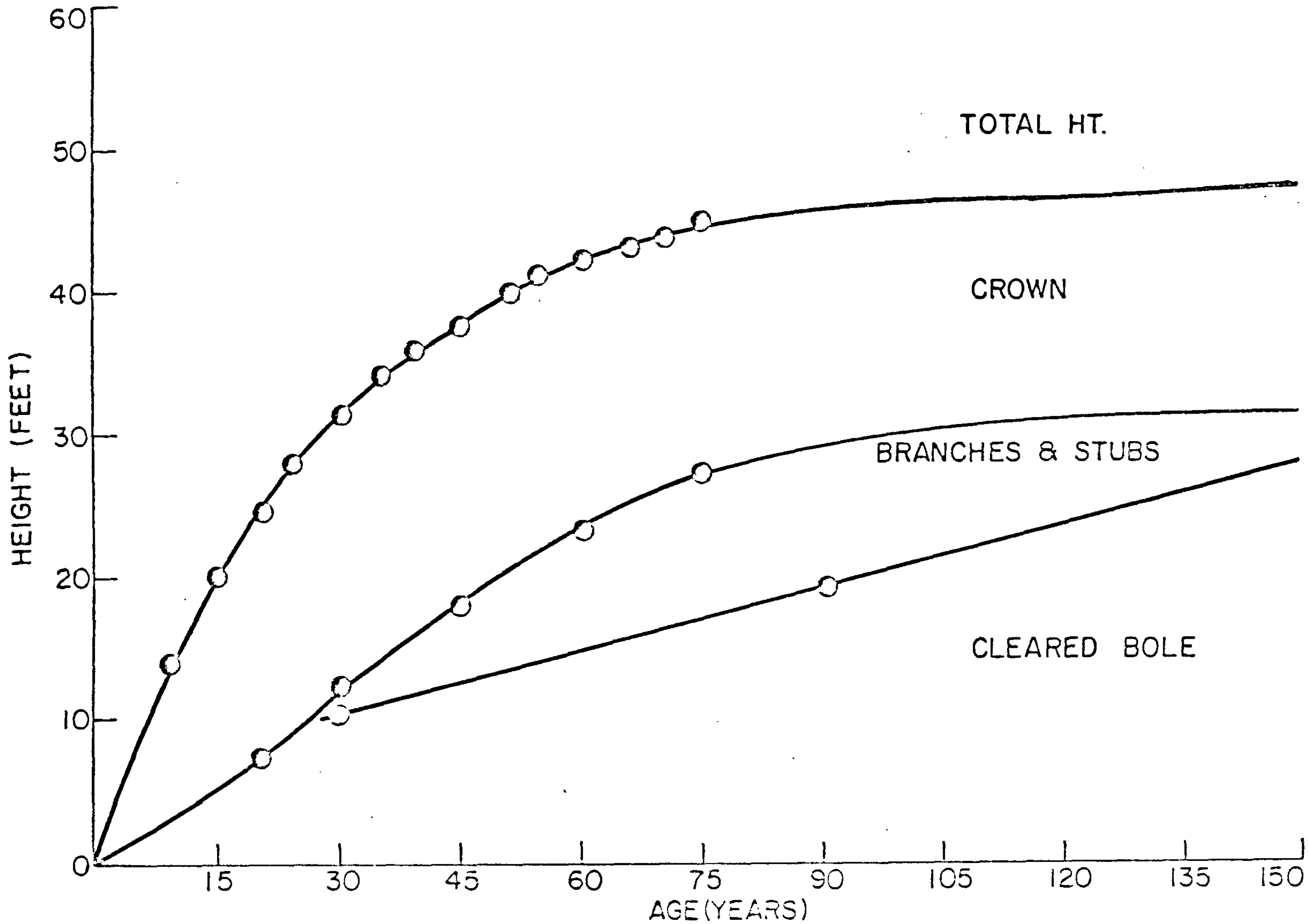

Figure 20. **Total height, height to base of crown and cleared height for site index 40, original spacing 10 feet by 10 feet.**

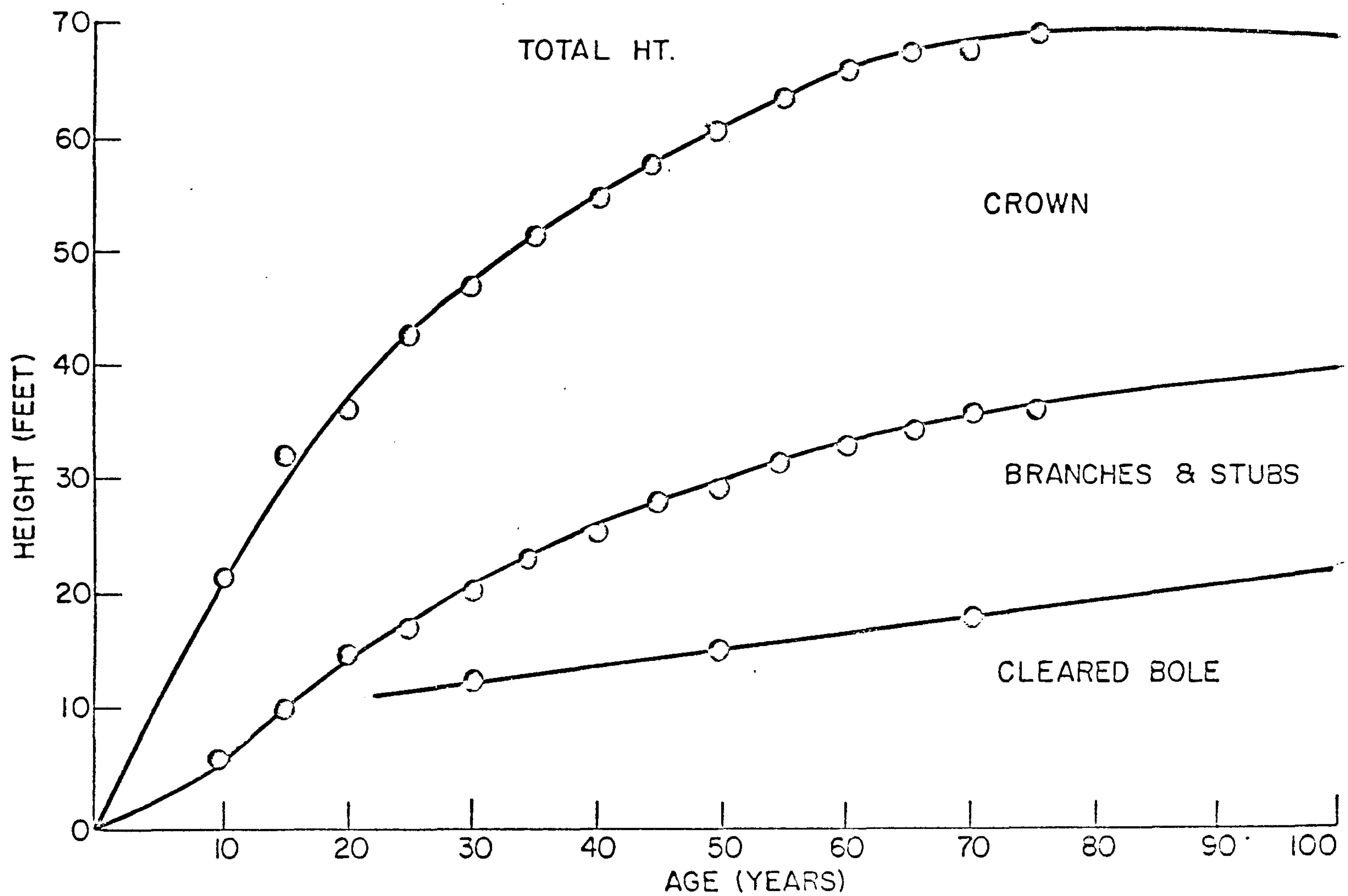

Figure 21. Total height, height to base of crown and cleared height for site index 60, original spacing 10 feet by 10 feet.

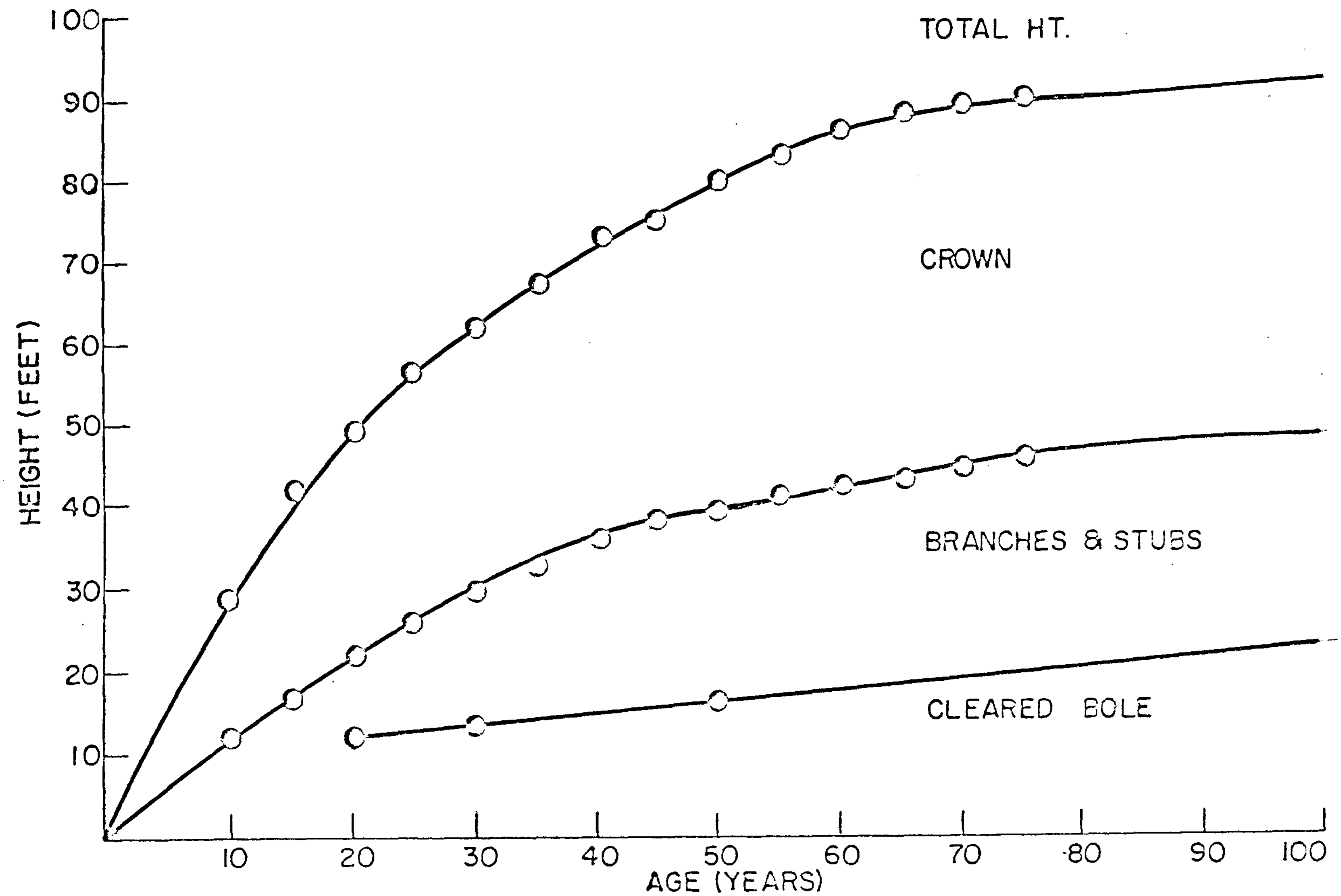

Figure 22. Total height, height to base of crown and cleared height for site index 80, original spacing 10 feet by 10 feet.