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To the Graduate Council:

I am submitting herewith a thesis written by Jerry L. Richeson entitled "Growth Responses of Loblolly Pine Plantations in East Tennessee to Various Fertilizer Treatments." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

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GROWTH RESPONSES OF LOBLOLLY PINE PLANTATIONS IN EAST TENNESSEE TO VARIOUS FERTILIZER TREATMENTS

A Thesis

Presented for the

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Degree

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Jerry L. Richeson

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ABSTRACT

The objective of this study was to determine the growth effects that various fertilizer and cultural treatments had on loblolly pine plantations in East Tennessee. After the growth effects were determined, an economic was conducted to determine if the fertilizer treatments were economically feasible.

Two study sites were established in East Tennessee. One site was on the Cumberland Plateau, and the other site was located in the Great Valley of East Tennessee. These two areas represented contrasting climates and stand characteristics. Sixteen treatments were replicated four times on the Plateau site, and 14 treatments were replicated four times on the Valley site.

DBH and height were recorded for five years after fertilization. From these measurements, diameter, height, basal area, cubic volume and cords growth were computed. Diameter at 17.3 feet above ground was measured for four years following fertilization in order to determine if fertilization influenced stem-form. Soil textural analyses were made for each site. Tests on soil pH, phosphorus and potassium were conducted before and periodically after fertilization to determine how fertilization would effect the level of these soil properties.

Fertilization made no significant difference in stem form although growth at 17.3 feet was greater than growth at 4.5 feet in 99.5 percent of treatment and control plots. K additions did not provide a growth stimulus over that provided by N and P. Nitrogen as urea gave the best results when compared to other N treatments. The urea-N also appeared to provide a stimulus for a longer period of time. It was found that fertilizer application on dry sites provided responses of short duration. Although the urea-N gave the best responses on the Plateau site, ammonium nitrate at the rate of 150 pounds of N per acre gave the best response at the Valley site. Results from thinning treatment at the Valley site indicate that fertilization can stimulate rapid recovery of the volume growth loss that usually follows thinning.

An economic analysis was made using response data generated from the study and cost assumptions based on other company operatives and current market prices for fertilizers. At the Plateau site economic feasibility was highest where: (1) N was applied as urea, (2) N-levels were low (75 pounds per acre as ammonium nitrate), and (3) K was not included in the fertilizer application. At the Valley site, economic feasibility was highest where: (1) K was not applied, (2) N was applied at intermediate (150 pounds per acre) to low levels as ammonium nitrate, and (3) P was not included in the fertilizer application.

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CHAPTER I

INTRODUCTION

Interest in fertilization as a means of increasing the productivity of forest lands has increased rapidly over the past decade. This interest has developed because of rising wood costs (restrictions on available diminishing not in physical sense), timber supplies, and the high prices and taxes paid for forest lands. Tests indicate that on many forest sites fertilization will increase tree growth. Where this is true, fertilization is one means of decreasing the land base needed to grow a particular volume of wood. As the competition for land increases, forests will probably be consigned to less productive areas. On such sites fertilization may increase tree growth by improving the nutrient status of the soil.

Fertilizers increase growth by eliminating the growth limiting effects that result from nutrient deficiencies. Most research efforts in the past have been concerned with the correction of acute nutrient deficiencies (Simmons, 1974). While the greatest growth increases will be realized when nutrient deficiencies are acute, the smaller responses realized on more fertile sites may be justified as relative prices of land and forest products continue to rise. Also, the absolute growth increase on better sites can be as great or greater than the larger percentage increases that generally characterize responses on the poorer sites.

Forest fertilization is currently progressing from the experimental to the applied stage. Although considerable information is available on the biological response aspects of forest fertilization, applied programs are handicapped by the general lack of data needed for economic analysis. Since the major responsibility of many forest managers is to supply wood at the lowest possible cost, the decision to fertilize on a commercial basis must be made with the assurance that it will produce an acceptable economic return.

The primary objective of this study was to determine the growth response of loblolly pine (*Pinus taeda* L.) plantations in East Tennessee to a wide range of fertilizer treatments. Once the magnitude of the growth response to each fertilizer treatment was determined, a preliminary economic analysis of the effect of treatments was possible. This type of analysis revealed whether the growth responses realized through fertilization provided the additional revenue necessary to make fertilization economically feasible.

CHAPTER II

LITERATURE REVIEW

Biological Aspects

There are several comprehensive reviews of forest fertilization. White and Leaf (1957) published a bibliography with 700 abstracts that pertain to world-wide forest fertilization research prior to 1957. Mustanoja and Leaf (1965) published another bibliography containing research published between 1957 and 1965. A review of fertilization on the trees of the southern forests is included in a publication by Walker and Tisdale (1959).

Fertilizer trials with forest trees have been underway for many years in Europe and Australia. C. O. Tamm (1958) summarized much of the European forest fertilization research. Many of the Australian forests, most of which are exotics, have been established on infertile soils. Responses to P and Zn fertilizers have been large enough to promote the wide use of these fertilizer elements in that country (Moulds and Applequest, 1957).

Over the past two decades, forest fertilization in the United States has been largely limited to research and special uses such as in seed orchards and seedling nurseries. Recently, however, commercial applications are becoming common on large forest holdings.

Nitrogen appears to be the element most tested in fertilization research. Radwan et al. (1971) reported that responses of Douglas-fir

(Pseudotsuga mengiesii (Mirb.) Franco) seedlings to urea and nitrate were essentially the same, and both fertilizers were superior to ammonium. They suggested that the magnitude of response of the three fertilizers is influenced by their different effects on soil pH, losses through leaching and volatilization, susceptability to transformations through microbial and enzymatic action, fixation by soil particles and availability characteristics. It is almost impossible to make a general statement that a plant prefers one nitrogen source to another because as the age of the plant, the pH, the concentration of other nutrients, and the carbohydrate content changes, the most favorable nitrogen source probably changes (Christersson, 1972). The highest growth rate of Scots pine (Pinus silvestris L.) seedlings grown in renewed nutrient solutions was obtained by a mixture of ammonium and nitrate followed by an ammonium nitrogen source, nitrate and urea (Christersson, 1972). The form of nitrogen supplied had little effect on total growth, but nitrate nitrogen stimulated root production more than did ammonia nitrogen (Leyton, 1952). Also, optimum root and shoot growth occurred between pH 4 and 5.

Ammonia loss from urea applied to forest soil may be high for many sites. This loss may be the reason growth responses of coniferous stands are lower where the N-source is urea rather than ammonium nitrate. Nommik (1973) investigated the influence of pellet size, addition of phosphoric acid, and addition of boric acid on the extent of ammonia loss from urea applied to forest soils. He concluded that gaseous loss from the large pellet urea was lower than that from the small-pellet urea but the difference diminished with time. An additional reduction of gaseous loss from the large-pellet resulted when concentrated orthophosphoric acid or ortho-boric acid was added.

Nitrogenous fertilizers move rapidly from the forest floor. During a 10-month period, 76 percent of the nitrogen from urea and 88 percent of the nitrogen from ammonium sulfate were leached beyond the top soil horizon (Cole and Gessel, 1963). There was, however, little elemental movement beyond the 36 inch depth in the soil profile.

Slash pine (Pinus elliottii Engelm.) responded equally to nitrogen applied in the spring and fall (McKee and Sommers, 1971). Apple trees also showed no preference for season of nitrogen application (Magness et al., 1948). Kawana (1966) reported that late summer to mid-autumn fertilization had adverse effects on slash pine growth. In addition to growth response, competing vegetation, leaching losses and volitalization should also be considered when choosing a time for applying nitrogen.

Nitrogen fertilization appears to be a promising silvicultural tool for increasing growth of Douglas-fir stands on soil of low natural productivity. Miller and Pienaae (1973) reported that ammonium nitrate applications at rates of 140, 280, and 420 pounds of nitrogen per acre increased volume growth by 55, 92, and 109 percent, respectively, during seven years following treatment. The maximum gain in total cubic volume was from the 280 pound-N treatment. Other researchers (Gessel and Shareff, 1957; Gessel and Walker, 1958) have found that nitrogen fertilization of Douglas-fir increases volume growth and causes more rapid suppression of small trees because the larger, and more vigorous trees responded more than the smaller trees. A spring application of ammonium nitrate at the rate of 400 pounds per acre, increased diameter growth of 24-year-old Douglas-fir trees 51 percent in the first growing season after application and 54 percent in the second growing season (Brix, 1971). Net photosynthesis was higher for fertilized trees from early July the first season until the end of July the second season.

Although nitrogen fertilizers have increased diameter growth of southern pines, the stimulation from a single application seldomly lasted more than two years (Zahner, 1959). Allen and Maki (1954) found that there was very little response of longleaf pine (Pinus palustris Mill.) seedlings to nitrogen alone applied to southern Mississippi soils. In 30 randomized complete block experiments installed in 8- to 20-year-old slash and loblolly pine plantations, 83 percent of the loblolly pine stands and 62 percent of the slash pine plantations responded to N treatment (Pritchett and Smith, 1973). A higher percentage (82) of 14- to 16-year-old trees gave a significant response to N and P fertilizers than either younger or older trees. Eighty-eight Kg per hectare of ammonium nitrate applied to a 15-year-old slash pine stand on moderate to poorly drained flatwoods soils resulted in an 18 percent increase in volume per tree over three years (Pritchett and Smith, 1968). Jackson and Cloud (1958) reported that ammonium nitrate applied at 14.5 Kg N per hectare increased stem growth of slash pine in Georgia during the first growing season after treatment. On a deep sand of the Lower Coastal Plain of Georgia, a 9-year-old slash pine plantation responded to 176 Kg N per hectare for the first three years following treatment (Walker and Youngberg, 1962).

Although most nitrogen fertilizer trials in mature northern conifer stands have shown a response (Armson et al., 1973), the growth of a young spruce plantation on a cutover site in the boreal forest of Quebec was not improved by N fertilization. The addition of 114 Kg of urea-N per hectare to a black spruce (Picea marjana Mill) stand gave a temporary response, and a sustained response at the end of 10 years was accomplished with an application rate of 448 Kg per hectare (Armson et al., 1973). Also, thinning before N addition gave larger and longer lasting responses.

A 48-year-old sugar maple (Acer saccharum Marsh.) and red maple (Acer Rubrum L.) stand in Wisconsin was fertilized with 168 Kg N (ammonium nitrate) per hectare (Carmean and Watt, 1973). During the first four years following fertilization, the growth responses peaked during the third and fourth growing seasons. Ammonium nitrate at 400 pounds available nitrogen per acre applied to a mixed-oak-hardwood forest resulted in a response which lasted for six years (Karnig, 1972).

Fowells and Kraus (1959) found that nitrogen application depressed phosphorus uptake by loblolly and Virginia pine (Pinus Virginiana Mill.). In eight-week old Monterey pine (Binus radiatal D. Don.) seedlings low in phosphorus, nitrogen treatment increased P absorption and translocation for a six-hour uptake period after treatment (Taber and McFee, 1972). Van Goor (1953) stated nitrogen and phosphate additions decreased the absorption of nitrogen. Some researchers (Farmer et al., 1970; Blackman and White, 1972; Walker and Youngberg, 1962) have found that nitrogen plus phosphorous fertilizers did not yield greater growth responses than those obtained by nitrogen fertilizer alone, but others (McKee; Linnartz et al., 1970) reported that a nitrogen plus phosphorous fertilizer did increase growth response more than just a nitrogen fertilizer.

Pritchett and Smith (1968) found that the application of 352 Kg per hectare of super phosphate doubled tree volume after five to eight years. In regional fertilizer trials installed in 28 young slash pine plantations in the Southeast, they found that phosphorus fertilizers increased growth in 63 percent of all tests. In two experiments in central New Brunswick, red spruce (Picea rubens, Sarg.), dominant at one of the experimental sites, responded to P, while balsam fir (Abies balsamea, L.), the dominant species of the second site did not respond (Krause, 1973). A 63 percent increase in merchantable volume of black spruce four years after the application of 56 Kg P per hectare as rock phosphate was reported by Van Nostrand and Bhure (1973). In a 48-year-old maple stand in Wisconsin, Carmean and Watt (1973) reported that the growth of plots that received 168 Kg P per hectare was similar to the growth on the non-fertilized plots throughout the seven year study. Since P fertilizers are not mobile in the soil they must be placed or applied where they can be reached by roots in order to be effective. Four-year-old slash pine responded to surface applications of rock phosphate, and an additional response occurred when rock phosphate was mixed with the soil (Brendemuehl, 1968). Bengston (1968) reported similar results working with slash pine seedlings. Also, mixing the fertilizer with the soil was superior to either surface or band applications.

Despite positive results from K application in early studies on infertile soils in New York, most recent research has concentrated on nitrogen and phosphorus because potassium has generally failed to increase growth. In pine and spruce stands in northern New York, Heiberg and White (1951) found that the increase in annual height growth produced by applying 200 pounds of KCl per acre was from 46 percent to

104 percent, and the response continued six years after treatment. A single application of K at the rate of 100 Kg per hectare yielded an increase in height growth of red pine (Pinus resinosa Ait.) that persisted over fifteen years (Heiberg et al., 1964). The red pine study was on strongly acid podozolic soils that developed on coarse glacial till or coarse-textured fluvioglacial outwash in New York. White pine (Pinus strobus L.) plantations 20- to 30-years-old growing on a droughty coarse-textured soil derived from fluvioglacial kame deposits in Maine responded significantly to K application (Stratton et al., 1968), but a plantation growing on sandy loam of alluvial origin did not. Diller et al. (1957) found significant differences (.05 level) between 50-year-old Japanese chestnut trees that received phosphorus and potassium and the trees that received no phosphorus and potassium. However, in the Southeast, slash pine response to K fertilization in regional fertilizer trials are persisting after five years on only one of twenty-eight experimental sites (Pritchett and Smith, 1973). Potassium fertilizer applied at the rate of 120 and 200 pounds K per acre to seven-year-old loblolly pine increased foliar K from 0.25 percent to 0.50 percent but did not affect growth (Wells, 1970).

No definite response pattern has evolved from studies using complete fertilizers (N, P and K). No significant response appeared the first season after fertilization (20-10-5) of a 23-year-old loblolly pine plantation, but there was a significant response to the treatment in the second and third growing seasons (Windsor and Reines, 1973) and by the fourth season there was again no significant difference. In a 60-year-old northern hardwood stand treated with 1000 pounds of dolomitic limestone and 3,000 pounds of 15-10-10 fertilizer, mean basal-area growth of trees from the lime plus NPK plot was greater than that of untreated plots (Safford, 1973). Pritchett and Smith (1972) found that a complete fertilizer gave the best response in young pine plantations in the lower Coastal Plain when compared to applying N alone or a combination of N and P. In Florida, pole-size slash pine had a higher growth response to a 7-7-7 fertilizer than to a 3-18-6 fertilizer (Koekstra and Asher, 1962). Van Cleve (1973) reported that application of a NPK fertilizer to 18-year-old quaking aspen (Populus tremuloides Michx.) did not significantly increase tip growth response but the addition of N alone did. A 20-year-old yellow-poplar (Liriodendron tulipifera L.) plantation responded significantly to a NPK treatment and a NK treatment over a five year period in Southwestern Michigan (Finn and White, 1966).

Information on microelement nutrition of forest trees is limited and much more research is needed to determine the extent to which shortages of microelements limit growth. A review of microelement research in forestry was presented by Stone (1968). In testing P in combination with 5 micronutrients (Zn, Mn, Cu, Fe, and B), Van Lear and Smith (1972) reported that crown height growth after treatment ranged from a low of 4.6 cm in the P only treatment to a high of 9.2 cm in the treatment that applied the 5 micronutrients. Zahner (1959) found that the application of 200 pounds of a minor element mixture (Fe, Zn, Ca, Mn, Co and Mg) with 300 pounds of N and with a NPK fertilizer to young loblolly pine in southern Arkansas did not increase diameter response any more than did nitrogen alone. Micronutrients can be applied separately or with macroelement fertilizers. Mortvedt and Giordano (1968) reported that for supplying small amounts of micronutrients, application with macronutrient fertilizers is an effective method, but they warned that with some combinations of micronutrient source and macronutrient carrier, chemical reactions can result in decreased effectiveness of the applied micronutrient.

Using fertilizers in thinned stands can increase the growth response which is realized from thinning alone. After five growing seasons, heavily thinned and fertilized (459 Kg urea N per hectare) black spruce plots established in Quebec doubled the rate of tree growth of the untreated control plots (Roberge et al., 1968). Thinning increased diameter growth of 40-year-old western white pine (Pinus monticola Dougl.) by 39 percent and fertilizing with a complete fertilizer caused an additional 36 percent increase (Ryker and Pfisyer, 1967). Neither thinning nor fertilization affected height growth. Cochran (1973) reported that individual ponderosa pine (Pinus ponderosa Laws.) trees located in thinned stands increased in diameter, height and basal area growth after fertilization. Similar results were reported by Agee and Beswell (1970). Four-year basal area growth of shortlead pine (Pinus echinata Mill.) was increased as much as 300 percent by thinning and the application of 300 pounds N per acre (Curlin, 1963). Nitrogen alone gave a 40 percent increase in basal area growth over the thinned-only plot. In young Douglas fir, fertilizing and thinning combined gave a greater diameter growth rate than either treatment separately (Erickson and Lambert, 1958). Thinning significantly increased diameter growth of maple poles but fertilization did not increase the response (Stone and Christenson, 1974). A combination treatment in which fertilizer was applied at 336 Kg N/ha and the stand was thinned to 50 percent of the initial basal area yielded 11 percent more dry wood per hectare per year for two years than did the control treatment in a 17-year-old loblolly pine plantation (Mallonee, 1974).

Economic Aspects

The economic feasibility of forest fertilization has not been considered in most forest fertilization studies. To supply wood at the lowest possible cost, the economic characteristics of the production tools available must be considered. Stoltenberg and Phores (1968) enumerate these characteristics as follows:

1. Precision of response predictions. Some of the past experiments have had low precision. Current research is making more precise response predictions because it is more appropriately conceived and designed.
2. Flexibility. Flexibility of a production tool means it can be applied to both selected and extensive areas and at any stage of stand development. Fertilization appears to be one of the more flexible production tools.
3. Compatability with multiple uses. Stream pollution seems to be the major problem with heavy applications of fertilizers. Otherwise, fertilization should not conflict with other uses of forest lands. Fertilization could help trees survive on heavily used recreational areas by increasing their vigor.

4. Cost. Cost can be divided into two categories. One concerns technology and cost-reducing innovations. Fertilizers rank high in this category because they are suited for mechanized spreading. The second cost category concerns the amount of time the cost has to be carried. Fertilizers rank high in this category also because they can be applied late in the rotation of a stand.

Simmons (1974) presents the following arguments in support of forest fertilization:

1. Fertilization can increase the value of a stand by increasing the average stand diameter.
2. Logging costs are lowered because the trees are of larger diameter.
3. Fertilization of stands close to the mill means that more wood volume can be grown close to the mill, thus reducing transportation costs.
4. Limiting fertilizer operations to sites that resemble experimental plots that give good responses will eliminate some of the uncertainty of fertilizer responses.

After reviewing the characteristics of forest fertilization, Schweitzer (1970) suggested that four basic questions must be asked in deciding if money should be invested.

1. What is changed by the investment?
2. How much more wood will fertilization produce?
3. When can the extra wood be harvested and at what price?
4. How much more money must be invested in the stand?

Economic feasibility, in terms of costs and returns, is a major consideration when evaluating fertilization. The economic desirability is measured by how much is added to the value of the stand in relation to the costs and length of time until harvest (Marty et al., 1966). Value, rather than volume, is used because it is the only consistent term which can measure all changes in the stand yield.

Cost, added value, and the time between investment and return are the primary factors influencing the economic desirability of forest fertilization.

Fertilization costs include all the cost incurred because a stand was fertilized. The main costs associated with forest fertilization are: (1) materials (fertilizers, etc.), (2) dissemination, and (3) overhead (administration).

Simmons (1974) used the following formula to estimate fertilization costs:

$$\text{Cost/Acre} = N\,(Mn + DISn) + P(Mp + DISp) + Adm.$$

Where: Adm = administrative costs per acre

N = pounds of elemental N per acre

P = pounds of elemental P per acre

Mn = cost of 1 pound of elemental N

Mp = cost of 1 pound of elemental P

DISn = dissemination costs per pound of elemental N

DISp = dissemination costs per pound of elemental P.

This formula takes into account applying the elements nitrogen and phosphorus on a pro rata basis.

Additional elements can be accommodated by adding the material and application costs to the formula; e.g., K(Mk + DISk), and the formula would be:

$$\text{Cost/Acre} = N(Mn + DISn) + P(Mp + DISp) + K(Mk + DISk) + Adm.$$

Where: K = pounds of elemental K per acre

Mk = cost of 1 pound of elemental K

DISk = dissemination costs per pound of elemental K.

The administrative costs (Adm) can be assumed as a fixed cost per acre.

Keipi (1972) considers additional factors when predicting fertilization costs. He estimates costs with the formula:

$$C = l + m + h + k + v + s.$$

Where: C = fertilization costs

l = spreading costs

m = marking costs (marking the area for application)

h = price of fertilizer

k = transportation costs

v = storage costs (if any)

s = planning and supervision costs.

Two components were added to this formula that were not in the preceding formula: (1) marking costs (m), and (2) storage costs (v). These are given as examples of additional costs and will not apply to all fertilization operations. These two formulae account for the major component costs of fertilization although more components could be added if needed.

Of the major component costs, the cost of fertilizer generally varies directly with the amount used. Spreading, marking, transportation, and storage costs are also influenced by the location, size, and shape of the area to be fertilized, while the administrative cost is generally considered a fixed cost.

To determine economic feasibility, costs must be compared to revenues. Before comparisons can be made, however, costs and revenues must be adjusted to a common point in time. Haley (1966) suggests discounting costs to accomplish this. The timing of the fertilizer applications within the rotation is a major factor influencing the discounted cost. If fertilizer is to be applied every five years during the entire rotation the discounted cost is calculated by:

$$I = \frac{C}{(1 + i)^5 - 1} .$$

Where: I = present worth of discounted fertilization cost

C = cost of a single application of fertilizer

i = discount rate.

If fertilizer is to be applied every five years during the final 15 years of a 25-year rotation, the present worth of the fertilization cost is calculated by (Haley, 1966):

$$I = \frac{C\,[(1 + i)^{15} - 1]\,(1 + i)^5}{[(1 + i)^5 - 1]\cdot[(1 + i)^{25} - 1]} .$$

The benefits of forest fertilization can be evaluated in three ways: (1) increased yields over a fixed time period, (2) shortened stand rotation, and (3) substitution of capital (fertilizer) for land.

With the added yield benefit, the stand is assigned a certain rotation length based on the tree size desired. At the end of the rotation if two stands of equal stocking and potential productivity were cut, one fertilized and one not fertilized, the additional volume that the fertilized stand yielded would be the benefit of fertilization. The value of the benefit of fertilization can be better assessed when the effect of fertilization on wood quality is known. Fertilized stands tend to have larger average diameter trees than do unfertilized stands. Therefore, fertilization may decrease harvesting costs per unit volume. This decrease may more than offset any decline in wood quality associated with fertilization.

Shortened stand rotation is another way to look at the benefits of fertilization. Using this approach, if two similar stands, one fertilized and the other not, were carried to a specified merchantable volume, the fertilized stand should produce this volume in a shorter time period. If the fertilized stand reached the specified volume five years earlier than the unfertilized stand the next rotation could be started five years earlier. This means that the fertilized areas would be growing more volume in a given amount of time because more rotations could be grown and harvested. For example, assume a rotation length of 30 years. In 150 years, five rotations could be harvested. If fertilization decreased each rotation length by five years, the same volume of wood could be produced in 125 years or an extra rotation could be harvested in 150 years.

Substituting capital (fertilizer) for land is a third method of evaluating fertilization benefits. If more wood volume is needed from company lands, the company can either buy more land on which to grow the needed wood (extensive management), or it can use more production tools such as fertilization to increase the yield from a fixed land base (intensive management). Since the price of land is rising, as are the taxes and other carrying costs, land owners could start fertilizing some portion of their existing lands instead of buying more. The investment in fertilizer may be considerably less than investing in additional land provided growth response levels are high enough to yield the additional wood needed. Segur (1960) reported that the acreage needed to grow enough wood volume to allow a certain percentage of protection for the mill could be reduced through intensive management. The following table illustrates this concept (Segur, 1960).

	Acres Per Ton Capacity	Growth in Cords Per Acre Per Year	Initial Investment* Per Ton of Mill Capacity
Average natural stands	1,250	0.5	$ 75,000
Improved natural stands	625	1.0	62,500
Selected land plantations with fertilization	325	1.67	25,000

*In 1960 dollars.

Fertilization has been added to the table because it is possible that fertilization of the selected land plantations could lower the acres per ton capacity by increasing the growth in cords per acre per year. The initial investment per ton of mill capacity depends on fertilization costs and land prices. This method of evaluation could lead to a higher level of planning because many more factors would be considered when determining the best alternative. In such cases, linear programming over time has been used to establish the best alternative (Thompson et al., 1968).

Reduction in hauling costs due to proximity to the mill should encourage greater investment in timber management on lands near the mill site. Selecting alternative sites for fertilization again represents a higher level of planning and possible use of Operations Research techniques in allocating available funds among management objectives.

Present net worth is a widely used profit criterion. Using this model, the net revenue that can be produced at a certain age is discounted for a predetermined number of years using a selected rate of interest. The present net worth calculations can be constructed to include terms for every conceivable cost item and revenue source.

Hughes and Post (1973) suggest using the present net worth method to evaluate forest fertilization. The formula they used is:

$$Pnw = \frac{R^t}{(1 + i)^t} - \frac{C(1 + i)^{t-n}}{(1 + i)^t} .$$

Where: Pnw = present net worth

R = revenue

C = cost

t = investment period

n = time period from present to investment in treatment

i = required rate of return.

If fertilization is profitable, all costs (C) are recovered by the end of the investment period (t) plus an amount equal to or greater than that earned had the cost amount been invested at the alternative rate of return for the same time period (Hughes and Post, 1973). According to the preceding equation, if the discount rate is increased, the present net worth would decrease. Other factors being equal, if the time period between stand establishment and fertilization is increased, the present net worth would be higher because the costs are carried over a shorter period. Therefore, delaying fertilization until near the end of the rotation decreases investment costs because the interest rate is carried over fewer years.

An expanded version of the present net worth approach has been developed by Haley (1967) in which a standard method for discounting costs for a given frequency of fertilization is presented. This method can be used for only one rotation or on the first plus all subsequent rotations.

The soil rent model is the traditional method for evaluating present net worth on a perpetual basis. Using this approach, rotations are considered to be carried to perpetuity. The soil rent formula is (Simmons, 1974):

$$SR = \frac{H}{(1+i)^n-1} \pm \frac{I(1+i)^{n-m}}{(1+i)^n-1} - \frac{E(1+i)^n}{(1+i)^n-1} - \frac{A}{i} .$$

Where: SR = soil rent

H = return from final harvest per acre

I = intermediate cash flows; either positive or negative

E = stand establishment costs per acre

A = annual costs per acre, such as managerial costs and property taxes

n = length of rotation in years

m = the age at which an intermediate cash flow occurs

i = interest rate.

This formula calculates the present value of an acre of land in forest production. Using this model to evaluate fertilization, the soil rent of stands with and without fertilization are comparable regardless of age differences at harvest time. This model is best suited for calculating the economic feasibility of fertilization when a shortened rotation is the desired benefit.

A simpler model can be used if the desired goal is added yield rather than shortening the rotation length (Simmons, 1974).

$$PVm = \frac{Fn}{(1 + i)^{n-m}} - Cm.$$

Where: PVm = present value of fertilization at the time of fertilizer application

Fn = value increment due to fertilization at the time of final harvest

Cm = cost of fertilization in year m

m = year of fertilizer application

i = interest rate.

Both of the models can be adjusted to allow for income tax.

Keipi (1972) has divided a present net worth formula which calculates forest profitability into two parts. Part (A) calculates the return contributed by the increased volume growth, and part (B) calculates the return contributed by gain in tree size. The formula is:

$$-G \underbrace{T\frac{R \cdot L}{100}(Bo - Ao)}_{A} + \frac{\overbrace{[(Bg - Ag) - (Bo - Ao)]\,[T\frac{R \cdot L}{100} + (V + T + L)]}^{B}}{(1 + i)^n} \geq 0.$$

Where: G = fertilization cost per acre

T = time between fertilization and final cut in years

R = increased growth due to fertilization, as a percent based on yearly current growth without fertilization

L = yearly current volume growth on the average without fertilization

Bo = price of timber in final cutting after fertilization

Ao = harvesting costs of final cutting with no fertilization

Bg = price of timber in final cutting after fertilization

Ag = harvesting costs of final cutting after fertilization

V = stand volume at time of fertilization

i = interest rate

n = time from fertilization to final cutting (years).

Part (A) is calculated by multiplying the increase in growth (percent) due to fertilization by the stumpage price of the final cut with no fertilization. Part (B) is calculated by multiplying the stumpage price increase due to fertilization by the total volume of the fertilized stand. Investment in fertilization is profitable if the calculated return is equal to or greater than zero.

Another profit criterion which has been used to determine the economic feasibility of forest fertilization is internal rate of return.

Union Camp[1] and Pritchett and Gooding[2] have used internal rate of return for predicting fertilization profitability (Appendix D). This criterion measures the rate at which an investment grows toward the return it evantually generates, and takes into account the amount and timing of costs and returns (Marty et al., 1966). The formula for a terminable series is (Chappelle, 1969):

$$\frac{Rt}{(1 + i)^t} = \frac{Ct}{(1 + i)^t} \text{ or } i = n\sqrt{\frac{Rt}{Ct}} - 1 \ .$$

Where: Ct = cost in year t

Rt = return in year t

n = rotation length

i = internal rate of return.

The added yield benefit is perhaps best calculated by the above formula. The formula for a perpetual series should be used when shortening the stand rotation is considered the benefit. This formula is (Chappelle, 1969):

$$\left[\frac{Rt}{(1 + i)^t}\right] \cdot \left[\frac{(1 + i)^n}{(1 + i)^n - 1}\right] = \left[\frac{Ct}{(1 + i)^t}\right] \cdot \left[\frac{(1 + i)^n}{(1 + i)^n - 1}\right] .$$

The internal rate of return for a perpetual series is the same as that for a terminable series, but there is a difference in discounted costs and returns for the two series.

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[1]Personal communication with F. S. Boerman, Research Forester, Union Camp Corporation.

[2]Personal communication with Dr. John Gray, Director, School of Forest Resources and Conservation, University of Florida.

The benefit/cost ratio is a third profit criterion that can be used to evaluate forest fertilization. The formula for calculating this ratio is (Chappelle, 1969):

$$\frac{B}{C} = \frac{Rt/\ (1 + i)^{t}}{C(1 + i)^{t-n}/\ (1 + i)^{t}}$$

Where: C = cost

R = revenue

i = interest rate

t = investment period

n = time period from present to investment in fertilization.

This equation can also be used for both terminable and perpetual series. The benefit/cost ratio must be one (unity) or greater for the investment to be profitable.

A fourth profit criterion which could be used to evaluate forest fertilization is cost-price. The cost-price of growing timber is the cost of producing a unit of output (Lundgren, 1973). The discounting and compounding formulae used in other investment calculations are used in the cost-price calculations. The equation for future net worth is the basic equation used to derive the cost-price formula. This formula is (Lundgren, 1973):

$$Pn = C(1 + r)^{n}/Vn.$$

The cost-price formula will give the price (Pn) that the expected unit volume (Vn) will yield given a predetermined discounted cost (C), interest rate (i), and rotation age (n). The price (Pn) obtained is the break even price for the investment. The calculated price is the amount that it costs to grow the unit volume of timber plus a return on the invested capital (Lundgren, 1973).

The various terms in the models just discussed cannot be predicted with certainty. Future prices and costs are uncertain; appropriate interest rates that should be used from time period to time period are uncertain; the response levels of forests to fertilizer is not precisely known; and the climatic factors influence response to an unknown degree.

Environmental conditions created by fertilization provide another source of uncertainty. Possible water pollution is the major ecological concern. Several precautions can be taken to minimize this possibility. These precautions represent either out-of-pocket costs or opportunity costs and are necessary costs of fertilization (Schweitzer, 1971).

Difficulties encountered in carrying out the operation of fertilization is another source of uncertainty. One organization has discovered that application irregularities require that the expectation of increased yields should be reduced by an average of 13 percent (Schweitzer, 1971). These irregularities can be attributed to human error, equipment failures, and problems associated with the size and shape of the area to be fertilized. Another reason for reducing expected yields is due to the heterogeneous nature of most forest ownerships (being broken by roads, streams, swamps, and rock outcrops).

Most of the research conducted in the past has been concerned with the response of a forest or individual trees to one fertilizer application. Few studies have been made concerning the optimum time to fertilize in the rotation period. To gain the most from the investment in fertilization, the period that will yield the best economic return should be determined. Also, future research should be undertaken to determine how often fertilizer should be applied to maintain a favorable growth level.

Stoltenberg and Phares (1968) suggest that experimental designs for forest fertilization should include complete factorials, fractional factorials, composites, and rotatable designs. They suggested that fertilization research is a two-step study. The first step is hypothesis-testing. In this step the classical designs (variance analysis) with replications and intensive treatments are used. These designs usually analyze large quantities of data. The second step is to quantify predictive relationships of fertilization. The factorials, composite, and rotable designs are used in this step. These designs yield an expression of the response surface or production function which is basic to economic analysis of the cost-benefit ratio of fertilization. In the second step, estimates can be made of the growth responses for levels and combinations of fertilizers other than those tested. If various growth responses can be predicted, the most profitable fertilizer combinations can be calculated. The second step will supply information of real value to the decision-making forest manager (Stoltenberg and Phares, 1968).

The economic analysis of forest fertilization can be broken into two phases. The first phase is predicting the profitability of forest fertilization. Several models have been devised to calculate economic feasibility; each model makes different assumptions in compiling variables for evaluation.

The second phase is determining the allocation of capital. Two models have been used in this phase. Simmons (1974) used the soil rent model (present net worth in perpetuity). Union Camp Corporation and Pritchett and Gooding have used the internal rate of return model.

A primary factor that too often determines the model used in the second phase is the bookkeeping system used by a particular company. Ideally, the model used should be a management decision and not one dictated by the companies' accounting system. Horizontally structured companies usually use internal rate of return, and vertically structured companies often use cash flow (present net worth). Capital is assumed to be the scarce resource when the internal rate model is used, while present net worth includes land as a factor and assumes capital is available at the discount rate selected. Therefore, the internal rate of return model favors less intensive timber management than does the net worth approach when high alternative rates of return exist.

The internal rate of return method is also favored over the soil rent model because the discount rate does not have to be assumed (Hall, 1962). However, Gansner and Larson (1969) point out difficulties in using the internal rate of return as a choice of profit criterion. Pitfalls in using internal rate exist regarding mutually exclusive alternatives and possible multiple returns under certain circumstances.

Forest managers must look critically at the different models, the assumptions on which they are based, and the terms they contain. It is generally recommended that more than one model be used to properly gauge the profitability of fertilization. After testing several models, the criterion which will best provide for the company's goals should be chosen.

Many companies invest in wood production to protect their future wood supply. If this is the case, the analysis involves more than profit pure. If a company was considering fertilization as a wood production tool, it would investigate long-term, company-wide benefits and costs other than those costs relevant just at the economic analysis of an individual fertilization operation.

In general, forest fertilization research has not dealt with economic analysis. Now that research has demonstrated that favorable growth responses are likely, more emphasis should be placed upon economic analysis to determine if these responses provide the additional revenue necessary to make fertilization economically feasible.

CHAPTER III

DESCRIPTION OF STUDY AREA

The study sites were established in 1969 in three loblolly pine plantations in East Tennessee. The plantations were approximately 14 years old at that time. Loblolly pine is not native to this region. The northern-most boundary of its natural range reaches to slightly north of Chattanooga, Tennessee. The planted pines are therefore approximately 60 miles north of their native range. Three study sites were established because of difference in soils, climate, competing vegetation and previous management of the land. Two sites are located in Rhea County on Waldens Ridge, the south-eastern flank of the Cumberland Plateau. This gently rolling upland is bounded on the west by the Sequatchie Valley and on the east by the Great Valley of East Tennessee. The Cumberland Plateau is the southern-most subdivision of the Appalachian Plateau province. One site will be referred to as the Plateau site and is located on undulating to gently rolling topography which is typical of a great portion of the Cumberland Plateau. The second site (Satellite) is also on the Plateau and is situated on a dry ridge. The third study site is located in the Valley and Ridge province and will be referred to as the Valley site. It is approximately 1000 feet lower than the two sites on the Plateau.

I. PLATEAU AND SATELLITE SITES

Location and Physiography

The Plateau and Satellite study areas are located approximately 8.5 miles west of Spring City, Tennessee. The coordinates of the study areas are N 35° 41' 40" and W 84° 58' 30".

This area is located in the Appalachian Plateau province which is a high, broad ridge characterized by relatively smooth areas dissected by dendritic drainage systems oriented in a southeasterly direction (Hasty, 1948). The streams in this area usually create deep, narrow, V-shaped valleys and flow eastward into the Tennessee River. The elevation of the Cumberland Plateau ranges between 1,400 and 2,000 feet and averages approximately 1,900 feet in the study area. The topography of the Plateau study site is undulating to gently rolling.

The Satellite plots are in two locations because plantings of sufficient uniformity and size and on a ridge site could not be found in one location. Both of the locations are on ridges, to test response to fertilizer treatments on the drier sites on the Cumberland Plateau.

Soils

The rocks that underlie the Cumberland Plateau are mainly sandstone with some shale, and rock strata are nearly level. The sandstones are of the Pennsylvania series of the Carboniferous system (Hasty, 1948).

The soils at the Plateau site belong to the Hartsells-Muskingum soil association (Hasty, 1948). This association is comprised of residual soils developed from underlying sandstone and occupies the ridge tops and smoother areas of the Cumberland Plateau. Hartsells fine sandy loam, rolling is the major soil phase found on the Plateau site. This rolling phase has slopes that vary from 5 to 9 percent, has very few outcrops of bedrock, has a low water-holding capacity, is low in phosphorus, and depth to sandstone bedrock is generally under 2 feet. The B horizon is generally in the loam textural class.

The soil on the Satellite site is Muskingum stony fine sandy loam, hilly phase (Hasty, 1948). This soil has a hilly relief with a slope that ranges from 9 to 30 percent. The soil also has a low water-holding capacity, low natural fertility and is approximately 1.5 feet deep.

Climate

The climate of the Plateau and Satellite sites is temperate and continental with moderate winters and warm summers (Hasty, 1948). It is characterized by short cold periods in the winter with the lowest recorded temperature being -20°. The summers are warm but maximum temperatures of 100°F are rare. A difference of 33.4° exists between the mean summer and winter temperatures. There are approximately 179 frost free days. The ground infrequently freezes to a depth of a few inches and remains frozen for only a few days at a time. The average precipitation on the Cumberland Plateau is 54.2 inches and snowfall averages 12.1 inches. Generally, the late summer and early fall seasons are dry because of the low water holding capacity of soils and reduction in the moisture reserve due to evaporation and transpiration in the spring and summer months. Climatological data collected at the Crossville AAP-AP, US Weather Bureau station are presented in Appendix E.

Vegetation

The Plateau and Satellite sites are in the Mixed Mesophytic Forest Region (Braun, 1964). Second growth Virginia pine, shortleaf pine, oak (Quercus), hickory (Carya), and dogwood (Cornus florida, L.) are the predominate forest species. Higrading and fire probably account for the significant pine component. In 1955-1956 the study area was acquired by Hiwassee Land Company and converted to loblolly pine plantations. Site preparation prior to planting consisted of an aerial application of 2, 4, 5-T to control unwanted hardwoods. Loblolly pine seedlings were hand planted at a 6 x 6 foot spacing. At least one aerial application of herbicides to control unwanted hardwoods has been applied since planting but prior to fertilization. Presently, the overstory is dominated by loblolly pine with a relatively dense hardwood understory, composed mainly of oaks and hickories. A few of the oaks and hickories reach into the upper crown class. Occasionally, volunteer shortleaf and Virginia pines compete with the planted loblolly pines in the study area. Care was taken to avoid this situation in locating study plots.

II. VALLEY SITE

Location and Physiography

The valley study area is located approximately 2.0 miles southeast of the town of Evensville at coordinates N 35° 33'·15" and W 84° 57'.

The Valley site is in Rhea County which is located in the Valley and Ridge province of the Appalachian Highlands physiographic province. This subdivision is characterized by parallel ridges and valleys oriented in a northeast-southwest direction which parallels the strike of the exposed rock (Hasty, 1948). Elevations in this portion of the Valley and Ridge province range from 600 feet to 1,000 feet.

The study plots are located on the gently sloping southern exposure of a ridge and plots are situated on both upper and lower slope positions. Plots were assigned to replications such that any influence of slope position would appear as a replication effect.

Soils

The rocks of the Valley and Ridge province are strongly folded and faulted and consist of alternation beds of shale, sandstone, and limestone. The differential weathering of these alternate beds is largely responsible for the valley and ridge topography. Sandstone is commonly found on the sharper ridges while dolomitic limestone and shale are commonly found on the slopes. The valleys are generally underlain by limestone. The topographic position and parent rock determine the kind of soils that develop in this province. The clay content of soil decreases from limestone to shale to sandstone (Buckner, 1972).

The soil of the Valley site is composed of approximately 75 percent Clarksville cherty silt loam of which 25 percent is the eroded hilly phase. This soil is characteristically found on slopes and ridges of the limestone valleys. The relief is generally rolling with slopes ranging from 5 to 12 percent. Parent rocks are cherty limestones. This soil is low in natural fertility. At least half of the surface soil of the eroded hilly phase has been lost by erosion. Clarksville soils are characterized by approximately an 8 inch surface soil of light yellowish gray cherty silt loam, 12 inches of brownish-yellow cherty silt loam which changes with depth to cherty silty clay. Bedrock, cherty dolomitic limestone, is at a depth of 10 to 30 feet or more (Hasty, 1948). Approximately 25 percent of the study area is composed of Greendale cherty silt loam. The Greendale soil developed in colluvium from Clarksville soils on upper slope positions. Prior to treatment plots were grouped into replications so as to remove differences due to slope position and soils from experimental error.

Climate

The climate of the Valley site is temperate and continental (Hasty, 1948). The summers are warm, and maximum temperatures of 100°F are rare with 108° being the highest on record. The winters are moderate with short cold periods; -20° is the coldest recorded temperature. There is a difference of 35.6° between the mean summer and winter temperatures and the average frost-free season is approximately 192 days.

The average precipitation in the Valley and Ridge province is 54.3 inches and snowfall averages 8.7 inches. Generally, favorable moisture conditions for plant growth exist in the spring, early summer and midsummer, but relatively dry conditions occur in late summer and fall. Table E-1 (Appendix E) gives climatological data collected by the U. S. Weather Bureau for Dayton, Tennessee.

Vegetation

The vegetation of the Valley and Ridge province is considered to be in the Oak-Chestnut Forest Region (Buckner, 1972). The forest region was named Oak Chestnut because these species were found on the broad uplands and gentle to moderate slopes which account for most of the area in the Valley and Ridge province. The chestnut blight (Endothia parasitica) eliminated the American chestnut in the 1930's. Therefore, the chestnut is no longer a major species in the Oak-Chestnut Forest region. Presently, oaks and hickories are found on areas previously occupied by American chestnut and oaks. Shortleaf and Virginia are the native yellow pines. Originally, these pines were found on the dry ridges and south-facing slopes, but they now occupy larger areas in the Valley due to old field abandonment. The moist and fertile sites are occupied by yellow-poplar, beech (Fagus grandifolia, Ehrh.), sugar maple, and other species which are site demanding.

The Valley study site was originally an old field. In 1955-56, the field was planted to loblolly pine at a spacing of 6 x 6 feet. Because the planting occurred in a field, hardwood competition was minimal. Presently, the Valley study site is composed of loblolly pine in dominate, codominate, intermediate, and suppressed crown classes. Only scattered hardwoods have become established in the understory as there are no nearby hardwood stands to serve as a seed source.

CHAPTER IV

METHODS AND MATERIALS

I. STUDY ESTABLISHMENT

This study was initiated in 1969 as the Hiwassee Land Company--The University of Tennessee Cooperative Forest Fertilization Study. The main objective of the study was to determine how various fertilizer treatments affected the growth of loblolly pine plantations owned by Hiwassee Land Company. Because Hiwassee Land Company owns extensive acreage on the Cumberland Plateau and in the Valley and Ridge province, three study sites were established. Two sites, Plateau and Satellite, were established on the Cumberland Plateau. One site, Valley, was established in the Valley and Ridge province.

Most of Hiwassee Land Company's pine plantations on the Cumberland Plateau are on sites converted from second growth hardwoods. Incomplete eradication of the original hardwood stand and vigorous sprouting are responsible for the dense hardwood understories that are characteristic of their older plantations. The Plateau and Satellite sites were located in areas that were considered representative of company ownerships on the Cumberland Plateau.

Plantations established on former farmland are typical of Company holdings in the Valley and Ridge province. Therefore, the Valley study area was located in a plantation that was established on an old field.

Plot Selection

To qualify as a study site the crowns of planted pines had to be closed and the stand well-stocked. Fertilizing prior to stand closure often stimulates competing vegetation more than the planted trees. Since stand conversion techniques did not give complete hardwood control on the Plateau and Satellite sites, there was the danger that hardwoods might respond more to fertilization than the planted pines. Another reason for waiting until stand closure was to avoid stimulating the growth of juvenile wood. The juvenile growth stage is largely completed by the time most plantations close. Also, if fertilizer is applied after stand closure, the carrying costs of the operation will be less than if fertilization took place earlier.

Finding areas where soil, topographic and vegative characteristics were sufficiently uniform to establish the Plateau and Satellite plots was difficult. Areas where mortality of planted trees was greater than 20 percent were not used. Study plots had to have approximately the same stocking density (minimum of 90 sq ft per acre) and soil depth to minimize variation among plots. Since soil depth on these shallow soils profoundly influence available moisture, the minimum depth to bedrock was established as 18 inches. Each plot was probed in at least three places to ascertain that this criterion was met.

Little difficulty was experienced in selecting plots at the Valley site. Soil depth was of no concern since depth to bedrock over the general area was 10 to 30 feet. Basal areas were higher and more uniform than on the Plateau. Again, areas with fully closed crowns and a basal area of at least 90 sq ft per acre were used as the guide for stocking density.

Plot Description

In 1969, 68 plots were established at the Plateau site; 12 plots were established at the Satellite site, and 56 plots were established at the Valley site. These plots were 0.20 acres in size and were located in 14-year-old loblolly pine plantations in as near a contiguous arrangement as stocking and soil conditions permitted. The treatment plots measured 93.34 feet square (1/5 acre). A 0.10 acre measurement plot (66 feet square) was centered within each treatment plot. Because the measurement plot was centered within the treatment plot each plot had a buffer strip 13.67 feet wide (Figure 1).

Selection of Measurement Trees

Within the 0.10 acre measurement plots all trees whose crowns were in the dominant or codominant position (not more than 3 feet below the average upper canopy level of the nearest 10-15 trees) were numbered with aluminum tags nailed to the trees at approximately 5 feet above groundline. During remeasurements, a tree was dropped from the study if the above criteria was not met. This required the elimination of many trees during the study. This criteria was established to eliminate trees that would not be of merchantable volume at the time of the first thinning.

Numbers were assigned to measurement trees as follows: (1) planted pines began with number 1 and progressed to the total count of planted pines meeting the selection criteria; (2) native pines within the measurement plot that met the selection criteria were numbered beginning with 500; and (3) hardwoods that met the selection criteria were numbered beginning with 700.

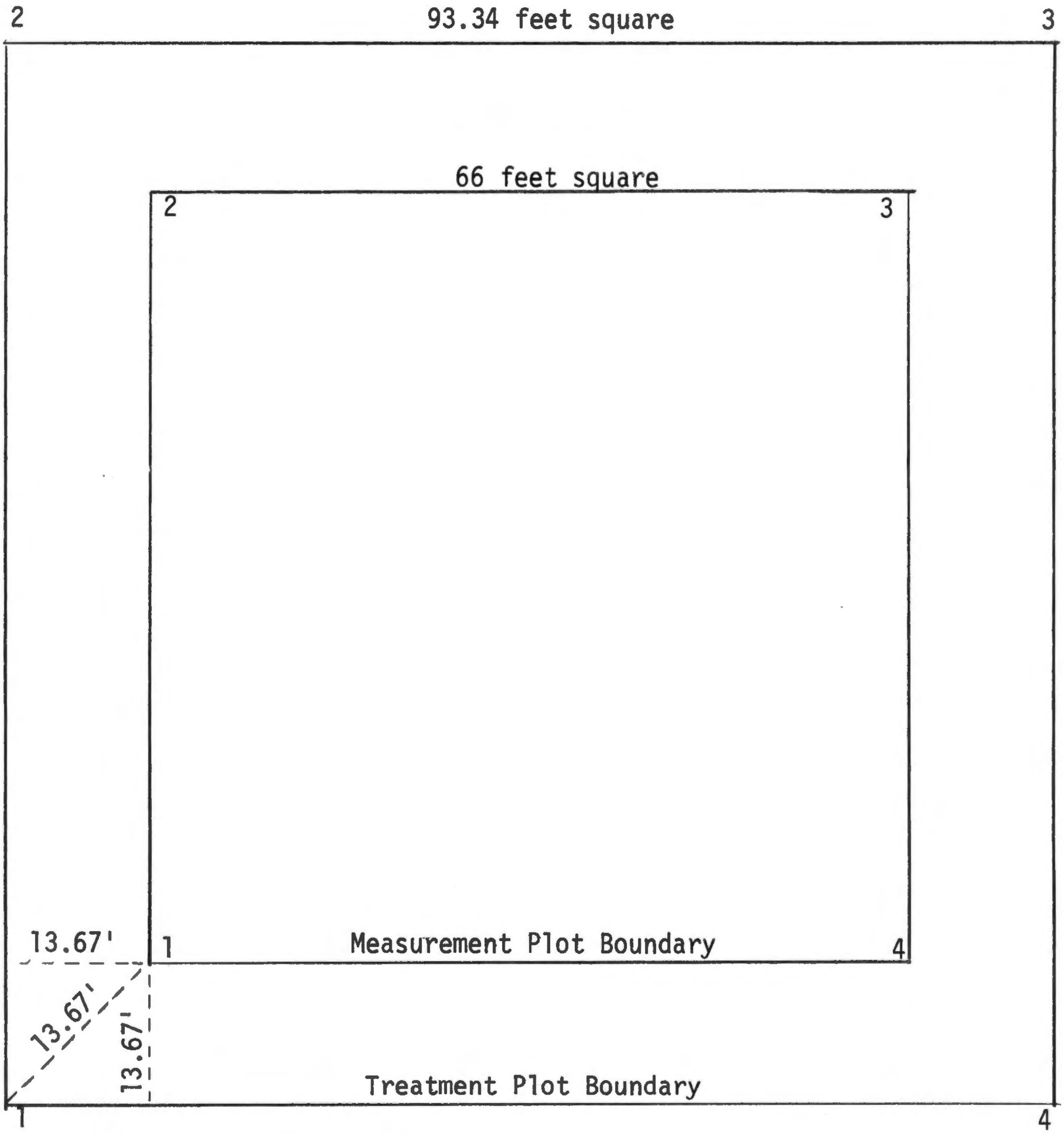


FIGURE 1. Design of treatment plot.

NOTE: Treatment plot = 0.20 acre;
Measurement plot = 0.10 acre.

Application of Fertilizer

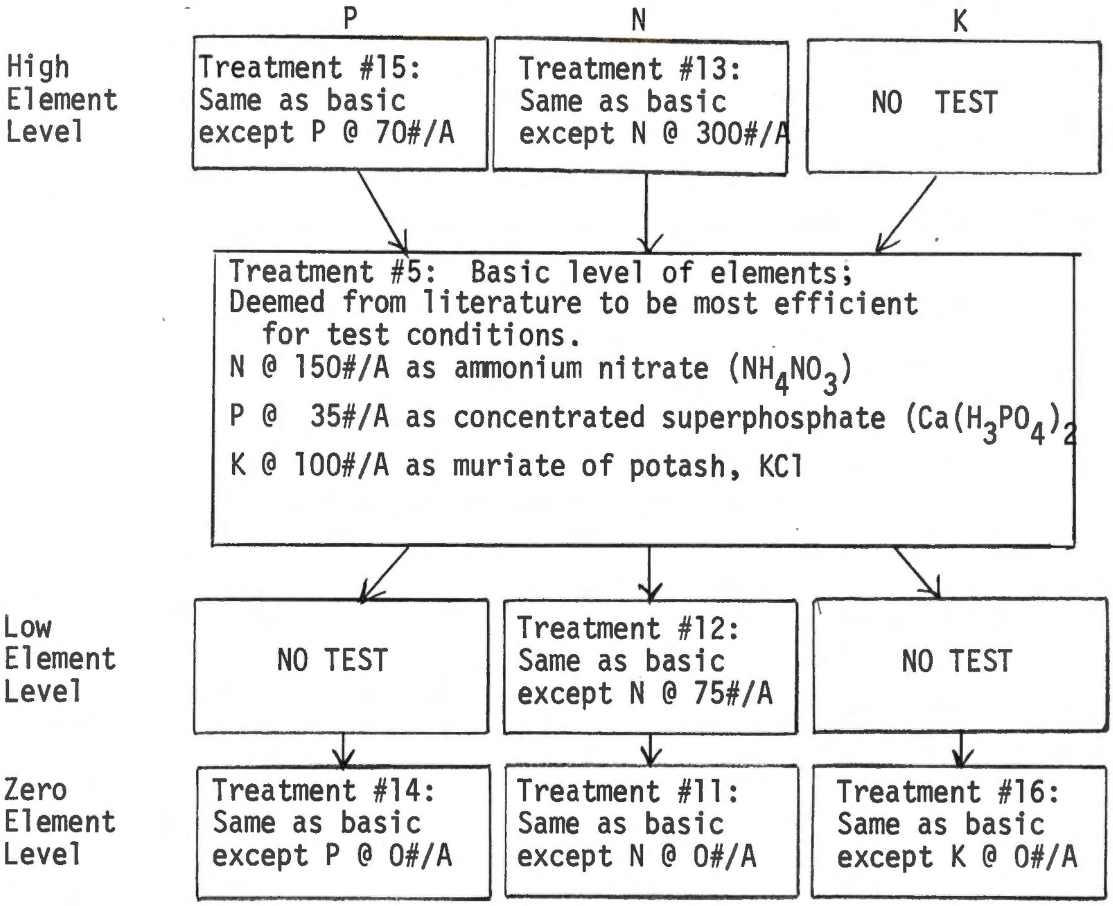
Fertilizers were applied at all three sites in March, 1970. The fertilizer was broadcast using hand-operated cyclone spreaders. Ropes were used to mark treatment-plot boundaries and aid in uniformly spreading the fertilizer.

II. TREATMENTS

Because no previous fertilization studies had been conducted in the loblolly pine plantations of East Tennessee, a large number of fertilizer treatments were applied. It was understood at the initiation of the study that this large number of treatments would not provide conclusive answers but would serve as a guide for further testing. After searching the literature, treatment (#5) consisting of 150 pounds of nitrogen, 35 pounds of phosphorus, and 100 pounds of potassium was thought to be the most efficient for the test conditions and was therefore called the basic treatment. Pivoting around the basic treatment were tests of various levels of N, P, and K plus combinations with other elements and cultural treatments (Figure 2).

The treatments were tested in a randomized block design with four replications. Nitrogen was applied as ammonium nitrate, NH_4NO_3 (34.5 percent N) except for treatment #10 where urea, $CO(NH_2)_2$ (46 percent N) was the nitrogen source. Phosphorus was applied as concentrated superphosphate, $Ca(H_2PO_4)_2$ (20 percent P), and muriate of potash, KCL (50 percent K) was the potassium source. Descriptions of the treatments are as follows:

A. Treatments Testing Selected Levels of Major Elements



A. Modifications of Basic Treatment

1. Treatment #6: Basic treatment (#5) plus hardwood control
2. Treatment #7: Basic treatment plus thinning
3. Treatment #8: Basic treatment plus hardwood control and thinning
4. Treatment #9: Basic treatment plus micronutrients
5. Treatment #10: Same as basic except N applied as urea

C. Other Tests

1. Treatment #1: Control; no treatments applied
2. Treatment #2: Hardwood control
3. Treatment #3: Thinning
4. Treatment #4: Hardwood control plus thinning
5. Treatments #17 and 18: Sludge equivalent to 50# and 100# N/A, respectively

FIGURE 2. Description of treatments applied in the study.

Treatment #1 (Control: Plots on which there was no fertilizing, no thinning and no hardwood control. This treatment was established at all three study sites.

Treatment #2 (Hardwood Control-HC): The hardwood control treatment was established only on the Plateau study site. All hardwoods over one foot high were eliminated by cutting with stump treatment for small stems and injection for the larger hardwoods. There should have been no difference due to time of treatment among plots because all were treated within a relatively short period of time.

An interesting side effect related to this treatment was severe breakage due to a wet snow in December, 1971. Apparently the dense hardwood understory that reached to the base of the line crown on the pine trees served to support the pines bent by snow and prevent breakage. Snow breakage was severe in all plots receiving the hardwood control treatment.

Treatment #3 (Thinning-T): The thinning treatment was established at the Plateau and Valley sites. Thinning was to be done according to Hiwassee Land Company policy. However, the Plateau plots were never thinned because their stocking was too low to meet Company criteria for thinning. Therefore, the thinning treatment on the Plateau site was considered as another control treatment (#1). The thinning treatment at the Valley site maintained the basal area of the experimental plot between 90 and 150 square feet per acre (between 18 and 30 sq ft per 0.20 acre treatment plot). The basal area was allowed to increase to between 130 and 150 sq ft per acre (26 to 30 sq ft per 0.20 acre plot), and then thinned to between 90 and 100 sq ft per acre (18 to 22 sq ft per 0.20

acre plot). Thinning was performed by Hiwassee Land Company foresters according to the general method used by the company. The Valley plots were thinned in the Spring of 1971, one growing season after fertilization.

Treatment #4 (Hardwood Control plus Thinning-HC+T): This treatment was planned only for the Plateau site. Because the plots never met the criteria for thinning, these plots received only the hardwood control treatment. Therefore, the hardwood control plus thinning treatment is considered as another hardwood control treatment (#2).

Treatment #5 (Basic NPK): This was the focal treatment initially selected as representing the levels of N, P and K that should be most efficient on these sites. Other treatments are modifications of this treatment designed to test variations in levels and forms as well as interactions. This treatment occurs at all three study sites.

Treatment #6 (Basic NPK plus Hardwood Control): Hardwood control plus the basic NPK fertilizer (150-35-100) were applied only on the Plateau site.

Treatment #7 (Basic NPK plus Thinning): Since there was no thinning on the Plateau site, this treatment is considered to be another basic NPK (150-35-100) treatment (#5). At the Valley site, the plots were thinned prior to the second growing season following fertilization, and this treatment determines the growth response due to thinning and fertilization. This treatment was not established at the Satellite site.

Treatment #8 (Basic NPK plus Hardwood Control and Thinning): Again, since no thinning occurred on the Plateau, this treatment is identical to treatment #6. This treatment was not tested at the Satellite and Valley sites.

Treatment #9 (Basic NPK plus Micronutrients): Minor and trace elements called for in this treatment were supplied as follows: calcium was present in the concentrated superphosphate and chlorine was present in the muriate of potash. Additional calcium plus magnesium, sulfur and the trace elements were supplied from gypsum, epsom salts and a micronutrient mix obtained from the Eaglepitcher Company, Joplin, Missouri (Table 1). The materials just named were applied individually to assure uniform distribution. This treatment was applied at the Plateau and Valley sites.

Treatment #10 (Basic NPK with N supplied as urea): Nutrient levels in this treatment were identical to the basic NPK (150-35-100) except that the nitrogen was supplied as urea instead of ammonium nitrate.

Treatment #11 (Zero N): A 0-35-100 fertilizer was applied to the Plateau and Valley sites to test effects of P and K without N.

Treatment #12 (Low N): This treatment applied P and K at the basic level but used a low N level (75-35-100); tested at both the Plateau and Valley sites.

Treatment #13 (High N): All three sites received the high N application (300-35-100).

Treatment #14 (Zero P): This treatment (150-0-100) was tested at the Plateau and Valley sites. It tested the growth responses to N and K without P.

Treatment #15 (High P): A higher level of phosphorus (150-70-100) than that used in the basic NPK was tested by this treatment at the Plateau and Valley sites.

TABLE 1. Source and application rates of secondary and trace elements applied in Treatment #9 (150-35-100-Micro).

Fertilizer Material Formula	Gypsum $CaSO_4 \cdot 2H_2O$	Epsom Salt $MgSO_4 \cdot 7H_2O$	Micro-Mix	Total
RATE: per 1/5 A. tmt. plot (lbs)	150	150	50	350
Equivalent per acre (lbs)	750	750	250	1750
Per acre rate at which elements are applied (lbs):				
Calcium (Ca)	175	X	X	175.0
Magnesium (Mg)	X	75	12.5	87.5
Sulphur (S)	197	199	45.0	441.0
Zinc (Zn)	X	X	7.5	7.5
Iron (Fe)	X	X	10.0	10.0
Manganese (Mn)	X	X	5.0	5.0
Copper (Cu)	X	X	5.0	5.0
Boron (B)	X	X	2.5	2.5
Molybdneum (Mo)	X	X	0.05	0.05
Chlorine (Cl) as in muriate of Potash		X	X	X

Treatment #16 (Zero K): A 150-35-0 fertilizer mixture was applied to the Plateau and Valley sites to test N and P at the basic levels but without K.

Treatment #17: This treatment was tested at the Valley site only. Treatment plant sludge containing 1.5 percent N was applied at a rate that would supply 50 pounds N per acre.

Treatment #18: This treatment was established only at the Valley site. Treatment plant sludge (1.5 percent N) equivalent to 100 pounds nitrogen per acre was applied to these plots.

III. EXPERIMENTAL DESIGN

A randomized complete block design was used at all three study sites. Seventeen treatment plots, fifteen treatments plus two control plots, were replicated four times on the Plateau site; three treatments were replicated four times on the Satellite site; and fourteen treatments were replicated four times on the Valley site (Figures 3, 4, and 5).

IV. DATA COLLECTION

To determine the growth responses and duration of fertilizer effects, diameter measurements, height measurements, and upper stem diameter measurements were taken in 1969 (before fertilization), and in 1970, 1971, 1973, and 1974. These three measurements were taken to determine the diameter, height, basal area, cubic volume and merchantable cord growth for each treatment plot. These growth data were used to represent the response of each plot to the treatment applied. Measurements were taken in 1969, 1970, and 1971 because it was thought that

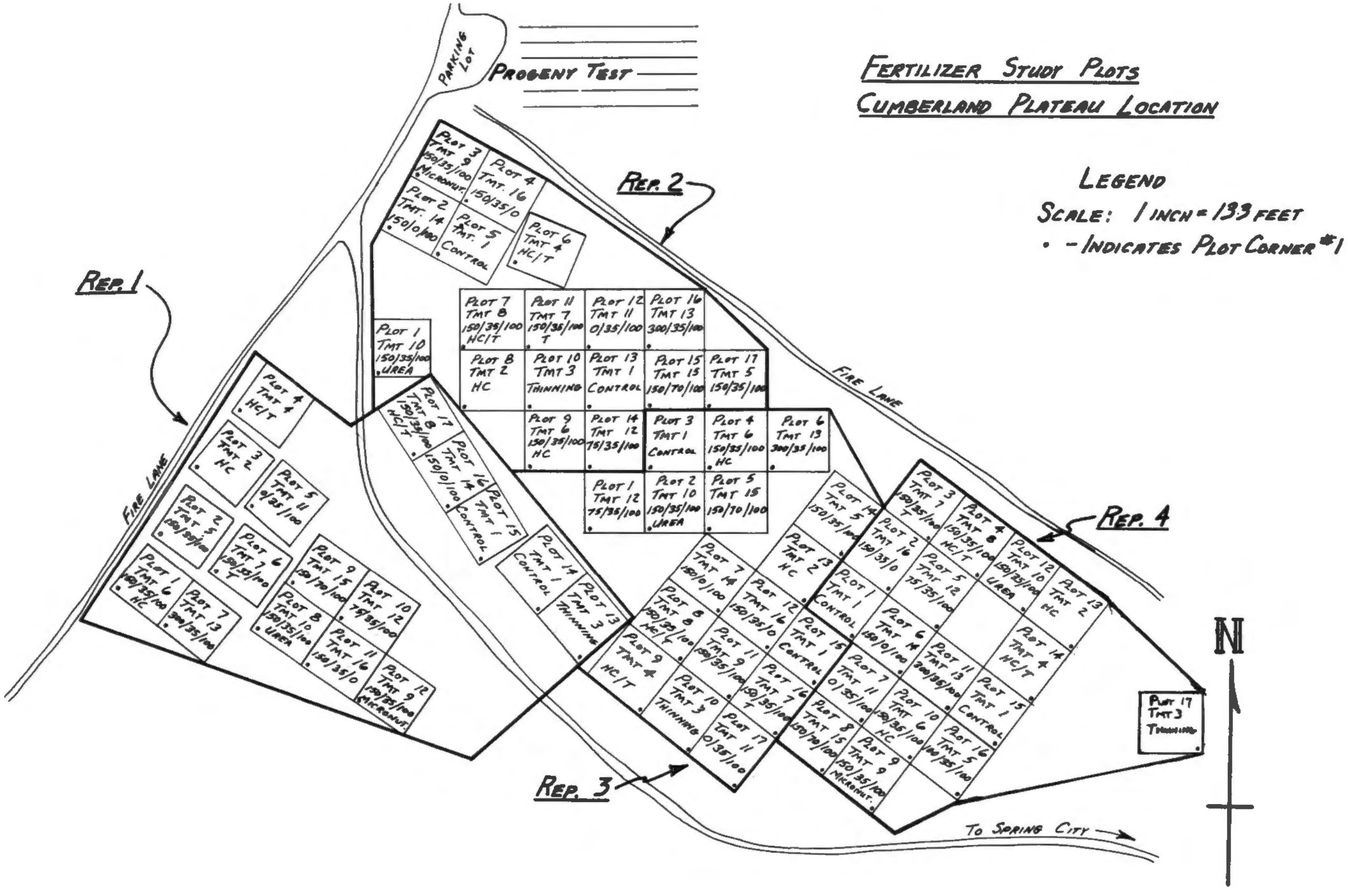


FIGURE 3. Schematic diagram of experimental plot layout showing replications and treatment plot locations on the Plateau site.

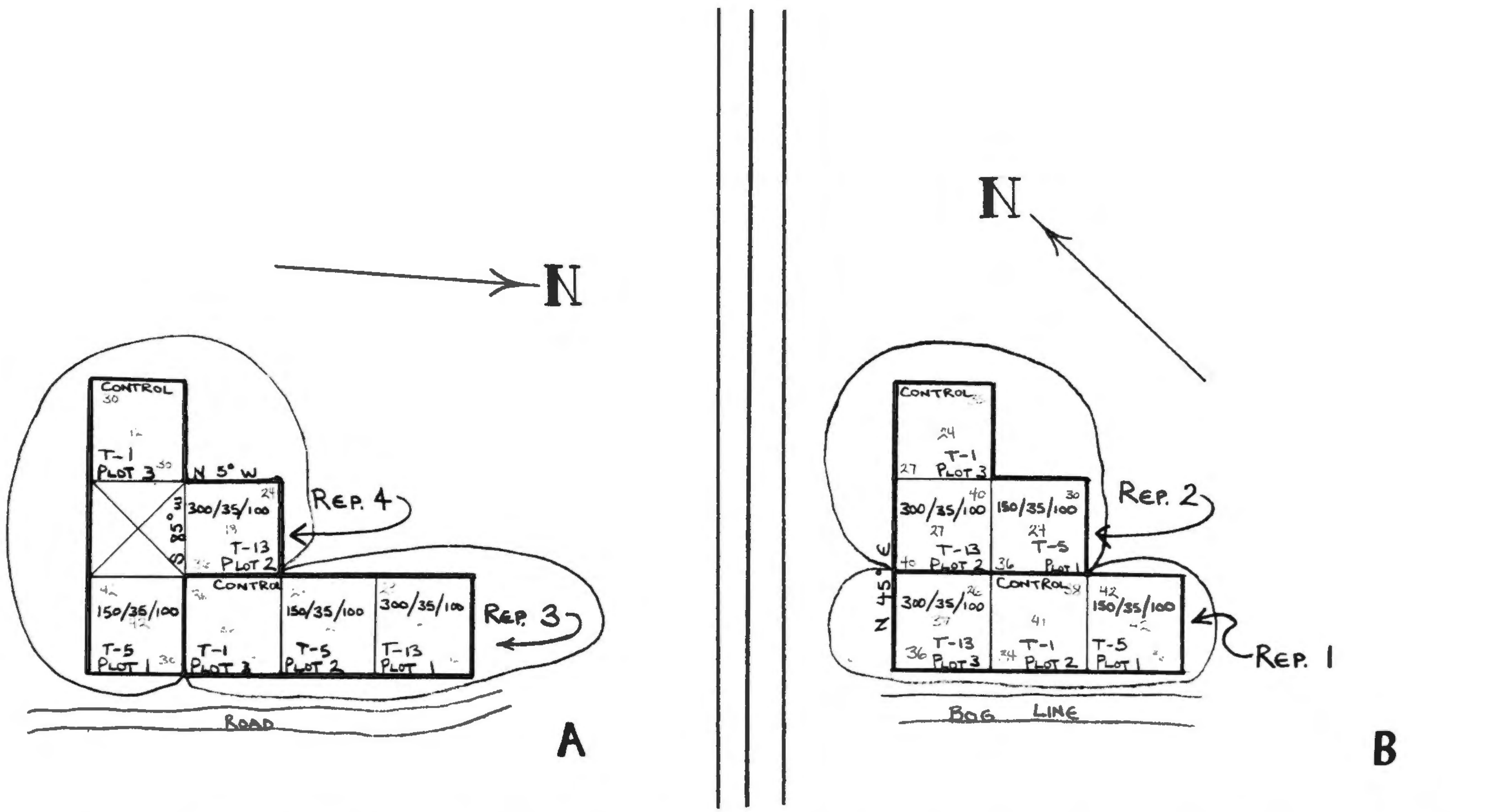


FIGURE 4. Schematic diagram of experimental plot layouts showing replications and treatment plot locations at the Satellite locations (A and B).

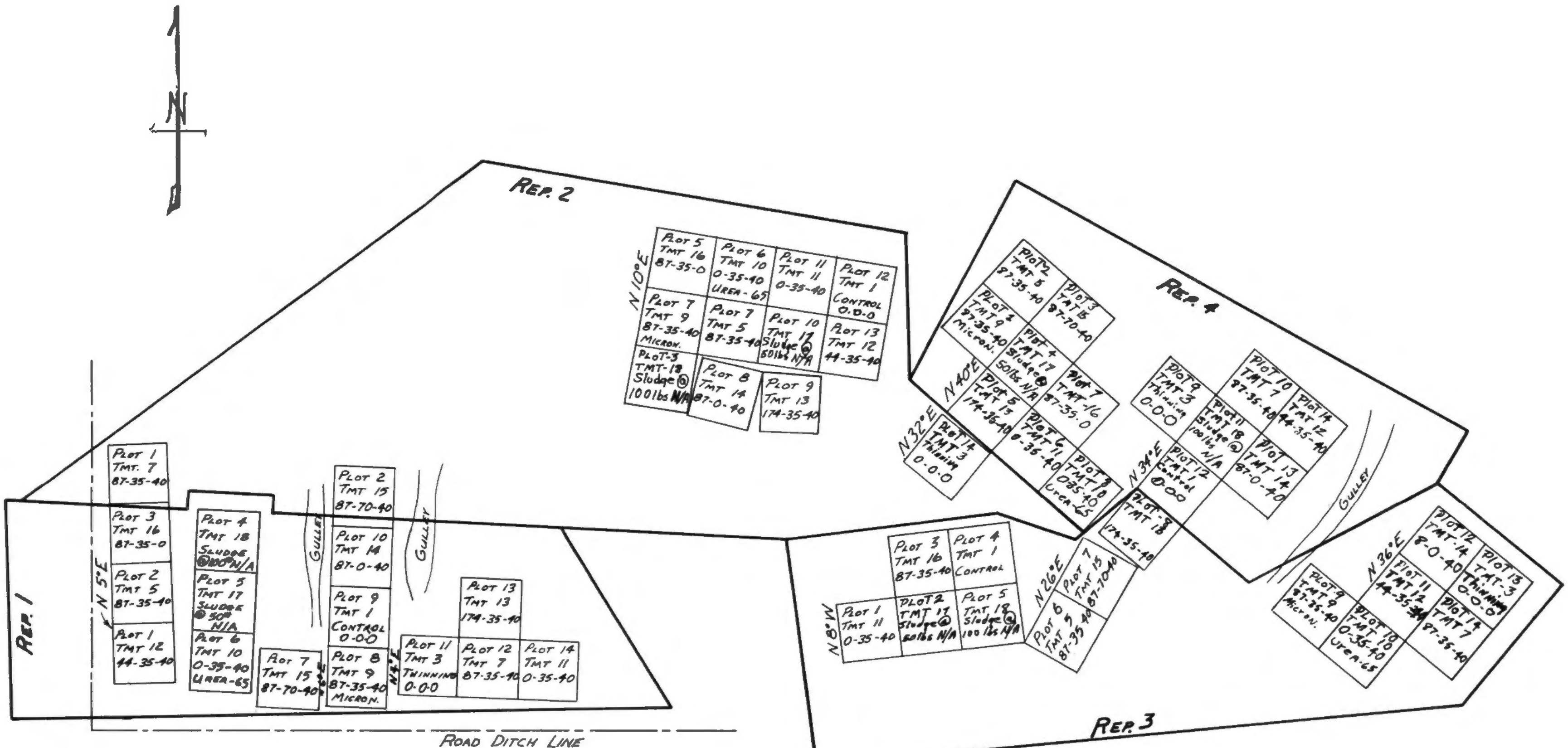


FIGURE 5. Schematic diagram of experimental plot layout showing replications and treatment plot locations at the Valley site.

the growth responses would be the highest the second year after treatment. Data were collected in 1973 and 1974 in order to determine if the responses were diminishing, stabilizing or increasing. Because no measurements were taken in 1972, increment cores were collected in 1974 to determine the growth for the 1972 and 1973 years separately. Soil samples were collected in 1969, 1972, 1973, 1974 and 1975 to determine the texture of the soils on the study sites and how long, and at what levels, the fertilizers applied remained in the soil.

Diameter Measurement

In each measurement plot, the diameter at 4.5 feet above the ground (DBH) was taken on all the dominant and codominant trees that were tagged. To assure remeasurement at the same height, the DBH level was marked with red paint. A D-tape was used to measure diameter to the nearest 0.1 inch. Diameter measurements were collected during the dormant season (December-January) in 1969 (before fertilization), and in 1970, 1971, 1973 and 1974 following fertilization.

A different procedure was used to collect diameter measurements in 1974. Instead of taking measurements on every tree that would probably be of merchantable volume at the first thinning, ten trees were selected from each measurement plot. To assure representative sampling, the diameter range in each treatment plot was divided into three equal classes and four trees in the upper diameter class, four in the middle class and two in the smallest class were randomly selected for measurement. The smaller sample in the smallest diameter class seemed appropriate since these trees were rapidly becoming suppressed. Because previous measurements indicated that the zero-N and the two sludge treatments (#11, #17 and #18, respectively), were giving poor responses, they were not remeasured in 1974.

Height Measurement

Height measurements were collected to the nearest foot on all sample trees. A telescoping measuring pole with a maximum height of 40 feet was used in 1969, 1970 and 1971. By 1973 the majority of the trees were over 40 feet tall, and the telescoping pole could not be used. A Christen Hypsometer modified to permit greater precision was used to measure height in 1973 and 1974.

Upper Stem Diameter Measurements

To determine if fertilization had an effect on stem form, ten trees within each measurement plot were randomly selected for measuring diameter at 17.3 feet above the ground line. Sample trees were marked with a red band painted around the tree just below DBH. In 1970 and 1971, the measurements were made with a caliper mounted on an aluminum pole and operated from the ground. Two measurements (90° apart) were taken on each sample tree and the average (nearest 0.1 inch) was recorded as the upper stem diameter measurement. In 1969 and 1973, a ladder was used to climb to the measurement point at 17.3 feet. A D-tape was used to measure the diameter to the nearest 0.1 inch.

Increment Core Collection and Measurements

In order to separate growth during the 1972 and 1973 seasons to enable plotting a growth curve with points for every year (no measurements were collected in 1972), increment cores were taken from the ten trees in each treatment plot that were measured in 1974. One increment core long enough to obtain the growth rings of 1972 and 1973 was taken from each tree. Core measurements consisted of obtaining the width (nearest 1/320 inch) of the 1972-1973 annual rings combined. The width of each separate ring (1972 and 1973) was then measured. The width of the 1972 (ring) was divided by the width of the two rings combined and multiplied by 100 to produce the percentage of growth that occurred in 1972. The ten percentages, one for each tree, were averaged to obtain the percentage of growth for each treatment plot for the 1972 season. This percentage was multiplied by the combined growth in 1972 and 1973 that had previously been obtained from diameter measurements following the 1973 season. This resulted in the amount of growth for that plot in the 1972 season. The growth that occurred in 1973 was calculated by subtracting the 1972 growth from the 1972-1973 combined growth.

Soil Samples

In August, 1969, samples of the A and B horizons were obtained from each treatment plot for chemical analysis. Physical analysis was also made on the Plateau samples. Three sample points within each plot were randomly selected and separate samples obtained of the two horizons. The three samples from the A1 horizon were thoroughly mixed and a single sample was taken from the composite to represent the plot. The same procedure was followed for the three samples from the B horizons.

In the spring of 1972, July, 1973, and September, 1974, the same sampling procedure was used to obtain samples of the A horizon from all three sites for chemical analysis. Samples collected in July, 1975 provided textural analysis for the soil at the Valley site.

The chemical analyses were conducted by the Agricultural Extension Service, Nashville, Tennessee, and included tests for pH, phosphorus and potassium. The hydrometer method for determining particle size distribution was used to determine the texture of the soil samples.

CHAPTER V

RESULTS AND DISCUSSION

Diameter, height, basal area and cubic volume growth were computed for all treatment plots for the 1970, 1971 and 1972-1973 growing seasons. Since trees were not measured following the 1972 season the measurement made following the 1973 season combined growth for 1972 and 1973. Encouraging responses over this four-year period plus the problem of separating growth for the 1972 and 1973 seasons prompted another remeasurement following the 1974 growing season in which the more promising treatment plots were remeasured and increment cores were taken to enable separation of the 1972-1973 growth. The plots dropped due to poor responses were the zero-N treatment (#11), sludge at 50# N/acre (#17), and sludge at 100# N/acre (#18). Four-year growth response is available on all treatments while five-year growth is available only on those plots considered to hold promise after four years.

Basal areas and cubic volumes were computed on the basis of the tree of average basal area and the tree of average cubic volume, respectively. The basal areas and cubic volumes are presented as averages for 1/10 acre treatment plots. In order to adjust to a per-acre basis, the values must be multiplied by 10. Basal area was computed by the formula, $0.005454\ D^2$. Since there was no difference in stem form between treated plots and control plots, the formula $0.0026638\ (D^2H)-0.6054$ (Smalley and Bower, 1968) was used to calculate cubic volume. Growth curves for diameter, height, basal area, cubic volume and merchantable cords over the five year period are in Appendix B.

Diameter growth is not a good indicator of response to treatments because it is strongly influenced by stand density. Height growth is a good measure of site quality and provides one measure of how treatment effects change with time. Basal area and cubic volume growth provide more meaningful evaluations of the effects of fertilizer treatments because stand density is a component of these measurements. Total cubic volume increments are the most meaningful indicators of treatment effects used in this report. A further refinement would be to determine the effects of fertilization on wood properties.

Plots which have large diameter growth may not have large basal area and/or cubic volume growth. Usually, greater diameter growth is achieved in a stand that is understocked. Since basal area and cubic volume growth are related to the number of stems in a stand, an open stand will likely have greater diameter growth but will have a smaller blow-up factor that may result in smaller basal area and/or cubic volume growth.

A Girard's Form Class (diameter outside bark at 17.3 feet divided by DBH at 4.5 feet) was used as a measure of stem form. Over a four-year period (1969-1973) growth differences due to treatments did not significantly change stem form. The analysis did confirm that growth was greater at 17.3 feet than at 4.5 feet resulting in a steadily increasing form class in all plots. On the Plateau site 98.5 percent of the plots grew an average of 0.21 inches more in four years at 17.3 feet than at 4.5 feet. The Satellite site plots grew an average of 0.21

inches more at upper stem diameter, and the Valley site plots grew an average of 0.35 inches more at 17.3 feet over the four-year period.

I. DIAMETER GROWTH

Table A-1 (Appendix A) shows the average diameter growth for five seasons. The average diameter growth in all treatments at the Plateau site was greater than in the control (Figure 6). The hardwood control plus basic fertilizer treatment (#6) provided the greatest diameter stimulus followed by the zero-K treatment (#16), High-P (#15) and hardwood control (#2). The diameter growth of the two hardwood control treatments (#6 and #2) may be related to decreased stand density due to pronounced snow breakage in plots receiving this treatment in 1971. The zero-K treatment (#16) provided a better growth stimulus than the high-K treatment (#5). This difference may be because the K element was added as a salt which could decrease water absorption by the tree and thus, decrease growth response. The high-P (#15) increased in diameter response ranking the last year of the study. This increase, plus the decrease in ranking for the low-P treatment (#14) the last year, may indicate that phosphorus remains in the system and is important in maintaining a prolonged diameter response. The high-N treatment (#13) gave a relatively poor diameter response for the five-year period. Growth response in this treatment peaked in the third season and has declined the fourth and fifth seasons. This decline could suggest that the N applied was lost from the system or was utilized by some other organism. Where N was applied as urea (#10), diameter response increased in rank the fifth season and is higher than ammonium nitrate for the five-year total.

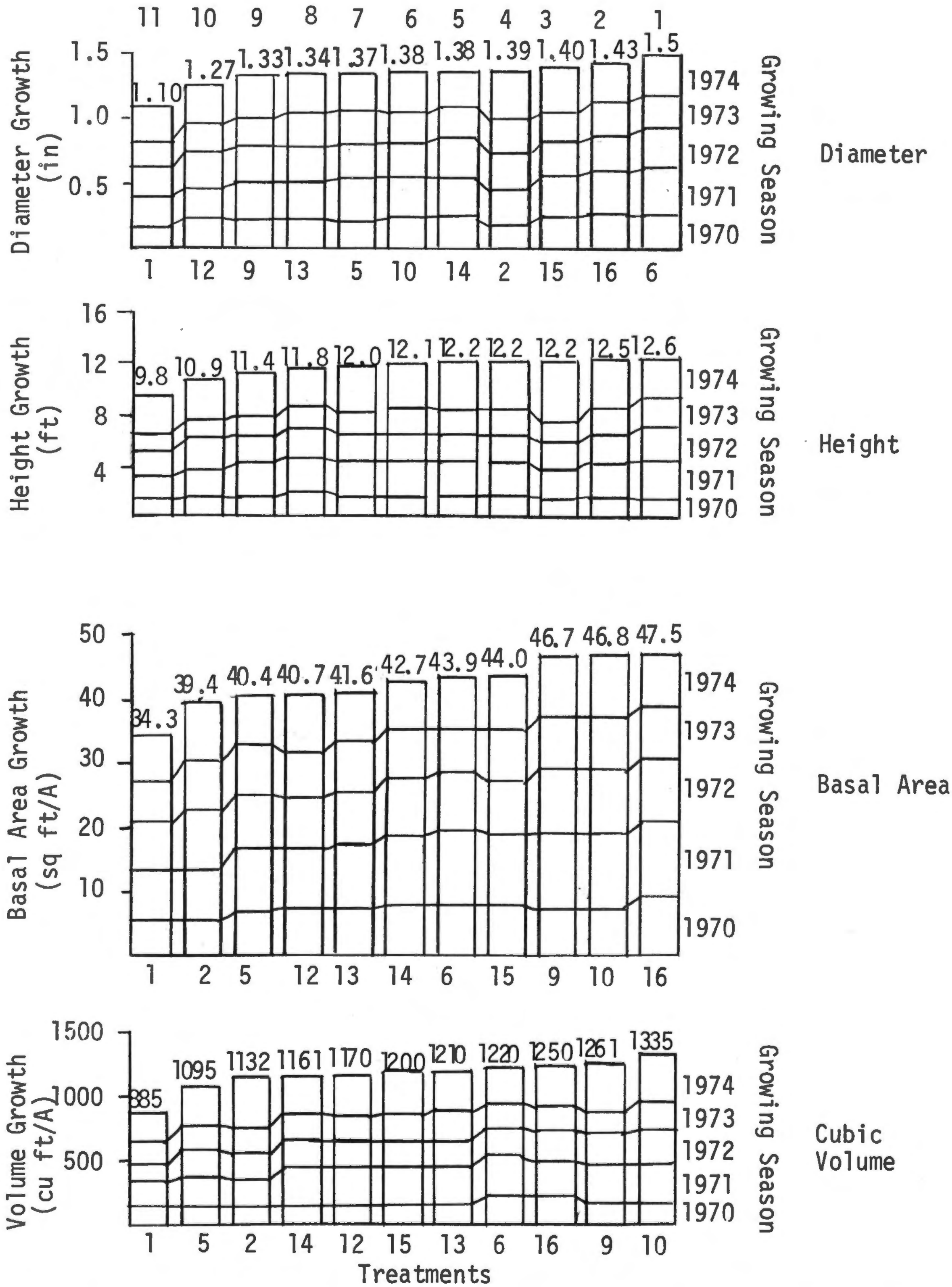


FIGURE 6. Diameter, height, basal area and volume growth for 5 years with treatments arranged by increasing growth for the Plateau site.

Perhaps the more slowly available urea-form keeps the nitrogen in the system and provides a diameter stimulus for a longer period. Diameter responses were poorest in the micronutrient treatment (#9) and the low-N (#12).

The two treatments applied to the Satellite site, basic (#5) and high-N (#13) gave the same diameter response over control (18 percent) (Figure 7). The difference between the responses of the two treatments and the control has decreased the last two years of study.

All treatments stimulated diameter growth at the Valley site (Figure 8). The thinning plus basic fertilizer treatment (#7) gave the greatest growth stimulus. Micronutrients (#9), thinning (#3), and the high-N (#13) followed treatment #7 in stimulating diameter growth. Although the high diameter responses in the thinned plots (#3 and #7) are largely due to decreased stand density following thinning, fertilization apparently gave an added stimulus. Diameter responses were good throughout the study in the micronutrient treatment which may suggest that the microelements are low and, when added, could increase the diameter response to the macroelement fertilizer. The high-N treatment (#13) gave the fourth highest diameter response. Apparently, the Valley site utilized more of the nitrogen and kept it in the system better than the Plateau site. Although urea (#10) stimulated a smaller total response than where N was added as ammonium nitrate (treatment #5), it increased in rank the fourth year which indicates that the urea may provide a stimulus for a longer period. The poor performance of the high P-treatment in stimulating a diameter response appears to be

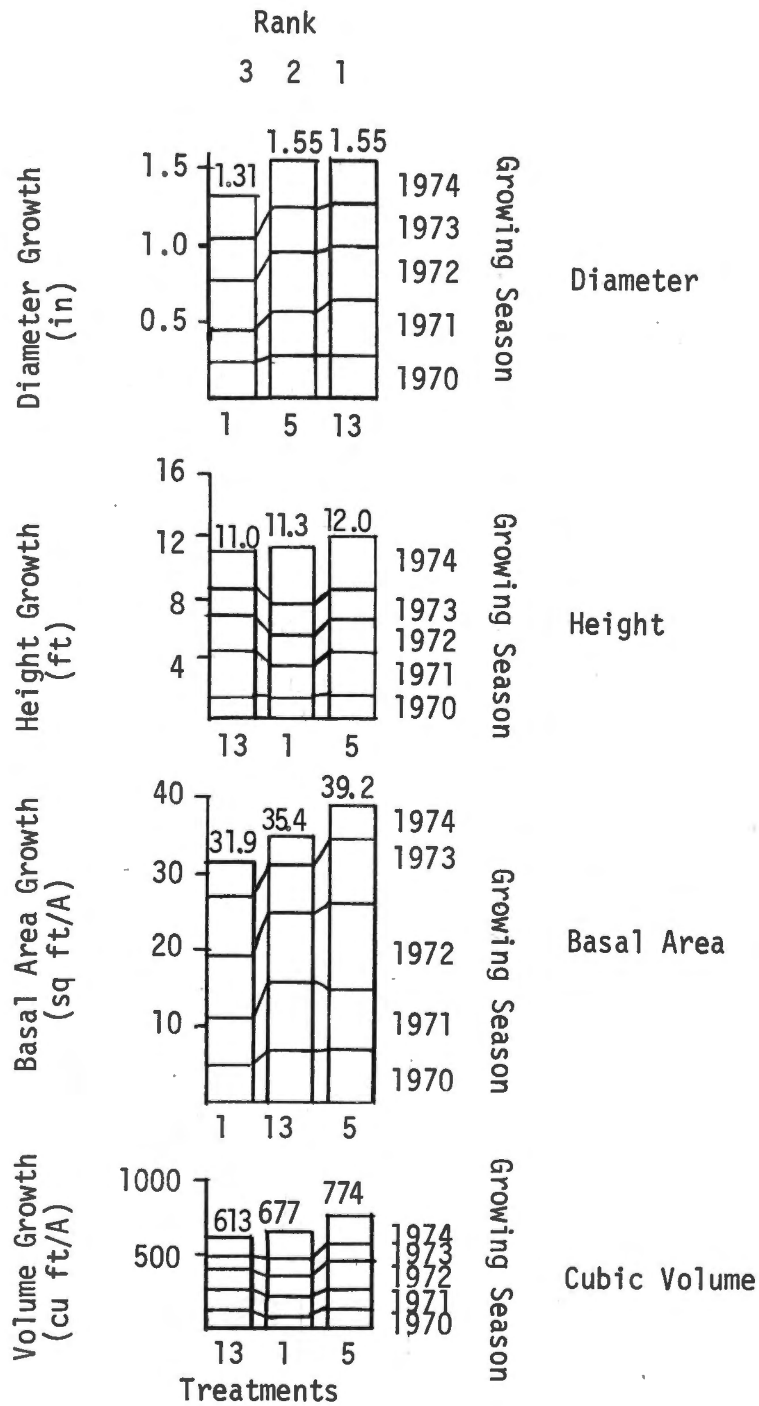


FIGURE 7. Diameter, height, basal area and volume growth for 5 years with treatments arranged by increasing growth for the Satellite site.

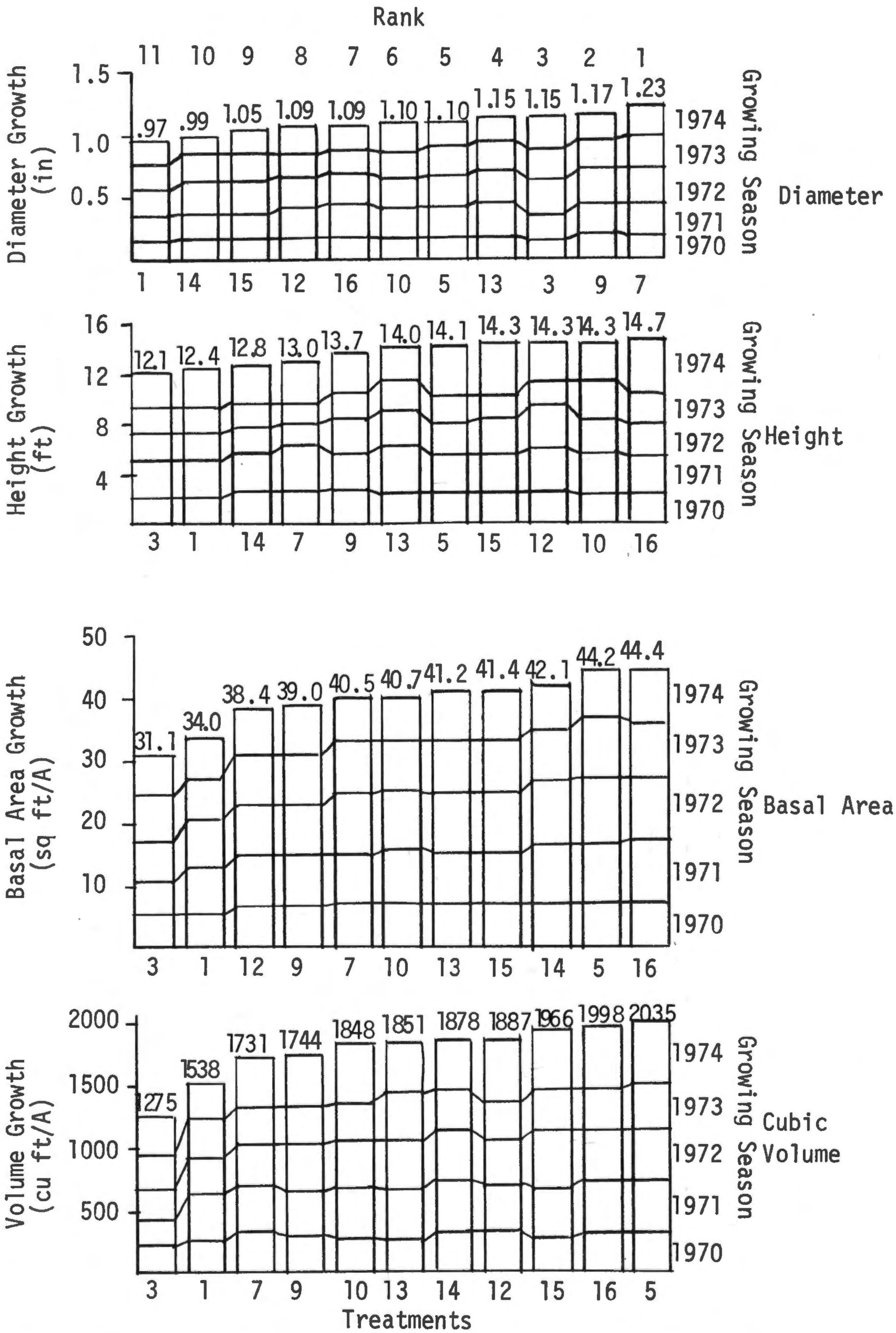


FIGURE 8. Diameter, height, basal area and volume growth for 5 years with treatments arranged by increasing growth for the Valley site.

related to stand density as it ranked considerably higher where height, basal area and volume are the measurement criteria (Figure 8).

II. HEIGHT GROWTH

Height growth for the five-year study period is given in Table A-2. P may be important to height growth since the high-P treatment was ranked first and the low-P treatment was ranked tenth at the Plateau site (Figure 6, page 57). The urea-N treatment gave a greater height growth response than the basic treatment (N as ammonium nitrate). The high-N treatment and low-N treatment were in intermediate and low positions relative to the control. The hardwood control treatment (#2) ranked third while the hardwood control plus fertilizer treatment (#6) ranked eight. The zero-K and micronutrient treatments gave intermediate height growth responses.

The basic treatment (#5) gave an 8 percent greater height growth response than the control at the Satellite site (Figure 7). The high-N treatment had 3 percent less height growth than the control.

The zero-K treatment (#16) gave the largest height growth response at the Valley site and appeared to be stimulating a response in the last year of study (Figure 8). N applied as urea (treatment #10) provided a greater and more uniform response than N applied as ammonium nitrate. The various N-levels, 75, 150, and 300 pounds per acre (treatments 12, 5 and 13, respectively), appeared equally effective in stimulating height growth.

These results suggest that high nitrogen levels are not effective in stimulating height growth and may be lost to leaching. As was true for the Plateau site, it appears that P may be important for height growth because the high-P treatment (#15) was ranked fourth and the basic (#5) and low-P (#14) treatments were ranked fifth and ninth, respectively. Height growth in the thinning treatment (#13) was slightly less than that of the control (#1), where thinned plots were fertilized (#7); however, there was a 7 percent increase over control.

III. BASAL AREA GROWTH

Table A-3 presents average basal area growth over five years for 1/10 acre treatment plots. The three best basal area growth responses for the Plateau site were supplied by the zero-K treatment (#16), N as urea (#10) and micronutrients (#9) where increases over control were 39, 36 and 36 percent, respectively (Figure 6, page 57, and Tables A-3 and C-3). Again, the urea-N (#10) treatment appeared to give a greater stimulus the last year. The micronutrient treatment provided a large stimulus to basal area growth on the Plateau site throughout the study. The high-P treatment (#15) was ranked higher than the two lower levels of P which indicates that the lack of P may be limiting growth at the Plateau site. Also, the zero-P (treatment #14) dropped in response relative to the other treatments the last year of the study which suggests that P is needed to provide a lasting basal area growth response. There is no evidence that K is increasing growth since the five-year growth response was greatest in the zero-K treatment (#16). Basal area growth in the hardwood control treatments (without and with fertilizer) was influenced by a snow storm in 1971 that broke many stems in the plots and reduced stand stocking. The high-N (#13) and low-N (#12) treatments provided 3 percent and 1 percent increases over the basic treatment, considerably less than the response to urea.

The basic treatment (#5) provided a 23 percent increase in basal area growth over the control at the Satellite site (Figure 7, page 59), and Tables A-3 and C-4). The high-N treatment (#13) increased growth only 11 percent indicating that on dry sites high N-levels provide less stimulus than do lower levels.

Although the thinning treatment (#3) yielded 9 percent less basal area growth than the control at the Valley site over the five-year period, it had greater growth than the control and the minus-P (#14) treatments the fifth year (Figure 8, page 60, and Table A-3). This suggests that it takes approximately three years for the basal area growth of thinned plots to regain the growth loss due to thinning. The thinning plus fertilizer treatment (#7) surpassed the control in basal area growth the growing season following thinning which indicates that the basal area growth loss due to thinning can be minimized with fertilization. The zero-K treatment (#16) gave the largest basal area growth over control at the Valley site (31 percent) and was followed by the basic (#5) and zero-P (#14) treatments (30 and 24 percent, respectively). The ability of the zero-P treatment (#14) to rank third for five years' growth may reflect fertilizer applications made while the area was a cultivated field. Phosphorus is not highly mobile in the soil, especially where there is a significant clay content. The urea-N treatment (#10) ranked sixth for the five-year study period but improved in response ranking the last year. Nitrogen as urea may increase basal area growth over a longer period when compared to the other treatments. The basic N-level (#5) stimulated a higher basal area growth response than either the high-N (#13) or the low-N (#12) treatments, suggesting that this N-level may approach the optimum for stimulating basal area growth.

IV. CUBIC VOLUME GROWTH

Table A-4 shows cubic volume growth for 1/10 acre treatment plots over five years. All treatments stimulated growth over that of the control for the five-year study period on the Plateau site (Figure 6, page 57). The control plots grew at an average rate of 2.21 cds/A/yr (Table A-5) for five years (assuming 80 cu ft of solid wood per cord). The urea-N treatment (#10) provided the best cubic volume growth over control (51 percent) for five years (average 3.34 cds/A/yr) followed by micronutrient (42 percent) and zero-K (41 percent) treatments. These three treatments were consistently in the higher ranks when compared to control for each of the five growing seasons. The high-N (#13) and hardwood control plus fertilizer treatment (#6) were next in cubic volume growth. In the hardwood control plots growth may have been decreased by the snow storm in 1971 which broke and eliminated some of the stems. Cubic volume growth in the hardwood control plot with fertilizer was 37 percent more than in the control, and in the hardwood control plot without fertilizer (#2) it was 28 percent more than control. The high-N treatment (#13) ranked fifth for the five-year period but its influence decreased slightly dropping its ranking the last two years of the study (Figure B-8). With such heavy applications (3-0 pounds of N/A) there is probably a large N-loss as this element is highly mobile in the soil. The zero-P treatment (#14) also had its largest cubic volume response over control the third year with a slight decline in response the fourth and fifth years (Figure B-9).

At the Satellite site, volume growth averaged 1.69 cds/A/yr in the control plots for five seasons (Table A-5). Fertilization at the basic rate (150-35-100) increased volume growth 14 percent over control (Figure 7, page 59). The high-N treatment (#13) (300-35-100) grew 9 percent less than the control. The high-N treatment had less cubic volume growth than the control for the third, fourth and fifth seasons (Figure B-13). The basic treatment (#5) had less growth than the control the fifth season (Figure B-12). Since the Satellite site was selected to represent a dry ridge these results suggest that on such severe sites increased nutrient levels will give only short lived responses and may even decrease yields.

Growth in control plots at the Valley site averaged 3.85 cds/A/yr for five years (Table A-4) which is 1.64 cords more per acre per year than in controls on the Plateau site. Absolute growth increases due to treatments were also greater at the Valley site (Tables A-4 and A-5) although percentage increases were generally greater on the Plateau (Table C-5). Since average diameter growth was considerably better on the Plateau than at the Valley and height growth was only slightly better at the Valley site, the greater volume growth at the Valley reflects the better stocking at this site. The basic treatment (#5) provided the best cubic volume growth for five seasons, 32 percent over control (5.09 cds/A/yr) followed by a 30 percent increase from the zero-K (#16) and a 28 percent increase from the high-P (#15). These three treatments were consistently in the top ranks for stimulating cubic volume growth in the individual study years (Figure 8, page 60). The low-N treatment (#12) gave a better response over control than the high-N treatment (#13), 23 and 20 percent, respectively. The high-N treatment (#13) was no more effective in stimulating volume growth than were treatments receiving low N-levels (#5 and #12) (Table A-4). The urea-N treatment ranked seventh for the five-year period and did not show any evidence of stimulating a prolonged cubic volume response. The micronutrient treatment gave a low response over the control (13 percent). Volume growth in the thinned-only treatment was 17 percent less than that of the control, but when fertilizer was added the growth was 12 percent greater than that of the control. These results suggest that fretilization can more than regain the cubic volume growth lost when thinning occurs.

Noteworthy is the very large increase in cubic volume growth the fifth season in all treatment plots with only a small increase in the control (Table A-4).

V. SOIL ANALYSIS

Textural analysis indicated that both the A and B horizons at both locations was a loam.

The pH values did not appear to be significantly different among treatments or between years for the three sites (Table E-2). The high-P treatment (#15) was significantly higher in pounds of P per acre than the other treatments at both the Plateau and Valley sites. There was a substantial decrease in pounds per acre of P and K in 1974, which may indicate that the elements were being leached into the B horizon by the fifth year after fertilization.

K-levels were fairly uniform at all sampling dates and were without apparent relationship to applied K.

VI. STATISTICAL ANALYSIS

Table C-1 shows the results of an analysis of variance of growth over the five-year study period. Tables C-2, C-3, C-4 and C-5 present the Duncan's New Multiple Range Test (5 percent level) for diameter, height, basal area and volume growth.

Although the Plateau site had a highly significant difference in diameter growth and a significant difference in height growth, there was no significant difference in basal area or cubic volume growth. The Plateau plots had a greater percentage increase in basal area and cubic volume growth over control than did the Valley plots (Tables C-4 and C-5), yet the Valley had highly significant differences in basal area and cubic volume growth and the Plateau did not. The apparent reason for this seeming anomaly is the uniform stocking at the Valley site and the highly variable stocking on the Plateau. This highly variable stocking at the Plateau site masked the effects of the treatments and prohibited the basal area and cubic volume responses from being significant.

VII. ECONOMIC ANALYSIS

The economic analysis conducted in this section assumes a commercial operation likely to be conducted by an industrial firm. Therefore, several direct costs were assumed at this scale.

Three direct costs which would be incurred in the fertilization operation are: (1) fertilizer, (2) dissemination, and (3) administration.

Fertilizer prices used in this analysis were those obtained in September, 1975 from the Tennessee Valley Authority, Muscle Shoals, Alabama. The prices were as follows: (1) Ammonium Nitrate--\$138/ton; (2) urea--\$160/ton; (3) concentrated superphosphate--\$158.40/ton; and (4) muriate of potash--\$96/ton. The micronutrient mixture price (\$220/ton) was obtained from the Eagle Pitcher Company, Joplin, Missouri.

Two dissemination costs (7¢/pound of fertilizer and 3¢/pound of fertilizer) and two administration costs (\$2/acre and \$1.75/acre) were used to calculate the economic returns. The dissemination prices were for application of the fertilizers by helicopter.

Two profit criteria, internal rate of return and cost-price, were used to evaluate the economic feasibility of the treatments. Each criterion has been discussed in the Literature Review Chapter. The internal rates of return for three response periods were calculated using two costs and two revenues (Tables D-1 and D-2). The formula used to calculate the internal rate of return is:

$$i = 100\left(\sqrt[n]{Y/AC} - 1\right) .$$

Where: n = number of years investment carried

Y = value of increased stumpage (based on stumpage price of \$10/cord and \$15/cord

AC = fertilization costs.

The cost-price criterion was used with two interest rates (.06 and .10) and two costs (high and low, as discussed) and were calculated for 10, 15 and 20 year response periods (Tables D-3 and D-4). The cost-price formula is (Lundgren, 1973):

$$Pn = C\ (1 + r)^n / Vn.$$

The ten-year response period assumes that the growth of the treatments over that of the control gradually dropped to no difference by the end of the ten years (25-year rotation). The 15-year period assumes that the growth response over control drops to zero 15 years after fertilization (30-year rotation). The 20-year planning period assumes that the growth response of the treatments over that of the control does not drop but maintains itself at the rate of growth found the fifth year after treatment as determined from a growth response curve. This response pattern is probable where one or more elements are critically low and, once added, they remain in the nutrient cycle resulting in a growth stimuli for an indefinite period.

The treatments that gave the most profitable internal rates of return and cost-price ratios at the Plateau site were: urea-N (#10), low-N (#12) and zero-K (#16) (Tables D-1 and D-3). A major reason why these treatments provided a higher return rate was because less fertilizer was applied than in most other treatments (except treatment #14 (150-0-100) which gave a poor response). The cost of application is substantially reduced when rates are lowered resulting in decreased overall costs and increased internal rates of return and cost-price ratios. As would be expected, a greater rate of return and cost-price ratio resulted when the treatment was assumed to respond at a high level to a 35-year rotation age. Because of their short duration and low response, the treatments at the Satellite site were unfeasible economically, given the assumption of the analysis.

The Valley site had more treatments having high return rates than did the Plateau (Tables D-2 and D-4). The zero-K (#16), basic (#15), low-N (#12), and zero-P (#14) treatments gave the highest returns. Again, fertilization rates were lower in these treatments. As was true on the Plateau, the best internal rate of return or cost-price ratio was found when the rotation lasted 35 years, the costs were minimum, the revenue was maximum and the interest rate was the lowest.

The treatments that gave the highest economic returns (#10--Plateau and #16--Valley) were used to analyze the economic feasibility[1] for 25, 30 and 35 year rotations and with the further assumption of no additional response after the last measurement (5-year response period). The 5-year response period was not feasible for any of the rotations at either site (Tables 2 and 3). The 10-year response period was marginally feasible for the 25-year rotation and unfeasible for the other two rotations on the Plateau site. On the Valley site, the 10-year response became economically feasible for the 25- and 30-year rotations using the high stumpage values and low cost assumptions. The 15-year response periods approached economic reasibility for the 30- and 35-year rotations at both sites especially assuming low costs and high returns. Where the response level five years after treatment is projected to a 35-year rotation age (20-year response period) both methods project a favorable economic return on the investment (Tables 2 and 3). The internal rates of return were highest when the spreading costs were low and the revenues

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[1]Economic feasibility is considered to be a return of 6 percent or more.

TABLE 2. Internal rate of return for the Plateau and Valley sites for: three rotation periods (25, 30, 35 years); four response periods (5, 10, 15, 20 years); two spreading costs: (1) 7¢/lb and $2/A administration, (2) 3¢/lb and $1.75/A administration; and two returns ($10/cord and $15/cord).

No.	Treatment Description N-P-K	Material (lbs/A)	Rotation (Yrs)	Response Period (Yrs)	Increase Over Control (cds/A)	COST: 7¢/lb & $2/A, Revenue $10/cd, Internal Rate of Return (%)	COST: 7¢/lb & $2/A, Revenue $15/cd, Internal Rate of Return (%)	COST: 3¢/lb & $1.75/A, Revenue $10/cd, Internal Rate of Return (%)	COST: 3¢/lb & $1.75/A, Revenue $15/cd, Internal Rate of Return (%)
Plateau						Cost=$101.17/A		Cost=$72.72/A	
10	150(Urea)-35-100	705	25	5	5.6	-[a]	-	2.3	1.4
				10	9.1	-	3.0	2.3	6.5
			30	5	5.6	-	-	-	0.9
				10	9.1	-	2.0	1.5	4.3
				15	14.7	2.5	5.3	4.8	7.7
			35	5	5.6	-	-	-	0.5
				10	9.1	-	1.5	1.1	3.2
				15	14.7	2.0	4.0	3.6	5.7
				20	24.6	4.5	6.7	6.3	8.5
Valley						Cost=$88.53/A		Cost=$63.88/A	
16	150-35-0	610	25	5	5.7	-	-	-	2.9
				10	11.3	2.5	6.7	5.9	9.3
			30	5	5.7	-	-	-	1.9
				10	11.3	1.6	4.4	3.8	6.9
				15	18.3	5.0	7.9	7.3	10.2
			35	5	5.7	-	-	-	1.5
				10	11.3	1.2	3.3	2.8	5.0
				15	18.3	3.7	5.8	5.4	7.5
				20	31.2	6.5	8.7	8.3	10.5

[a]Cost greater than benefit.

TABLE 3. Cost-price analysis for the Plateau and Valley sites for: three rotation periods (25, 30, 35 years); four response periods (5, 10, 15, 20 years); two spreading costs: (1) 7¢/lb and $2/A administration, (2) 3¢/lb and $1.75/A administration; and two interest rates (6 percent and 10 percent).

No.	Treatment Description N-P-K	Material (lbs/A)	Rotation (Yrs)	Response Period (Yrs)	Increase Over Control (cds/A)	COST: 7¢/lb & $2/A Revenue 6% Stumpage Price Needed	COST: 7¢/lb & $2/A Revenue 10% Stumpage Price Needed	COST: 3¢/lb & $1.75/A Revenue 6% Stumpage Price Needed	COST: 3¢/lb & $1.75/A Revenue 10% Stumpage Price Needed
Plateau						Cost=$101.17/A		Cost=$72.72/A	
10	150(Urea)-35-100	705	25	5	5.6	32.34	46.79	23.24	33.63
				10	9.1	19.90	28.79	14.30	20.70
			30	5	5.6	43.36	75.52	31.17	54.28
				10	9.1	26.68	46.47	19.18	33.40
				15	14.7	16.52	28.77	11.87	20.68
			35	5	5.6	57.99	121.58	41.68	87.39
				10	9.1	35.69	74.82	25.65	53.78
				15	14.7	22.09	46.32	15.88	33.29
				20	24.6	13.20	27.68	9.49	19.89
Valley						Cost=$88.53/A		Cost=$63.88/A	
16	150-35-0	610	25	5	5.7	27.80	40.23	20.06	29.03
				10	11.3	14.02	20.29	10.12	14.64
			30	5	5.7	37.27	64.92	26.90	46.85
				10	11.3	18.80	32.75	13.57	23.63
				15	18.3	11.61	20.22	8.38	14.59
			35	5	5.7	49.86	104.53	35.45	75.42
				10	11.3	25.15	52.72	18.15	38.04
				15	18.3	15.53	32.56	11.20	23.49
				20	31.2	9.11	19.09	6.57	13.78

were high. The cost-price ratio was more economically feasible when the costs and interest rates were low.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Various fertilizer and cultural treatments were applied to 14-year-old loblolly pine plantations on the Cumberland Plateau and in the Great Valley of East Tennessee. Diameter and height measurements were taken for five years following fertilization in order to assess the growth responses to the individual treatments. Although diameter, height and basal area growth were calculated, cubic volume growth was the most meaningful parameter for evaluating response to treatment. Diameter at 17.3 feet was measured for four years following fertilization in order to determine if fertilization had any effect on stem form.

The major findings from the study are summarized as follows:

1. There was no significant difference in stem form (diameter at 17.3 feet minus diameter at 4.5 feet) between the treatment plots and the control plots although 99.5 percent of the plots (treatment and control) grew more at 17.3 feet than at 4.5 feet.

2. Fertilizer application on dry sites (Satellite plots) provided responses of short duration. The high-N level appeared to suppress growth; it grew less in cubic volume than did the control the third, fourth and fifth seasons. These results indicate that fertilization of dry sites on the Cumberland Plateau is not economically feasible.

3. N as urea at 150 pounds per acre gave the best cubic-volume growth response on the Plateau site when compared to the other N

treatments. The urea form may provide a stimulus for a longer period of time. The high-N treatment on the Plateau declined in response the last two years of the study indicating that the high level of highly double N was probably lost from the cycle.

4. Micronutrients appeared to provide a greater growth stimulus on the Plateau than at the Valley.

5. K additions did not provide a growth stimulus over that provided by N and P.

6. The zero-P treatment dropped in response over control the fourth and fifth years, and the high-P treatment increased in response the later years of the study. These results suggest that P may be necessary to obtain a prolonged growth response.

7. The Valley site is naturally more productive than the Plateau site and plantation stocking was much higher since trees were planted on an old field where hardwood competition was absent. In general, while percentage response was greater on the Plateau, absolute volume response was greater at the Valley site.

8. 150 N/A appears to be the best N level for the Valley site. The low-N gave a better response than the high-N level. The urea-N treatment did not show any evidence of giving a prolonged volume response at the Valley site but did on the Plateau.

9. The results from the thinning treatments (without and with fertilizer) suggest that fertilization can stimulate rapid recovery of the volume-growth loss that usually follows thinning.

10. The results of the analysis of variance of basal area and cubic volume growth response on the Plateau site may have been masked by the highly variable stand densities.

11. The treatments that applied smaller amounts of fertilizer per acre appeared to be more economically feasible. The most economical treatments on the Plateau site appeared to be the N as urea, low-N and the zero-K. At the Valley site the treatments that appeared most promising economically were the zero-K, basic, low-N and zero-P.

12. Several treatments should be further tested at the Plateau site. The urea-N treatment should be followed to determine if it is going to continue to provide a response. Study of the micronutrient treatment should be continued to determine if it will continue to give the high response after five years that it did during the study period. Since K additions did not provide a growth response over the zero-K, the zero-K treatment should be remeasured. Treatments testing various P-levels should be further investigated since there is some indication that P may be necessary to maintain prolonged volume response. The basic treatment should also be remeasured to provide data for comparisons.

13. The Satellite site should not be remeasured because the growth of the treatments was less than that of the control the fifth year.

14. The basic, zero-K, high-P, low-N and zero-P should be studied for a longer period of time at the Valley site. These treatments were providing the largest volume responses at the end of the fifth year. Further study will be necessary to determine whether the high-P treatment will continue to maintain volume response at a high level while that in the zero-P decreases.

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APPENDICES

APPENDIX A

DIAMETER, HEIGHT, BASAL AREA, CUBIC VOLUME AND MERCHANTABLE CORD GROWTH FOR THE THREE LOCATIONS

TABLE A-1. Five seasons diameter growth for planted loblolly pine arranged by treatments for the three locations.

Treatment No.	Description	Original DBH	DBH Growth 1st Year	2nd Year	3rd Year	4th Year	5th Year	Total	Final DBH
Plateau									
1	Control	4.91	.18	.22	.22	.19	.30	1.10	6.01
2	Hardwood Control (HC)	5.05	.19	.27	.28	.26	.38	1.39	6.44
5	150-35-100	4.89	.21	.33	.27	.24	.32	1.37	6.26
6	150-35-100-HC	5.08	.26	.36	.30	.26	.37	1.55	6.63
9	150-35-100-Micro	4.68	.21	.30	.28	.21	.34	1.33	6.01
10	150(Urea)-35-100	5.02	.24	.32	.26	.22	.35	1.38	6.40
11	0-35-100	5.00	.18	.25	.21[a]	.21[a]	-	.85[b]	5.85[b]
12	75-35-100	4.93	.23	.24	.26	.22	.32	1.27	6.20
13	300-35-100	4.99	.23	.28	.28	.25	.29	1.34	6.33
14	150-0-100	5.03	.25	.30	.31	.24	.31	1.38	6.41
15	150-70-100	4.90	.24	.32	.26	.23	.35	1.40	6.30
16	150-35-0	4.85	.28	.32	.29	.23	.33	1.43	6.28
Satellite									
1	Control	4.52	.22	.22	.32	.26	.29	1.31	5.83
5	150-35-100	4.63	.27	.31	.37	.29	.29	1.55	6.18
13	300-35-100	4.31	.28	.34	.37	.27	.30	1.55	5.86
Valley									
1	Control	6.53	.16	.20	.21	.20	.18	.97	7.50
3	Thinning (T)	6.53	.16	.19	.27	.27	.28	1.15	7.68
5	150-35-100	6.59	.19	.23	.26	.23	.19	1.12	7.71
7	150-35-100-T	6.59	.19	.24	.29	.27	.25	1.23	7.82
9	150-35-100-Micro	6.63	.20	.25	.26	.23	.24	1.17	7.80
10	150(Urea)-35-100	6.44	.18	.23	.25	.21	.23	1.10	7.54
11	0-35-100	6.29	.16	.18	.20[a]	.20[a]	-	.74[b]	7.03[b]
12	75-35-100	6.73	.19	.22	.25	.22	.22	1.09	7.82
13	300-35-100	6.40	.19	.26	.26	.23	.21	1.15	7.55
14	150-0-100	6.23	.17	.21	.24	.21	.16	.99	7.22
15	150-70-100	6.49	.18	.21	.25	.21	.20	1.05	7.54
16	150-35-0	6.16	.20	.25	.24	.20	.21	1.09	7.25
17	Sludge @ 50# N/A	6.45	.15	.18	.21[a]	.21[a]	-	.75[b]	7.20[b]
18	Sludge @ 100# N/A	6.43	.16	.20	.23[a]	.23[a]	-	.82[b]	7.25[b]

[a]1972-1973 growth divided by two.

[b]Based on four years growth.

TABLE A-2. Five seasons height growth for planted loblolly pine arranged by treatments.

Treatment No.	Description	Original Height	Height Growth 1st Year	2nd Year	3rd Year	4th Year	5th Year	Total	Final Height
Plateau									
1	Control	32.8	1.3	2.0	1.79	1.61	3.0	9.8	42.6
2	Hardwood Control (HC)	32.5	1.5	2.4	2.06	1.84	4.4	12.2	44.7
5	k59-35-100	32.3	1.9	2.4	2.26	1.94	3.7	12.2	44.5
6	150-35-100-HC	33.2	2.0	2.7	2.28	1.92	3.0	11.8	45.0
9	150-35-100-Micro	32.0	1.7	2.7	2.15	1.65	3.9	12.0	44.0
10	150(Urea)-35-100	30.8	1.6	2.6	2.43	2.07	3.9	12.4	43.2
11	0-35-100	32.6	1.7	2.0	1.8[a]	1.8[a]	-	7.3[b]	39.9[b]
12	75-35-100	32.8	1.6	2.5	2.11	1.79	3.3	11.4	44.2
13	300-35-100	33.0	1.6	2.7	2.45	2.15	3.2	12.1	45.1
14	150-0-100	33.2	1.8	2.1	2.19	1.71	3.1	10.9	44.1
15	150-70-100	33.0	1.6	3.1	2.38	2.12	3.6	12.6	45.6
16	150-35-0	32.1	1.9	2.6	2.29	1.81	3.6	12.2	44.3
Satellite									
1	Control	29.3	1.4	2.2	2.20	1.80	3.8	11.3	40.6
5	150-35-100	30.0	1.5	2.7	2.44	1.86	3.1	12.0	42.0
13	300-35-100	28.6	1.5	2.9	2.49	1.81	2.4	11.0	39.6
Valley									
1	Control	43.7	2.1	3.0	2.21	2.09	2.6	12.4	56.1
3	Thinning (T)	43.7	2.1	3.0	2.07	2.03	3.2	12.1	55.8
5	150-35-100	43.8	2.5	3.0	2.52	2.18	3.1	14.1	57.9
7	150-35-100(T)	43.8	2.5	3.7	1.82	1.68	3.1	13.0	56.8
9	150-35-100-Micro	43.2	2.9	2.8	2.50	2.20	3.3	13.7	56.9
10	150(Urea)-35-100	44.0	2.3	3.3	2.62	2.18	3.9	14.3	58.3
11	0-35-100	41.8	2.3	2.5	2.1[a]	2.0[a]	-	8.9[b]	50.7[b]
12	75-35-100	44.5	2.7	3.3	2.31	2.09	3.9	14.2	58.7
13	300-35-100	43.7	2.4	3.7	2.86	2.54	2.9	14.0	57.7
14	150-0-100	42.4	2.5	3.1	2.21	1.89	3.1	12.8	55.2
15	150-70-100	43.2	2.4	3.0	2.78	2.32	3.7	14.2	57.4
16	150-35-0	41.9	2.4	3.0	2.63	2.17	4.5	14.7	56.6
17	Sludge @ 50# N/A	43.3	2.4	3.4	2.3[a]	2.2[a]	-	10.3[b]	53.6[b]
18	Sludge @ 100# N/A	43.5	2.7	2.7	2.3[a]	2.2[a]	-	9.9[b]	53.4[b]

[a]1972-1973 growth divided by 2.

[b]Based on four years growth.

TABLE A-3. Five seasons basal area growth for 1/10 acre measurement plots arranged by treatments. (Multiply values by 10 to place on an acre basis.)

Treatment No.	Description	Original Basal Area	Basal Area Growth 1st Year	2nd Year	3rd Year	4th Year	5th Year	Total	Final Basal Area
Plateau									
1	Control	7.69	.59	.74	.72	.64	.74	3.43	11.12
2	Hardwood Control (HC)	7.01	.56	.79	.87	.78	.97	3.94	10.95
5	150-35-100	7.02	.66	1.02	.84	.72	.82	4.04	11.06
6	150-35-100-HC	7.41	.80	1.14	.89	.75	.86	4.39	11.80
9	150-35-100-Micro	8.06	.76	1.15	1.03	.79	.98	4.68	12.74
10	150(Urea)-35-100	8.17	.79	1.14	.96	.81	.99	4.68	12.85
11	0-35-100	8.20	.63	.89	.78[a]	.78[a]	-	3.08[b]	11.28[b]
12	75-35-100	7.99	.77	.85	.85	.72	.89	4.07	12.06
13	300-35-100	7.47	.75	.94	.90	.78	.80	4.16	11.63
14	150-0-100	7.93	.80	1.02	.92	.76	.74	4.27	12.20
15	150-70-100	7.47	.80	1.07	.89	.80	.91	4.41	11.88
16	150-35-0	7.97	.96	1.15	.99	.79	.86	4.75	12.72
Satellite									
1	Control	5.86	.54	.59	.86	.70	.53	3.19	9.05
5	150-35-100	5.89	.70	.83	1.08	.82	.53	3.92	9.81
13	300-35-100	5.39	.69	.91	.90	.65	.40	3.54	8.93
Valley									
1	Control	11.83	.58	.72	.73	.70	.63	3.40	15.23
3	Thinning (T)	11.83	.58	.47	.71	.69	.73	3.11	14.94
5	150-35-100	12.65	.76	.93	1.05	.90	.78	4.42	17.07
7	150-35-100-T	12.65	.76	.74	.96	.89	.79	4.05	16.70
9	150-35-100-Micro	10.94	.65	.86	.87	.76	.74	3.90	14.84
10	150(Urea)-35-100	12.04	.71	.89	.94	.79	.81	4.07	16.11
11	0-35-100	11.69	.62	.69	.79[a]	.78[a]	-	2.88[b]	14.57[b]
12	75-35-100	11.57	.67	.81	.86	.77	.75	3.84	15.41
13	300-35-100	11.00	.65	.92	.94	.84	.78	4.12	15.12
14	150-0-100	13.04	.71	.91	1.04	.89	.70	4.21	17.25
15	150-70-100	12.48	.69	.83	1.00	.84	.79	4.14	16.62
16	150-35-0	11.96	.78	.99	1.00	.84	.87	4.44	16.40
17	Sludge @ 50# N/A	11.91	.58	.70	.80[a]	.80[a]	-	2.88[b]	14.79[b]
18	Sludge @ 100# N/A	11.89	.60	.79	.85[a]	.84[a]	-	3.08[b]	14.97[b]

[a]1972-1973 growth divided by 2.

[b]Based on four years growth.

TABLE A-4. Five seasons cubic volume growth for 1/10 acre measurement plots arranged by treatments. (Multiply values by 10 to place on an acre basis.)

Treatment No.	Treatment Description	Original Volume	Volume (Cu Ft) Growth 1st Year	2nd Year	3rd Year	4th Year	5th Year	Total	Final Volume
Plateau									
1	Control	100.7	14.1	19.0	16.5	14.7	24.5	88.5	189.2
2	Hardwood Control (HC)	92.7	15.1	23.4	20.3	18.1	36.2	113.2	205.9
5	150-35-100	92.5	15.4	24.1	20.3	17.4	32.3	109.5	202.0
6	150-35-100-HC	99.0	21.4	32.2	21.1	17.8	28.8	121.6	220.6
9	150-35-100-Micro	103.4	19.0	27.9	24.1	18.4	36.6	126.1	229.5
10	150(Urea)-35-100	108.1	19.3	30.2	25.2	21.4	38.3	133.5	241.6
11	0-35-100	106.5	16.2	22.3	18.5[a]	18.4[a]	-	75.4[b]	181.9
12	75-35-100	105.2	18.6	24.7	21.6	18.3	33.7	116.8	222.0
13	300-35-100	95.2	18.1	25.5	24.7	21.6	31.0	120.9	216.1
14	150-0-100	106.2	18.9	25.8	23.9	18.7	28.8	116.1	222.3
15	150-70-100	98.9	16.7	27.4	22.3	19.8	33.2	119.6	218.5
16	150-35-0	102.8	21.3	28.8	23.1	18.3	33.3	124.8	227.6
Satellite									
1	Control	66.5	9.2	12.3	14.3	11.7	20.2	67.7	134.2
5	150-35-100	66.2	11.4	16.6	16.9	12.8	19.6	77.4	143.6
13	300-35-100	59.2	11.6	16.3	12.6	9.1	11.8	61.4	120.6
Valley									
1	Control	199.9	26.9	34.9	31.3	29.6	31.2	153.9	353.8
3	Thinning (T)	199.9	21.3	22.4	25.5	25.0	33.3	127.5	327.4
5	150-35-100	212.1	30.5	42.1	41.5	35.9	53.4	203.6	415.7
7	150-35-100-T	212.1	33.1	36.9	32.5	29.9	40.8	173.2	385.4
9	150-35-100-Micro	185.8	30.1	37.1	35.1	31.0	41.2	174.5	360.3
10	150(Urea)-35-100	204.8	28.1	40.9	36.8	30.7	48.4	184.9	389.7
11	0-35-100	190.4	26.6	30.6	29.4[a]	29.4[a]	-	116.0[b]	306.4
12	75-35-100	198.8	31.2	39.1	35.7	32.1	50.6	188.7	387.5
13	300-35-100	187.1	26.5	42.3	39.6	35.2	41.5	185.1	372.2
14	150-0-100	211.0	31.2	42.3	38.3	32.9	43.1	187.6	398.6
15	150-10-100	207.2	29.5	39.7	42.9	35.7	48.8	196.6	403.8
16	150-35-0	199.2	30.5	41.4	40.1	33.1	54.6	199.8	399.0
17	Sludge @ 50# N/A	199.7	26.9	34.8	33.6[a]	33.6[a]	-	128.9[b]	328.6
18	Sludge @ 100# N/A	200.3	29.1	35.1	34.2[a]	34.2[a]	-	132.6[b]	332.9

[a]1972-1973 growth divided by 2.

[b]Based on four years growth.

TABLE A-5. Five seasons cords growth for 1/10 acre measurement plots arranged by treatments. (Multiply values by 10 to place on an acre basis.)

Treatment No.	Description	Original Cords/ Plot	Cords Growth 1st Year	2nd Year	3rd Year	4th Year	5th Year	Total	Final Cords/ Plot
Plateau									
1	Control	1.26	.18	.24	.21	.18	.31	1.12	2.36
2	Hardwood Control (HC)	1.16	.19	.29	.25	.23	.45	1.41	2.57
5	150-35-100	1.16	.19	.30	.25	.22	.40	1.36	2.52
6	150-35-100-HC	1.24	.27	.40	.26	.22	.36	1.51	2.76
9	150-35-100-Micro	1.29	.24	.35	.30	.23	.46	1.58	2.87
10	150(Urea)-35-100	1.35	.24	.38	.31	.27	.47	1.67	3.02
11	0-35-100	1.33	.20	.28	.23[a]	.23[a]	-	.94[b]	2.27
12	75-35-100	1.31	.23	.31	.27	.23	.42	1.46	2.77
13	300-35-100	1.19	.23	.32	.31	.27	.39	1.52	2.70
14	150-0-100	1.33	.24	.32	.30	.23	.36	1.45	2.78
15	150-70-100	1.24	.21	.34	.28	.25	.42	1.50	2.73
16	150-35-0	1.28	.27	.36	.29	.23	.42	1.57	2.84
Satellite									
1	Control	0.83	.11	.15	.18	.14	.25	.83	1.68
5	150-35-100	0.83	.14	.21	.21	.16	.24	.96	1.79
13	300-35-100	0.74	.14	.20	.16	.11	.15	.76	1.51
Valley									
1	Control	2.50	.34	.44	.39	.37	.39	1.93	4.42
3	Thinning (T)	2.50	.27	.28	.32	.31	.42	1.60	4.09
5	150-35-100	2.65	.38	.53	.52	.45	.67	2.55	5.20
7	150-35-100-T	2.65	.41	.46	.41	.37	.51	2.16	4.82
9	150-35-100-Micro	2.32	.38	.46	.44	.39	.51	2.18	4.50
10	150(Urea)-35-100	2.56	.35	.51	.46	.38	.60	2.30	4.87
11	0-35-100	2.38	.33	.38	.36[a]	.36[a]	-	1.43[b]	3.83
12	75-35-100	2.48	.39	.49	.44	.40	.63	2.35	4.84
13	300-35-100	2.34	.33	.53	.49	.44	.52	2.31	4.65
14	150-0-100	2.64	.39	.53	.48	.41	.54	2.35	4.98
15	150-70-100	2.59	.37	.50	.54	.45	.60	2.46	5.05
16	150-35-0	2.49	.38	.52	.50	.41	.68	2.49	4.99
17	Sludge @ 50# N/A	2.49	.34	.43	.42[a]	.42[a]	-	1.61[b]	4.11
18	Sludge @ 100# N/A	2.50	.36	.44	.43[a]	.43[a]	-	1.66[b]	4.16

[a]1972-1973 combined growth divided by 2.

[b]Based on four years growth.

APPENDIX B

GROWTH CURVES FOR THE FIVE-YEAR STUDY PERIOD FOR DIAMETER, HEIGHT, BASAL AREA, CUBIC VOLUME AND MERCHANTABLE CORDS

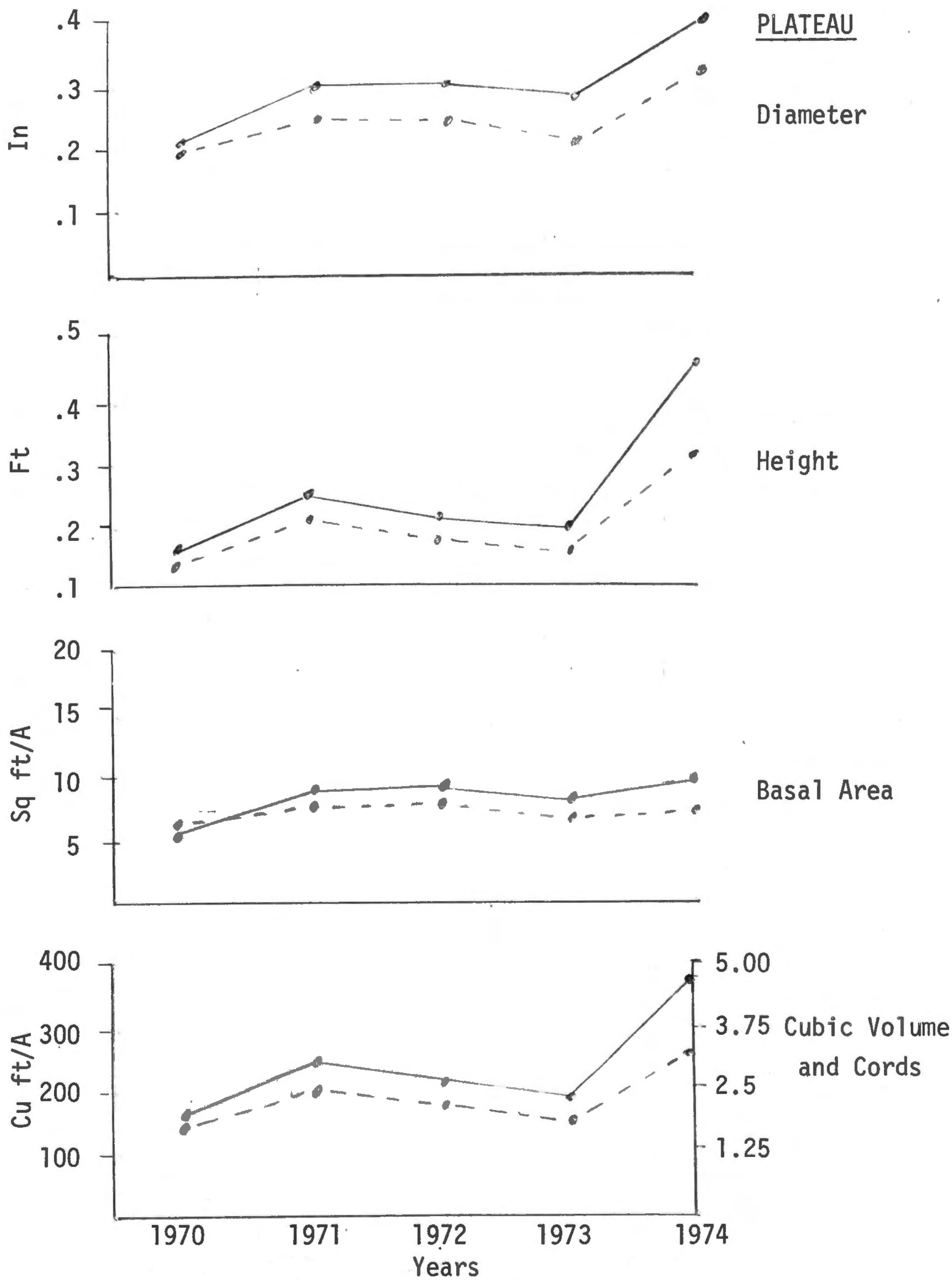

FIGURE B-1. Diameter, height, basal area and volume growth over 5 years for hardwood control treatment (-) as compared to control (---).

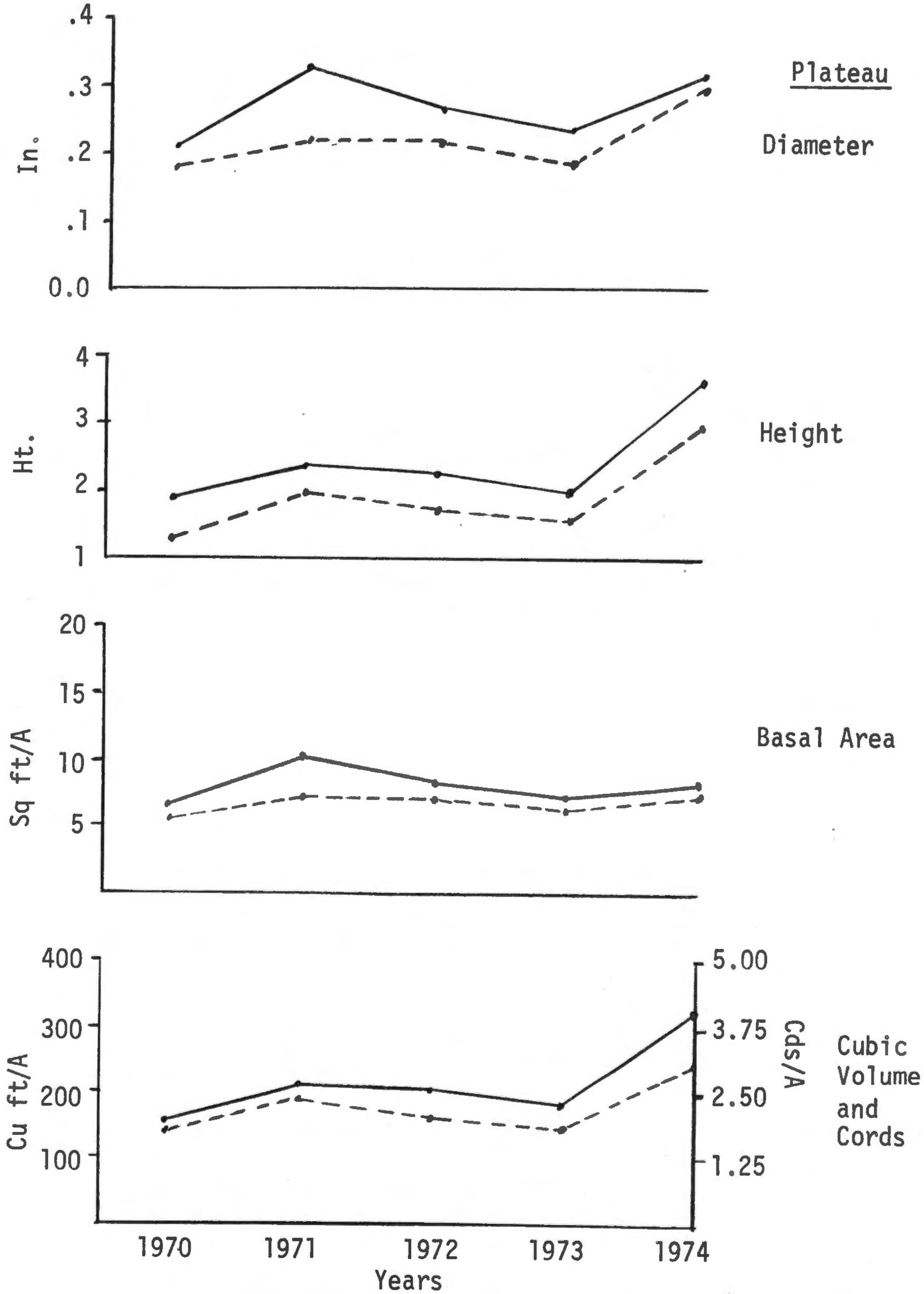

FIGURE B-2. Diameter, height, basal area and volume growth over 5 years for 150-35-100 treatment (——) as compared to control (---).

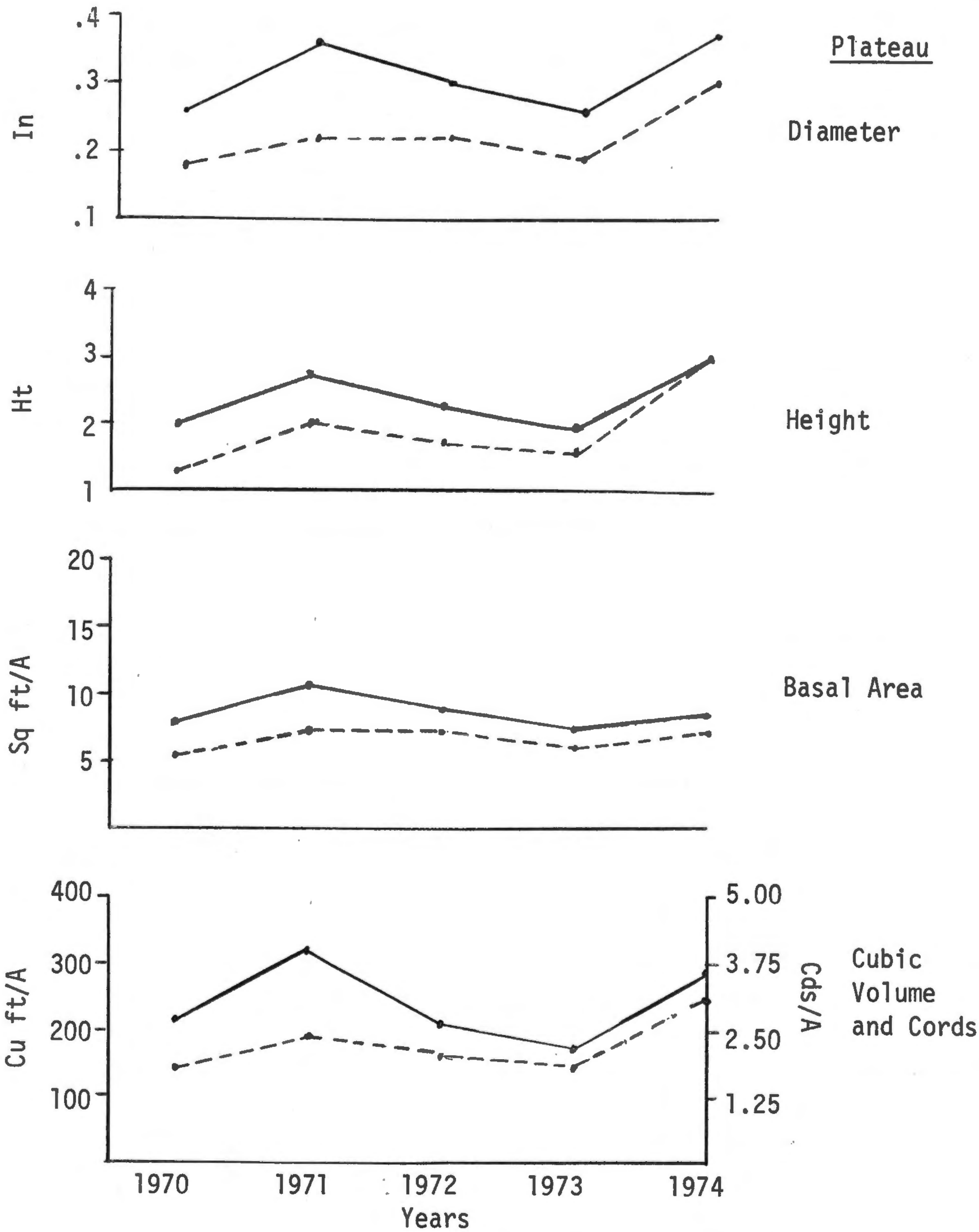

FIGURE B-3. Diameter, height, basal area and volume growth over 5 years for 150-35-100-HC treatment (——) as compared to control (---).

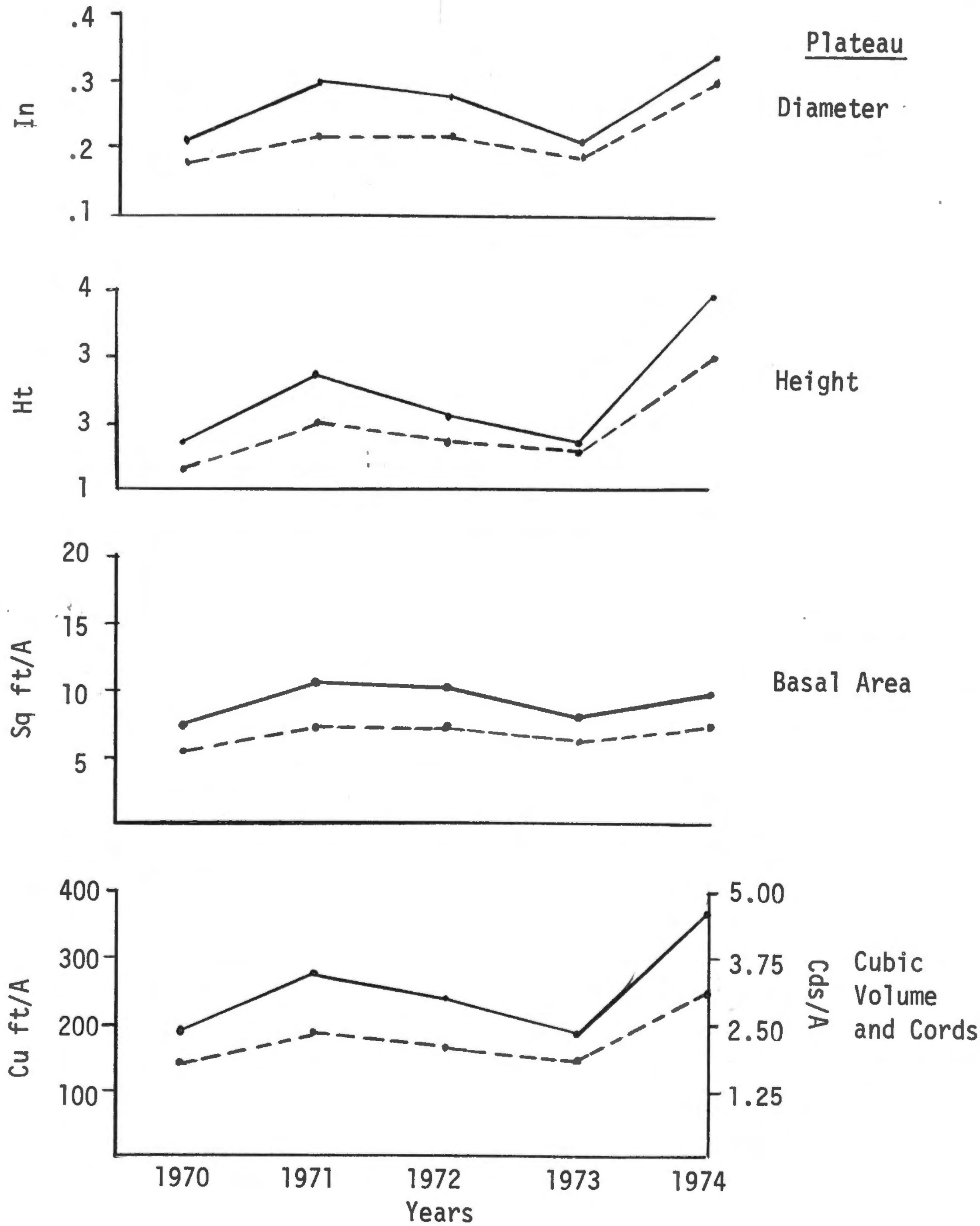

FIGURE B-4. Diameter, height, basal area and volume growth over 5 years for 150-35-100-Micro treatment (——) as compared to control (---).

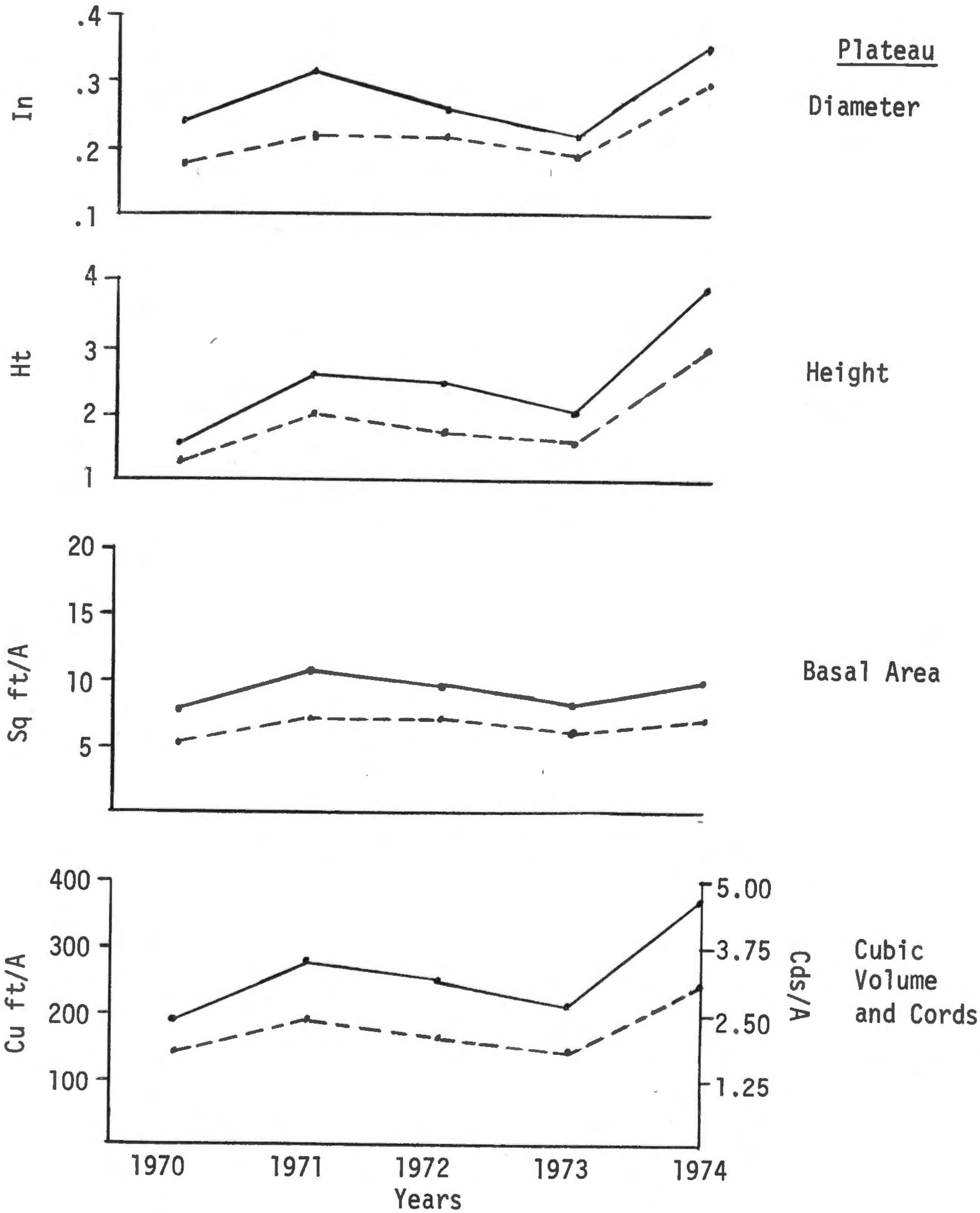

FIGURE B-5. Diameter, height, basal area and volume growth over 5 years for 150(Urea)-35-100 treatment (——) as compared to control (---).

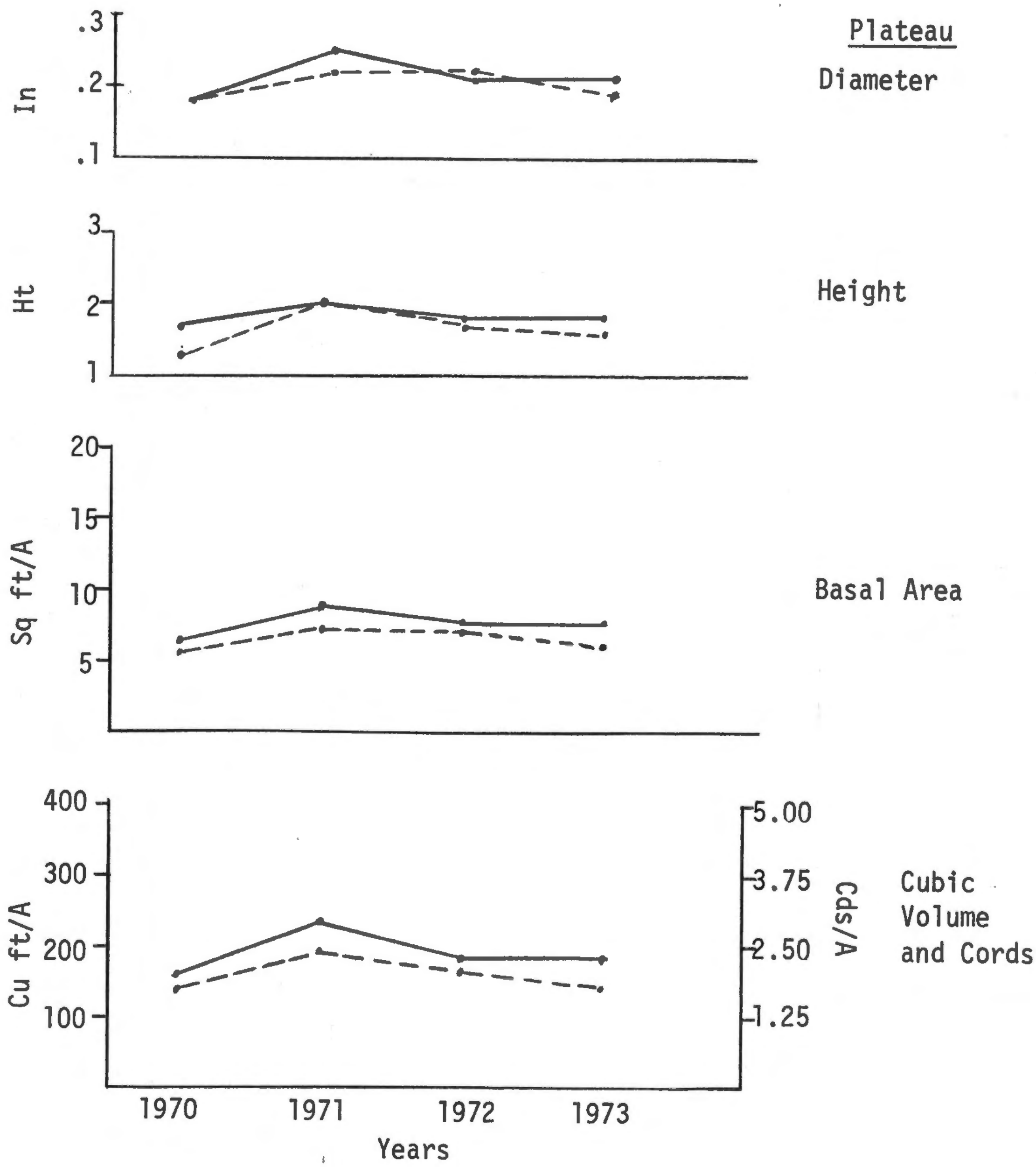

FIGURE B-6. Diameter, height, basal area and volume growth over 4 years for 0-35-100 treatment (——) as compared to control (---).

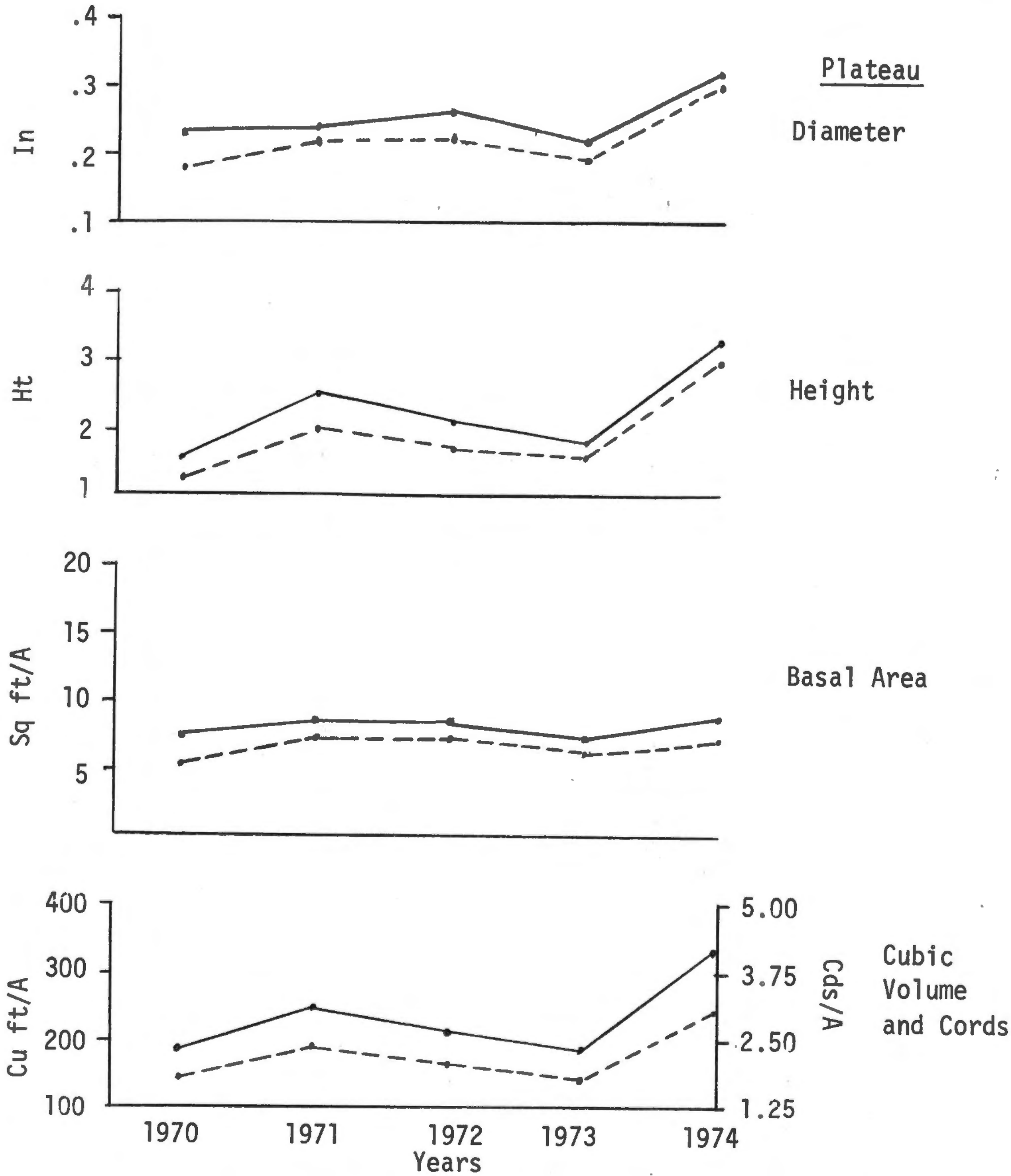

FIGURE B-7. Diameter, height, basal area and volume growth over 5 years for 75-35-100 treatment (——) as compared to control (---).

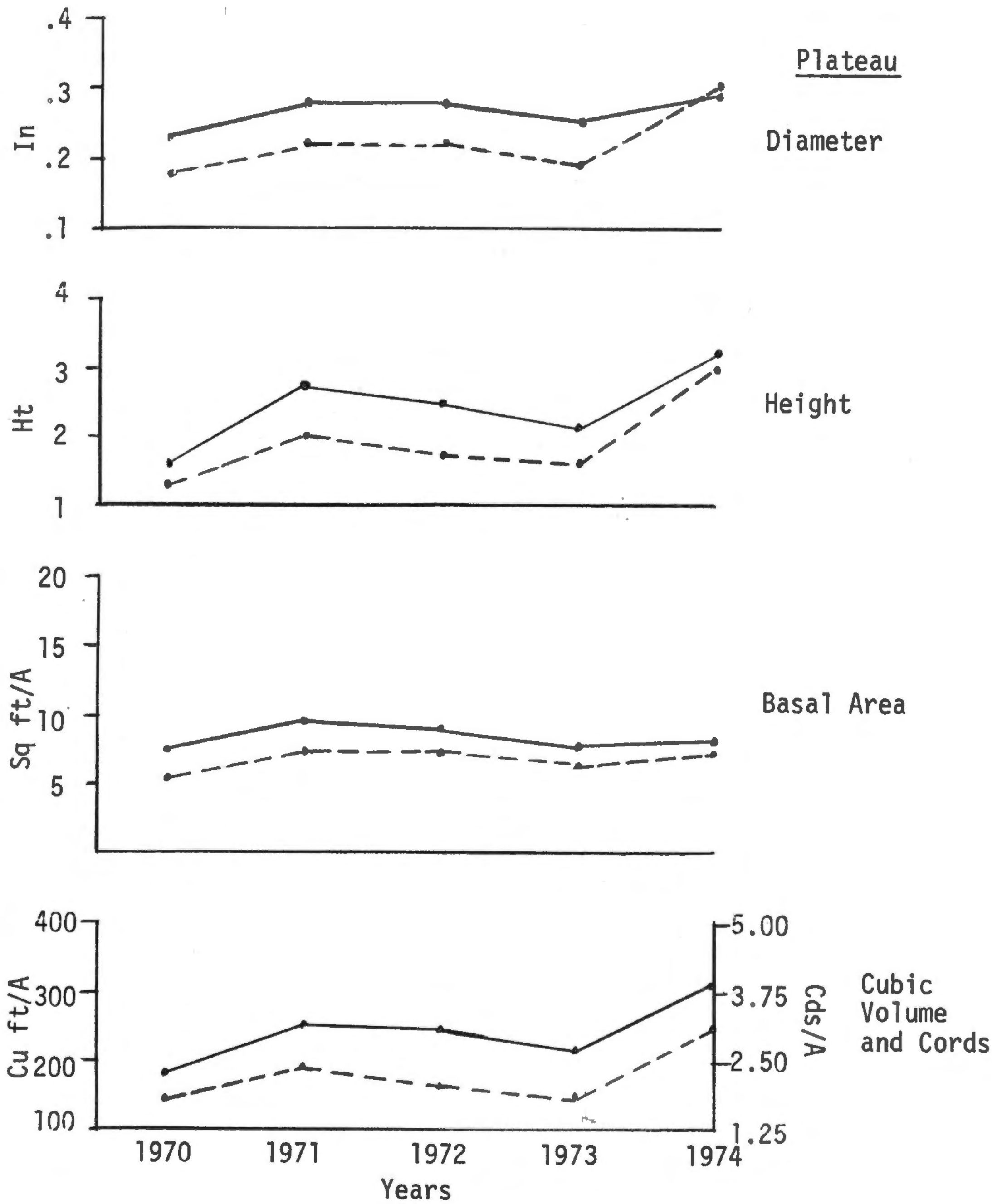

FIGURE B-8. Diameter, height, basal area and volume growth over 5 years for 300-35-100 treatment (——) as compared to control (---).

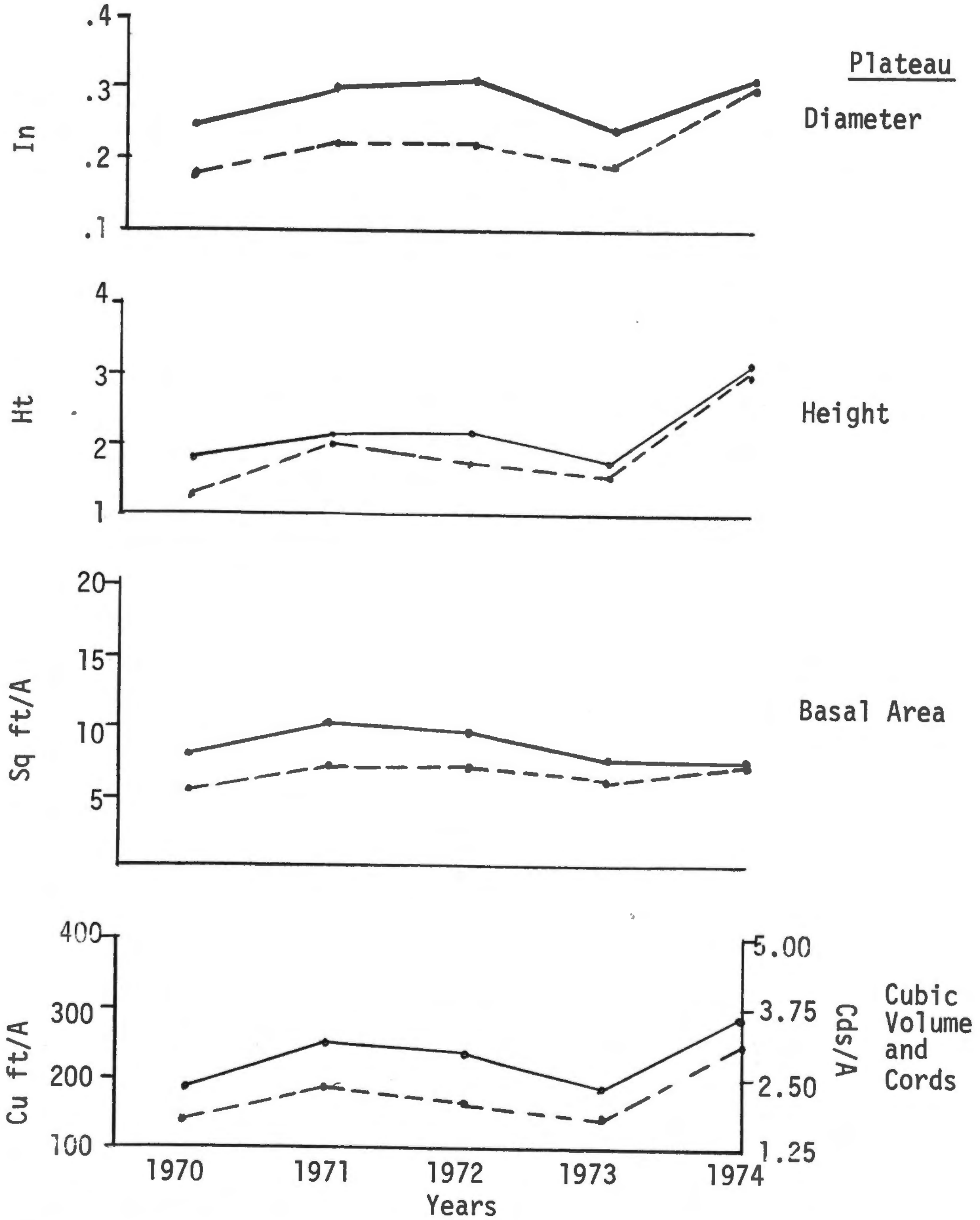

FIGURE B-9. Diameter, height, basal area and volume growth over 5 years for 150-0-100 treatment (——) as compared to control (---).

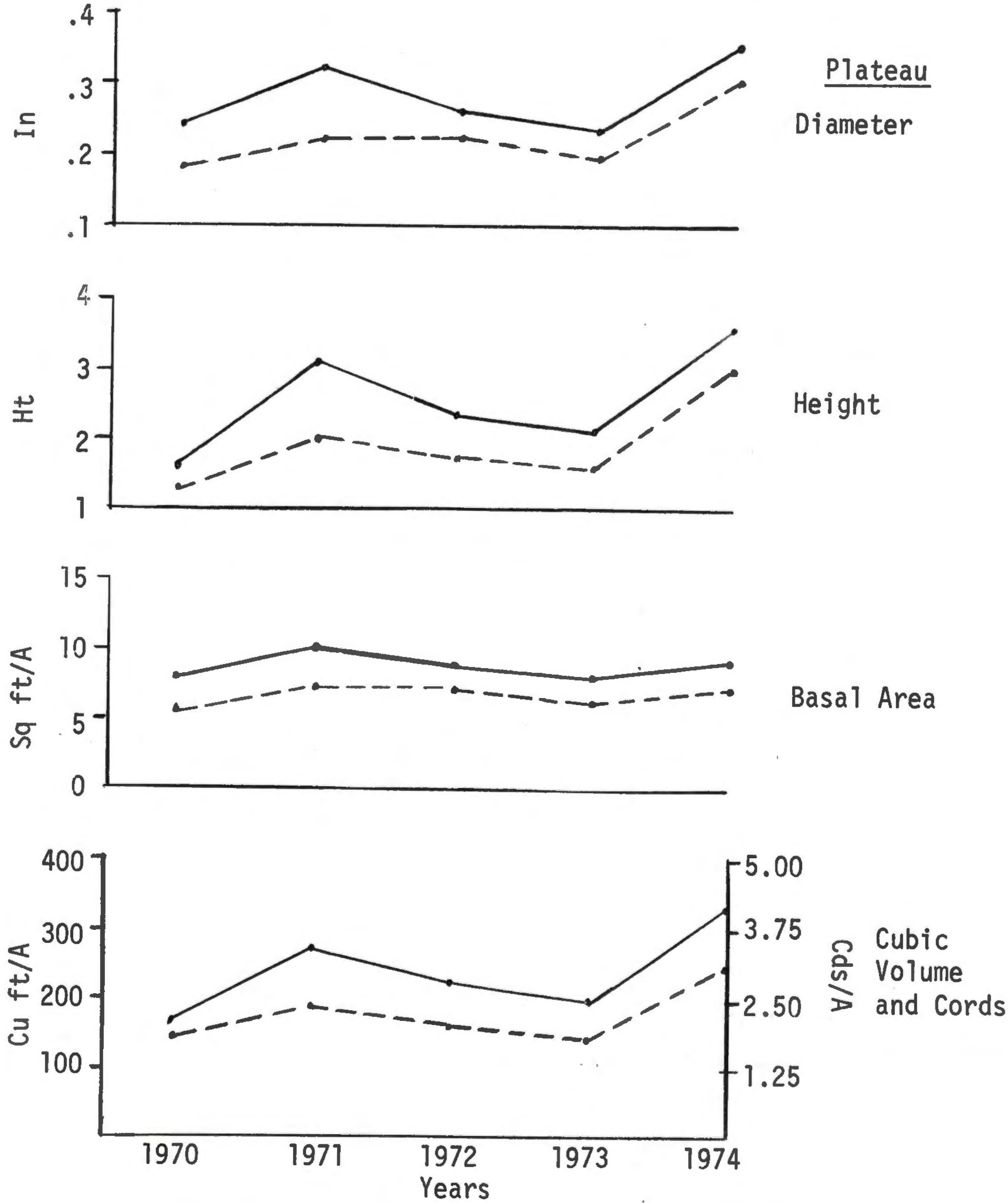

FIGURE B-10. Diameter, height, basal area and volume growth over 5 years for 150-70-100 treatment (——) as compared to control (---).

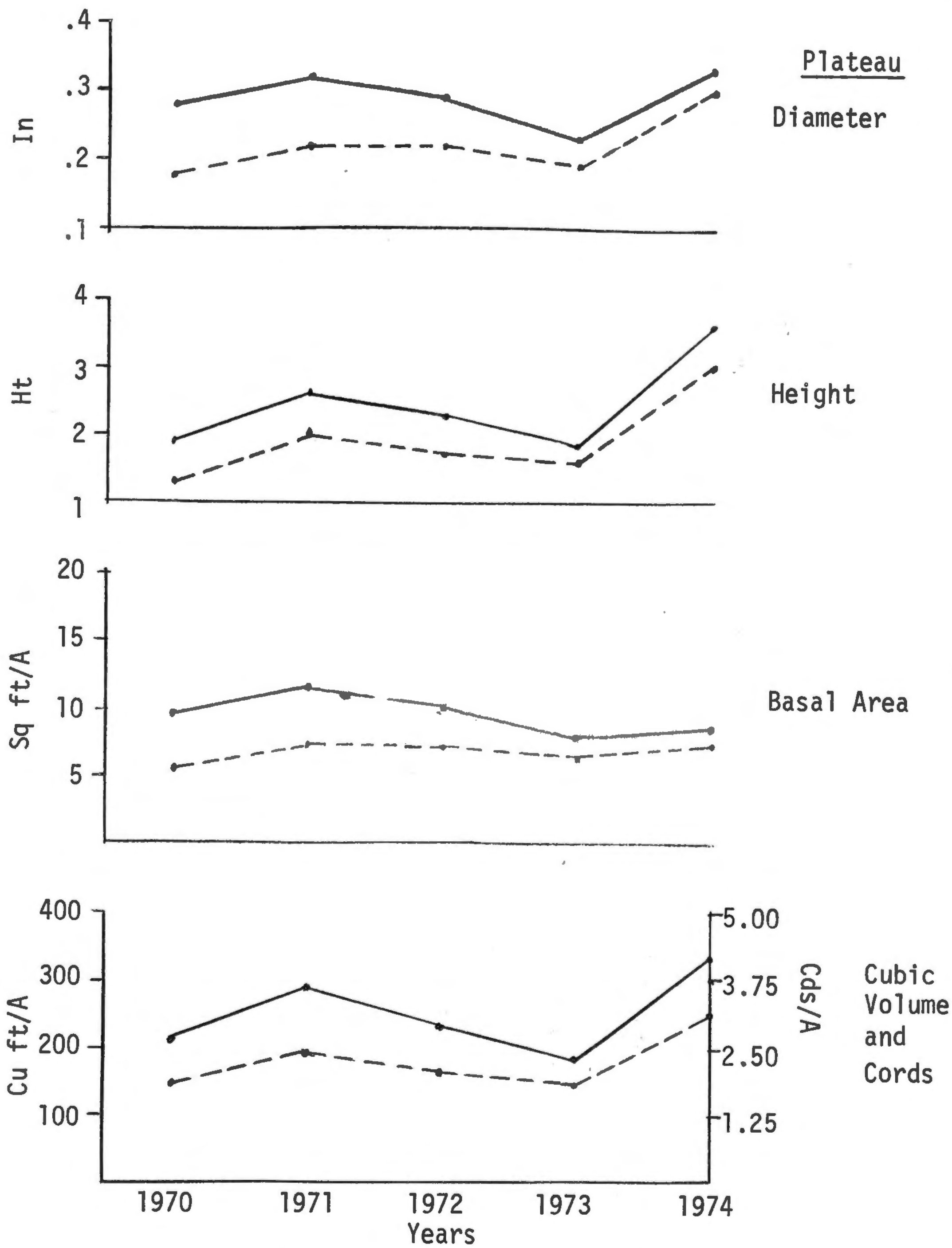

FIGURE B-11. Diameter, height, basal area and volume growth over 5 years for 150-35-0 treatment (——) as compared to control (---).

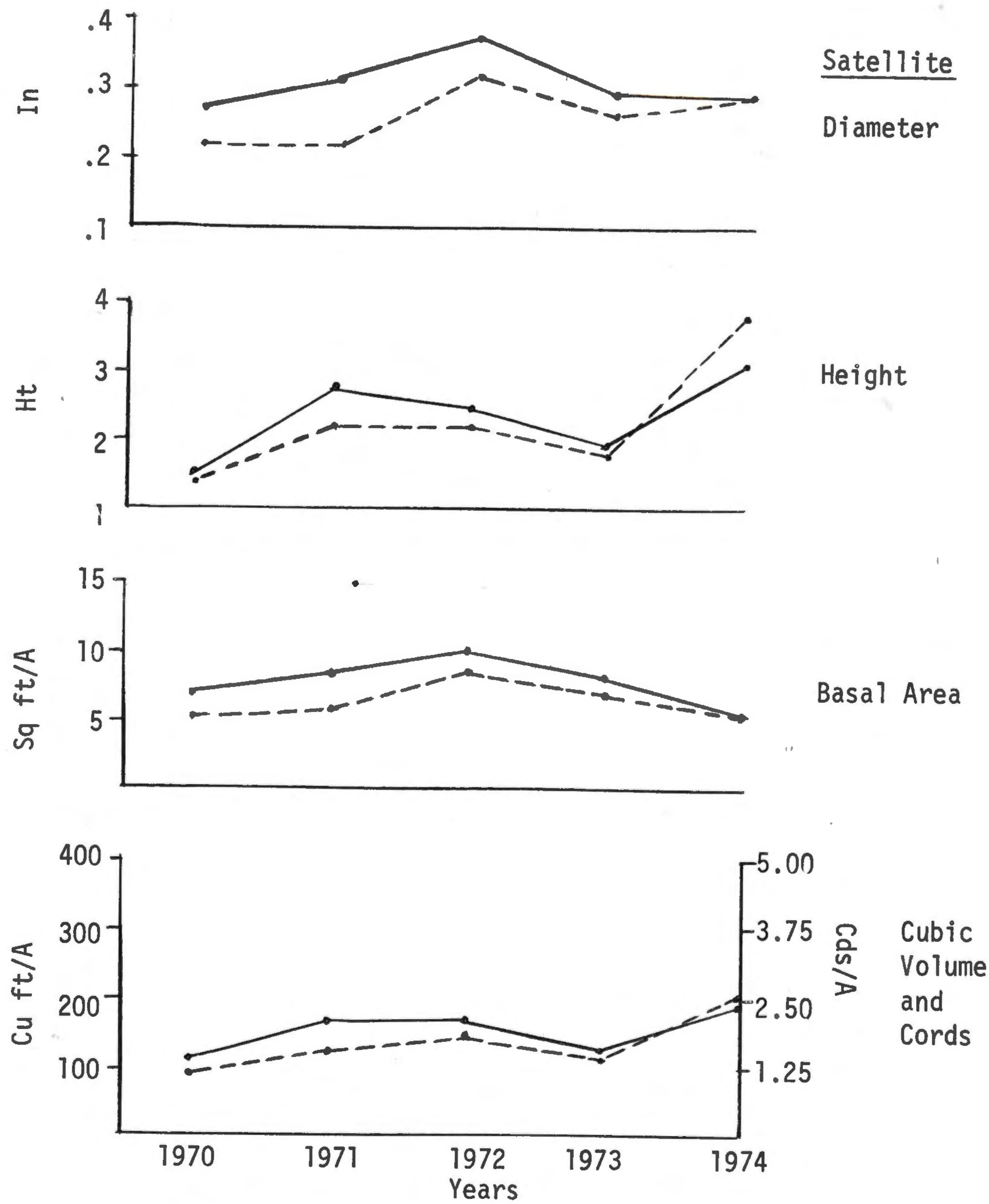

FIGURE B-12. Diameter, height, basal area and volume growth over 5 years for 150-35-100 treatment (——) as compared to control (---).

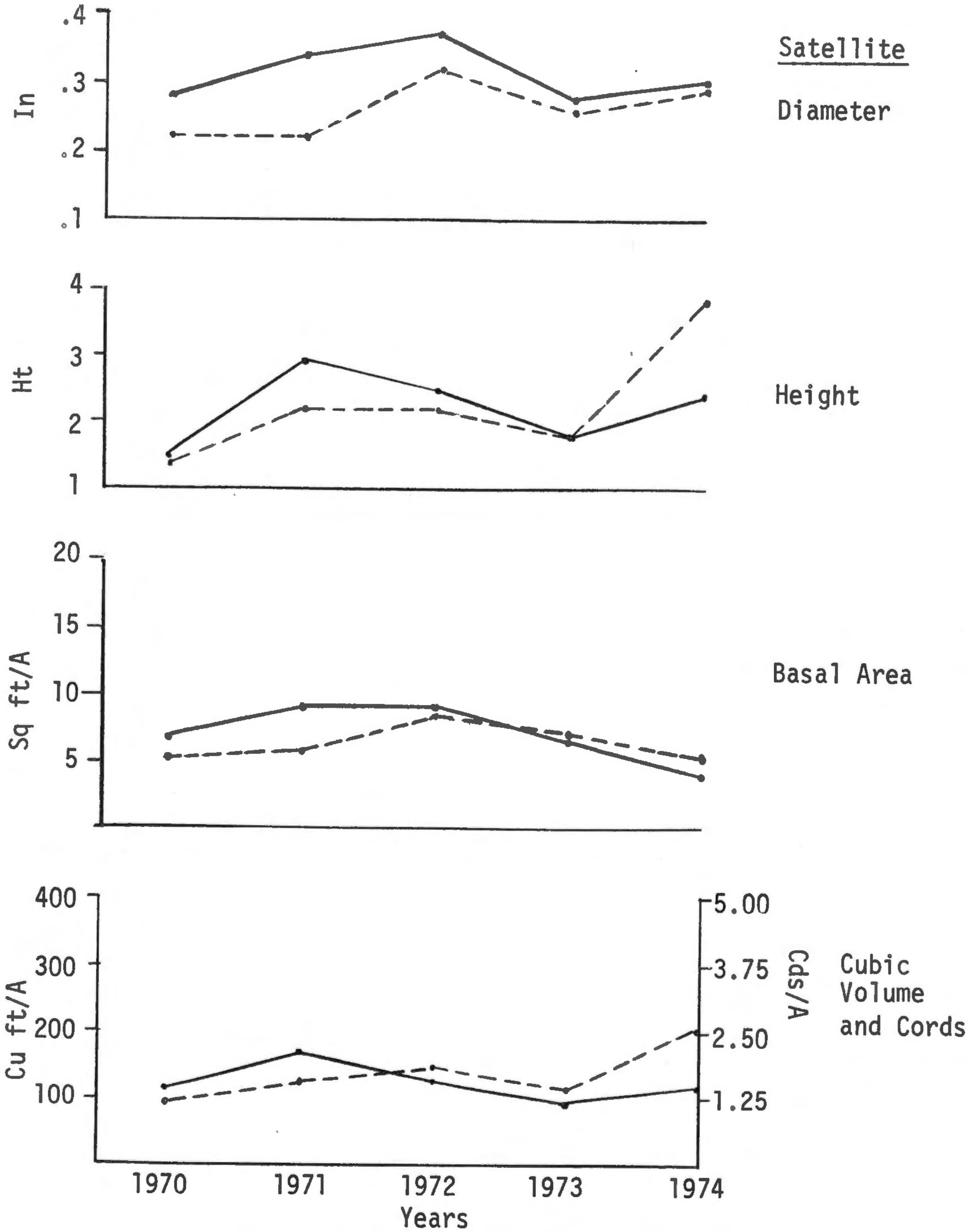

FIGURE B-13. Diameter, height, basal area and volume growth over 5 years for 300-35-100 treatment (——) as compared to control (---).

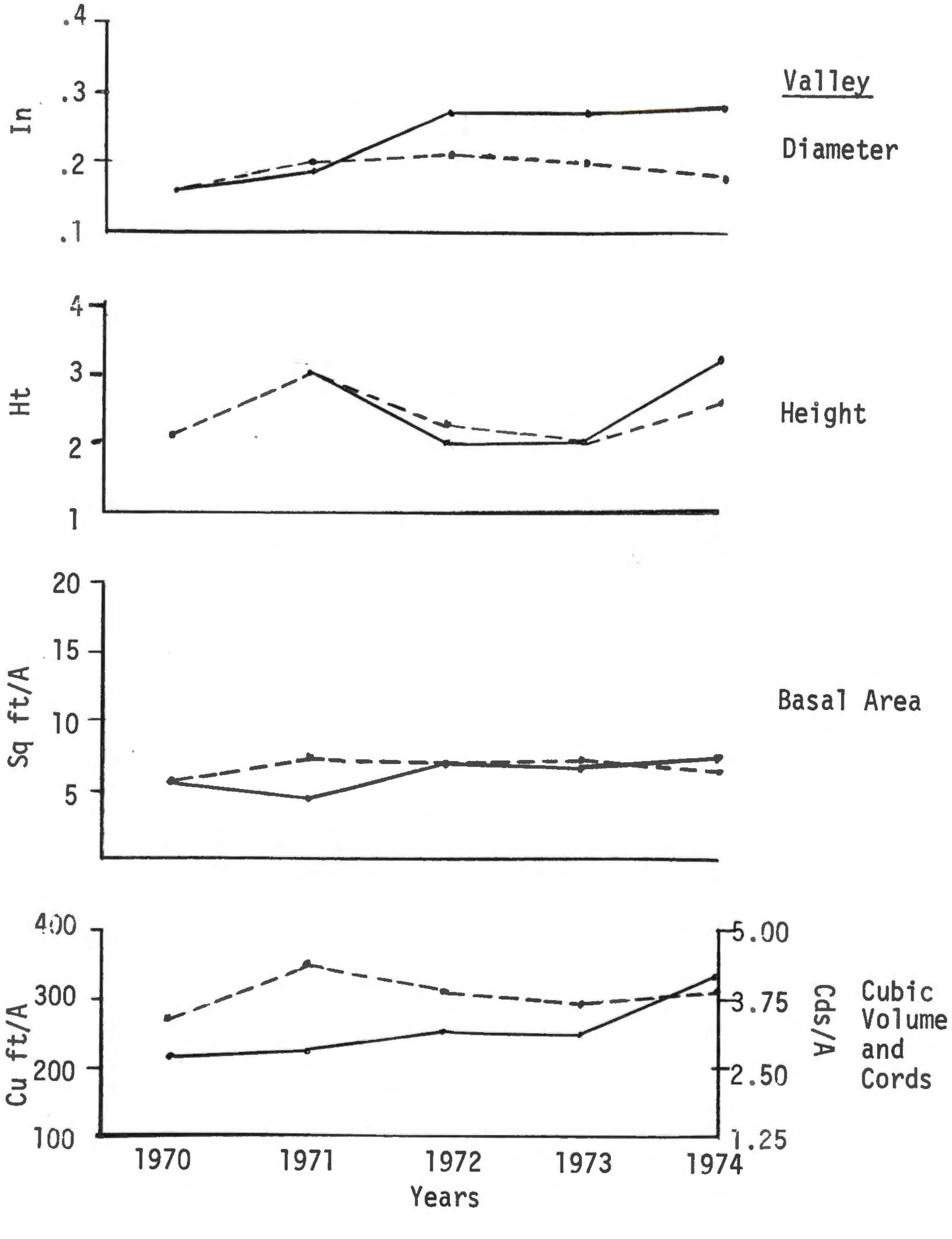

FIGURE B-14. Diameter, height, basal area and volume growth over 5 years for thinning treatment (——) as compared to control (---).

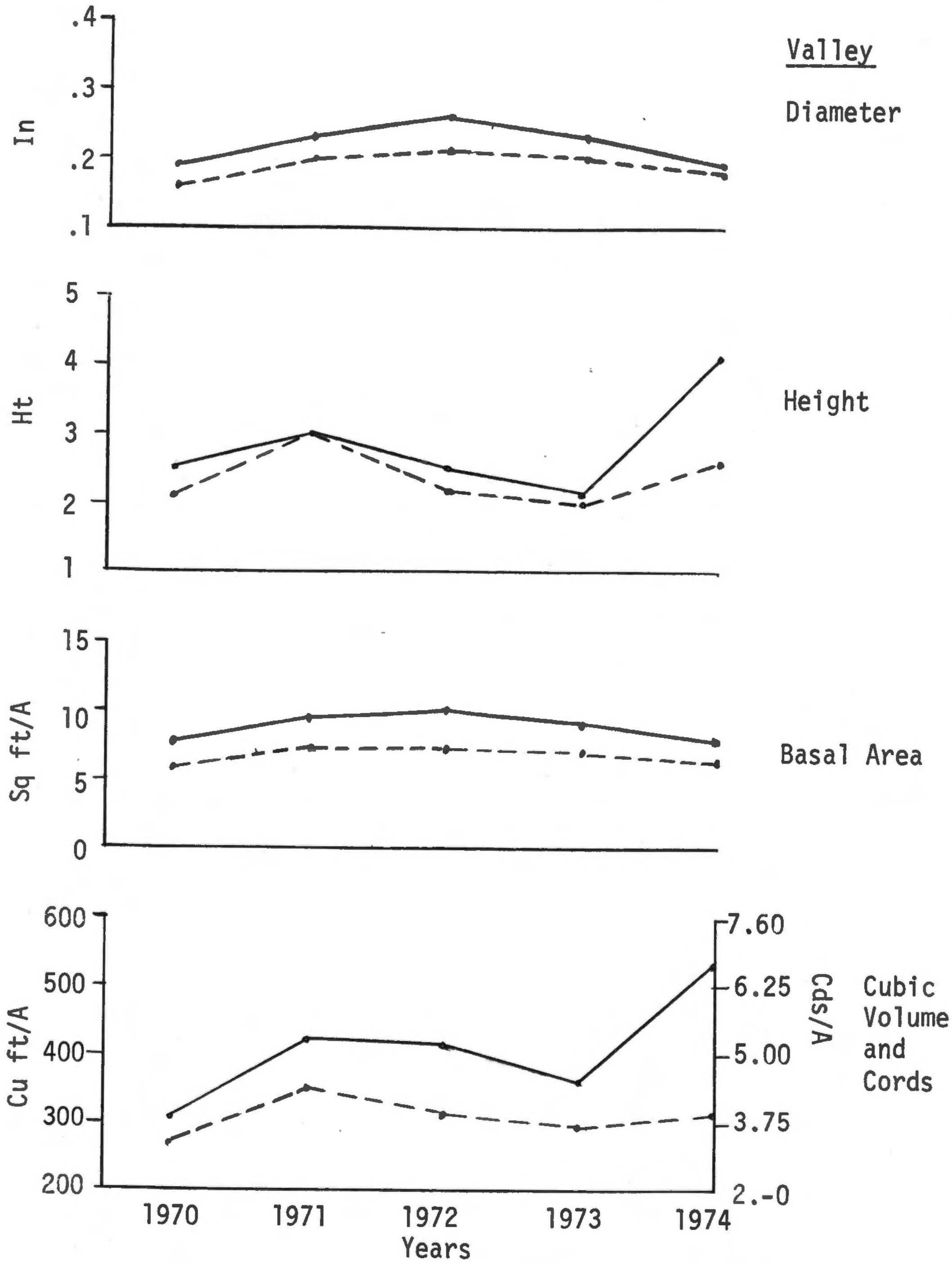

FIGURE B-15. Diameter, height, basal area and volume growth over 5 years for 150-35-100 treatment (——) as compared to control (---).

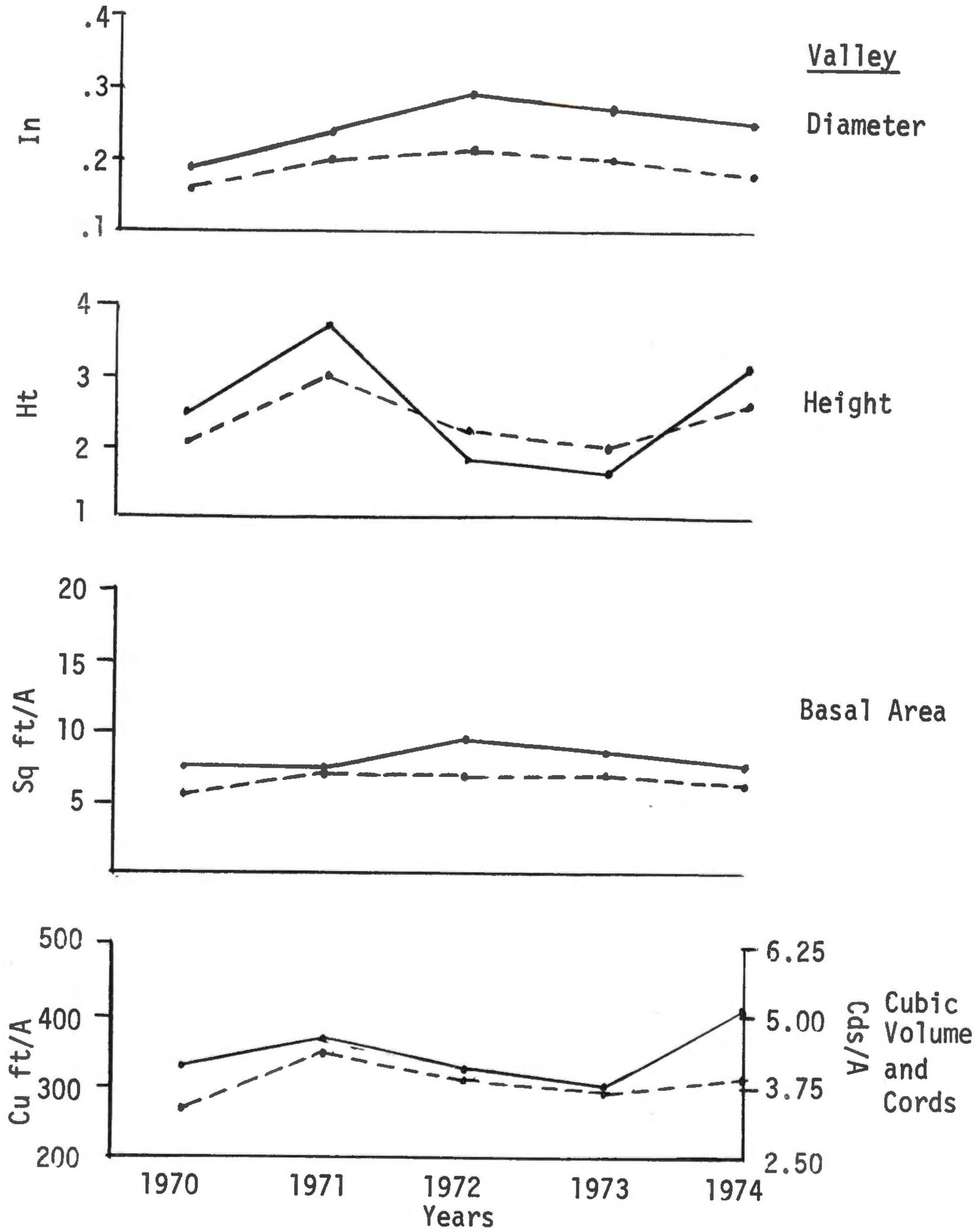

FIGURE B-16. Diameter, height, basal area and volume growth over 5 years for 150-35-100-T treatment (——) as compared to control (---).

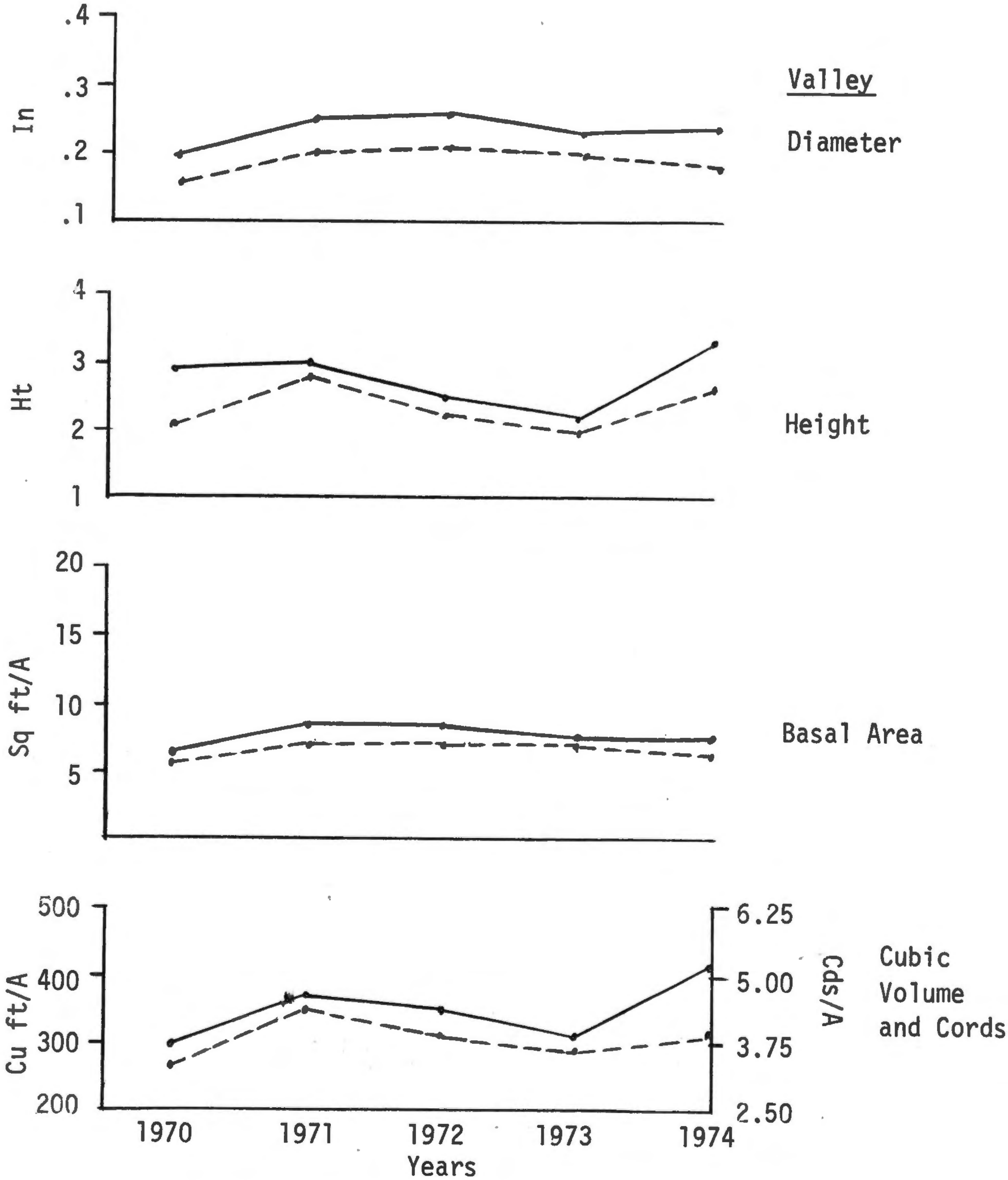

FIGURE B-17. Diameter, height, basal area and volume growth over 5 years for 150-35-100-Micro treatment (——) as compared to control (---).

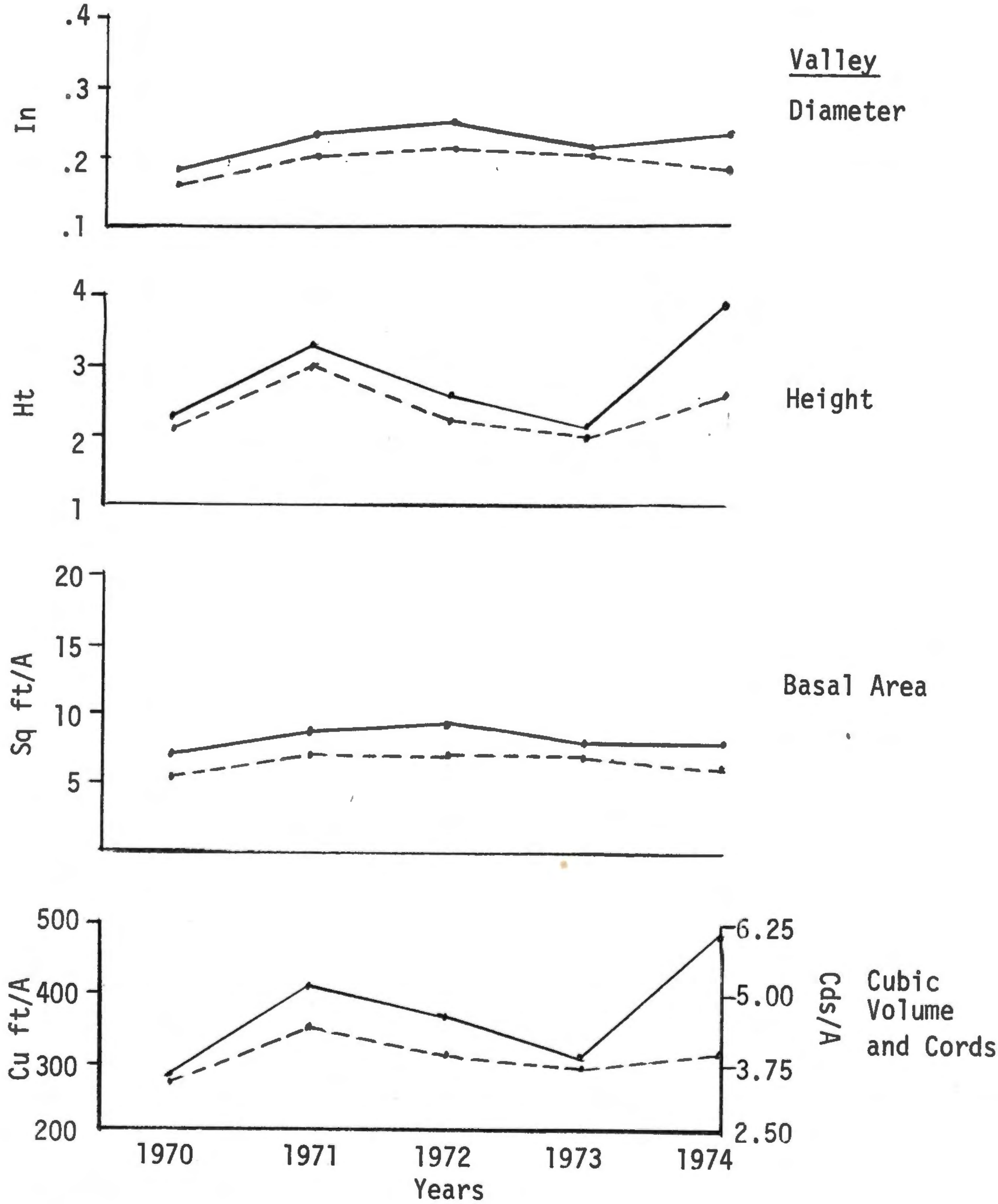

FIGURE B-18. Diameter, height, basal area and volume growth over 5 years for 150(Urea)-35-100 treatment (——) as compared to control (---).

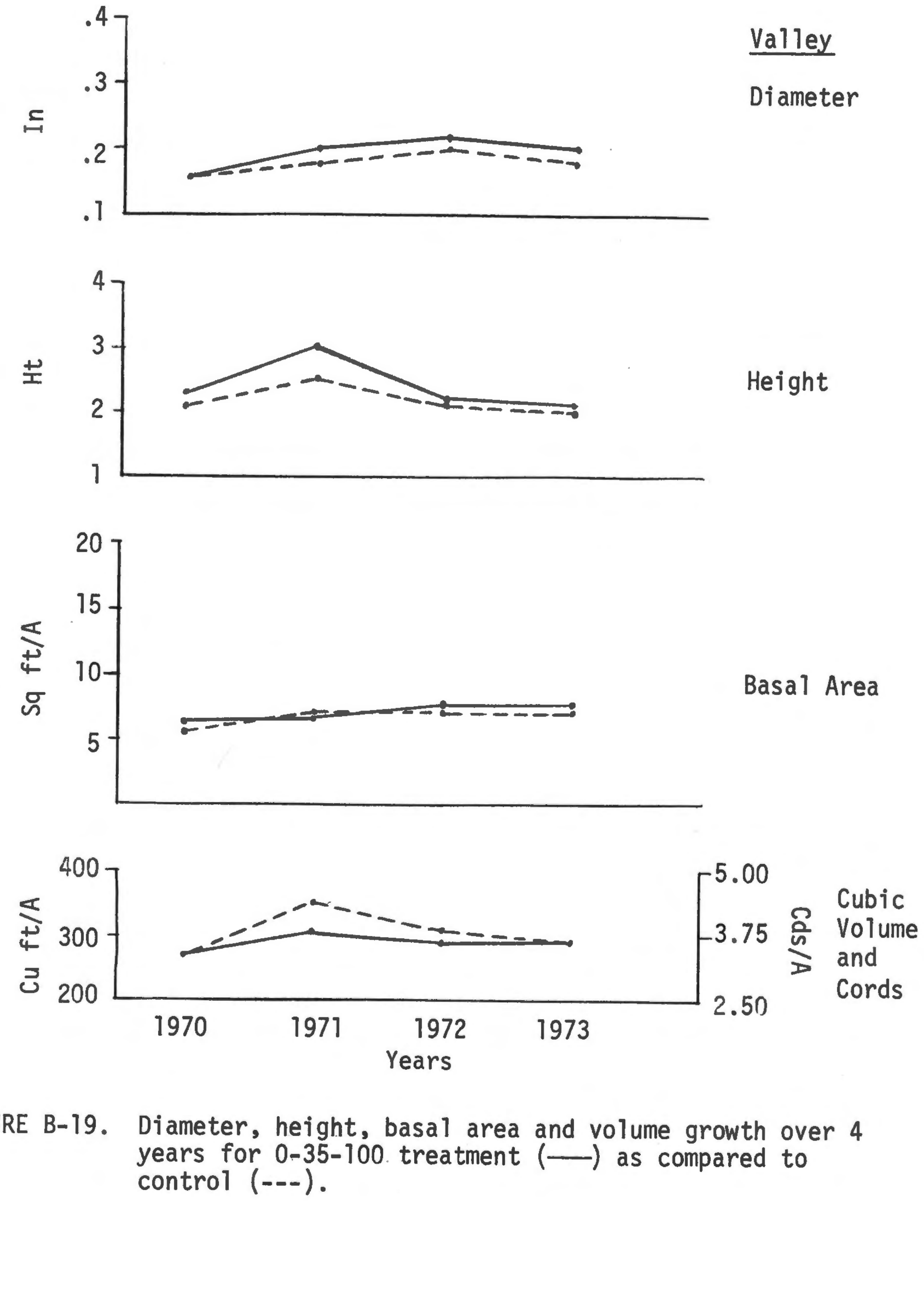

FIGURE B-19. Diameter, height, basal area and volume growth over 4 years for 0-35-100 treatment (——) as compared to control (---).

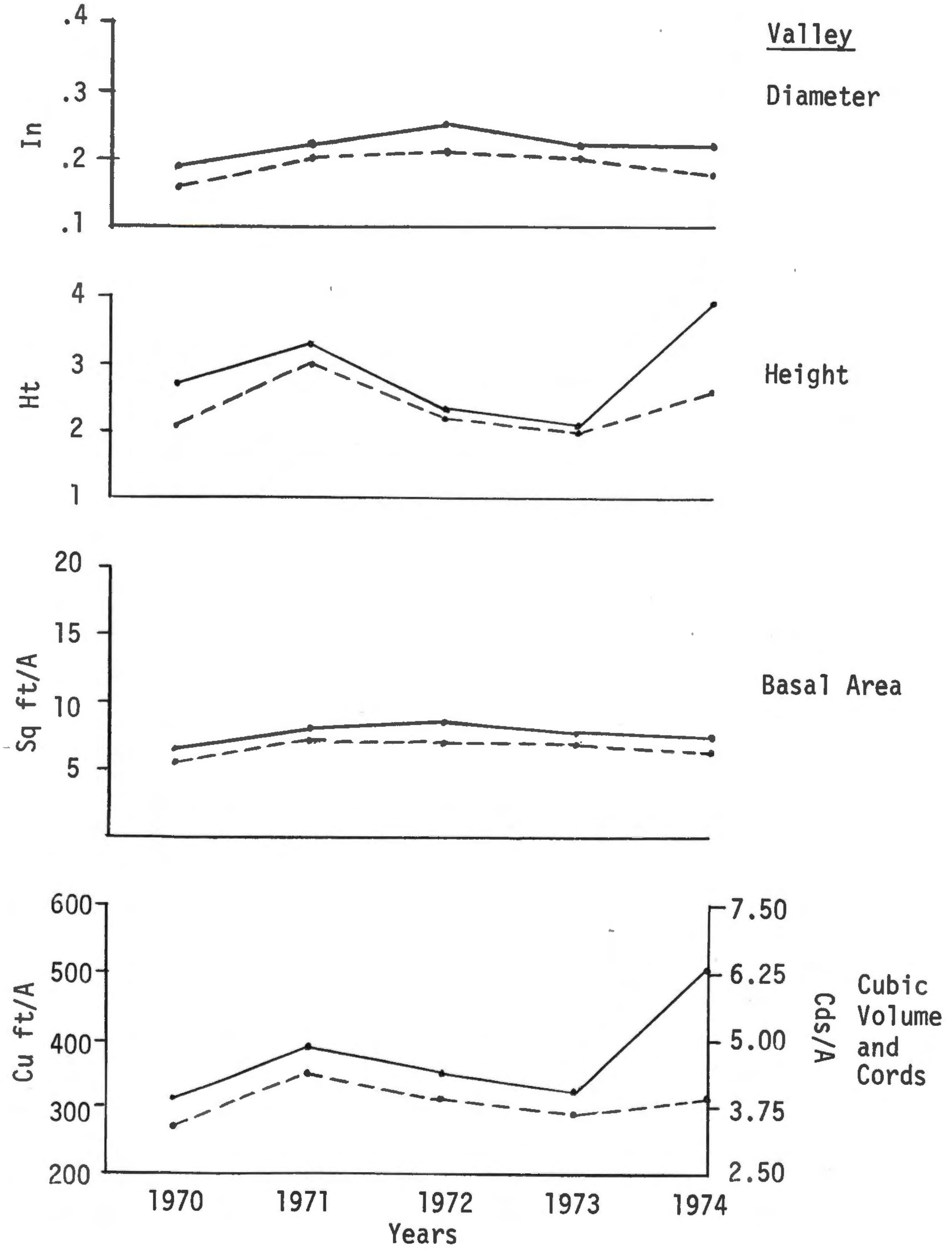

FIGURE B-20. Diameter, height, basal area and volume growth over 5 years for 75-35-100 treatment (——) as compared to control (---).

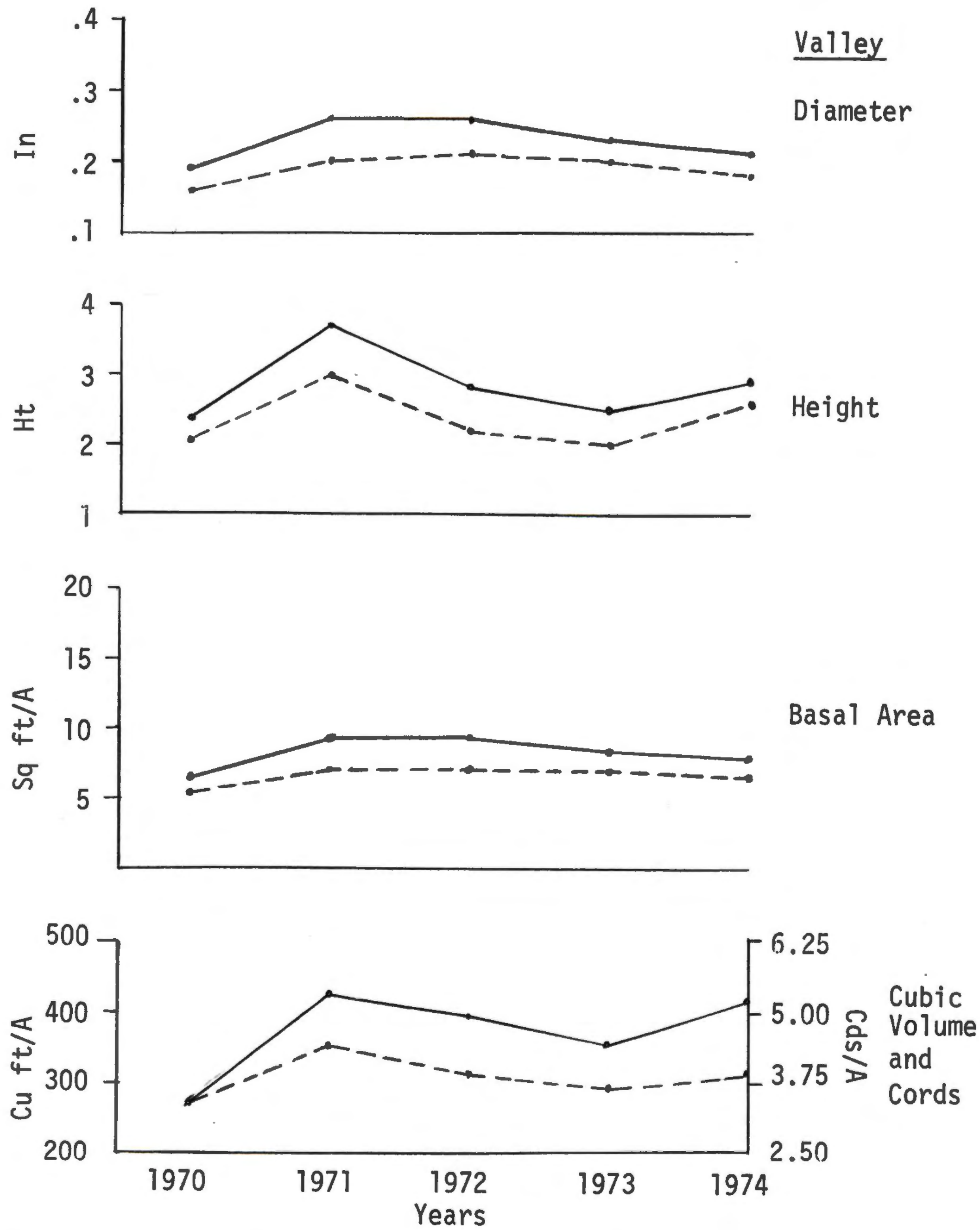

FIGURE B-21. Diameter, height, basal area and volume growth over 5 years for 300-35-100 treatment (——) as compared to control (---).

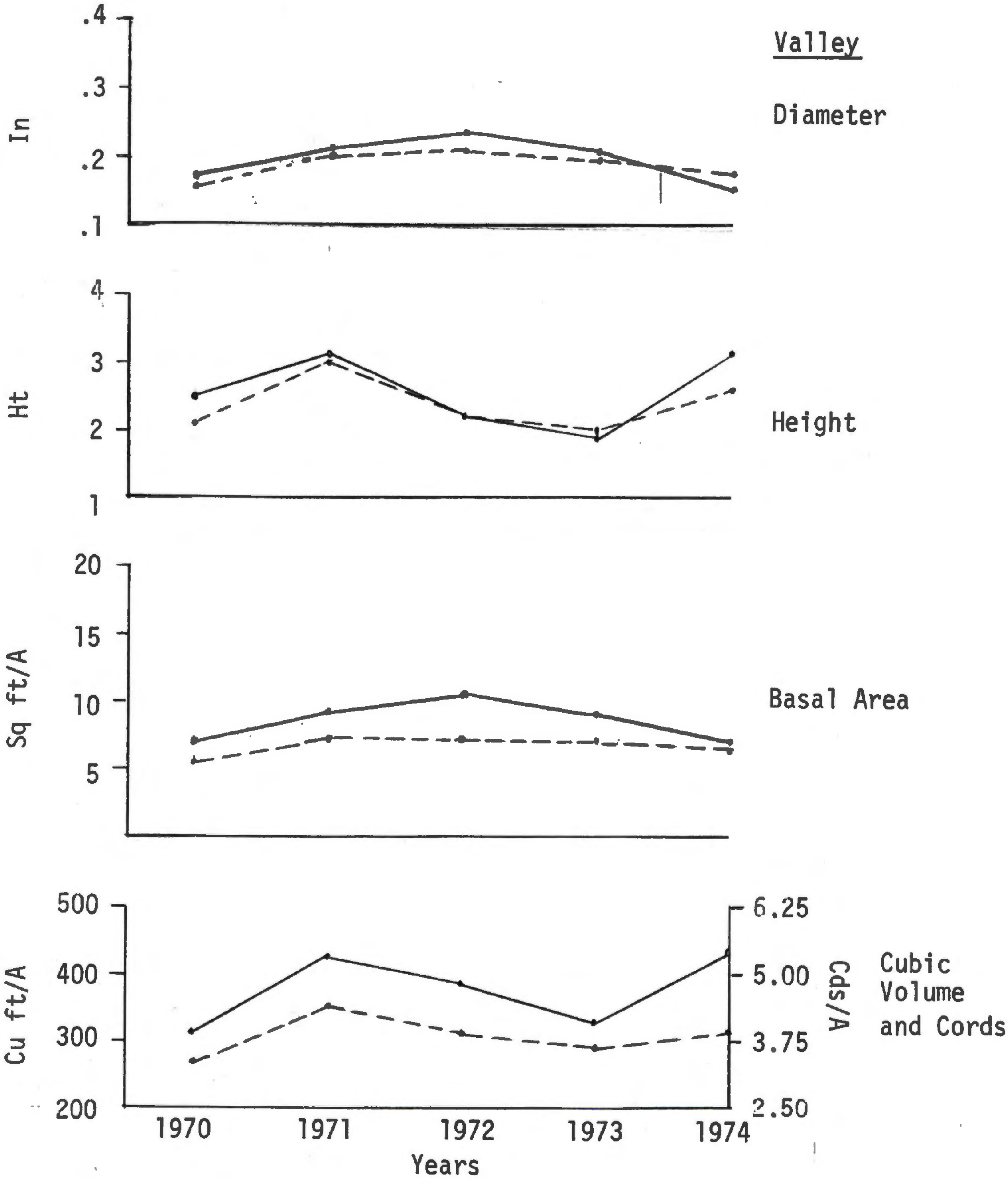

FIGURE B-22. Diameter, height, basal area and volume growth over 5 years for 150-0-100 treatment (——) as compared to control (---).

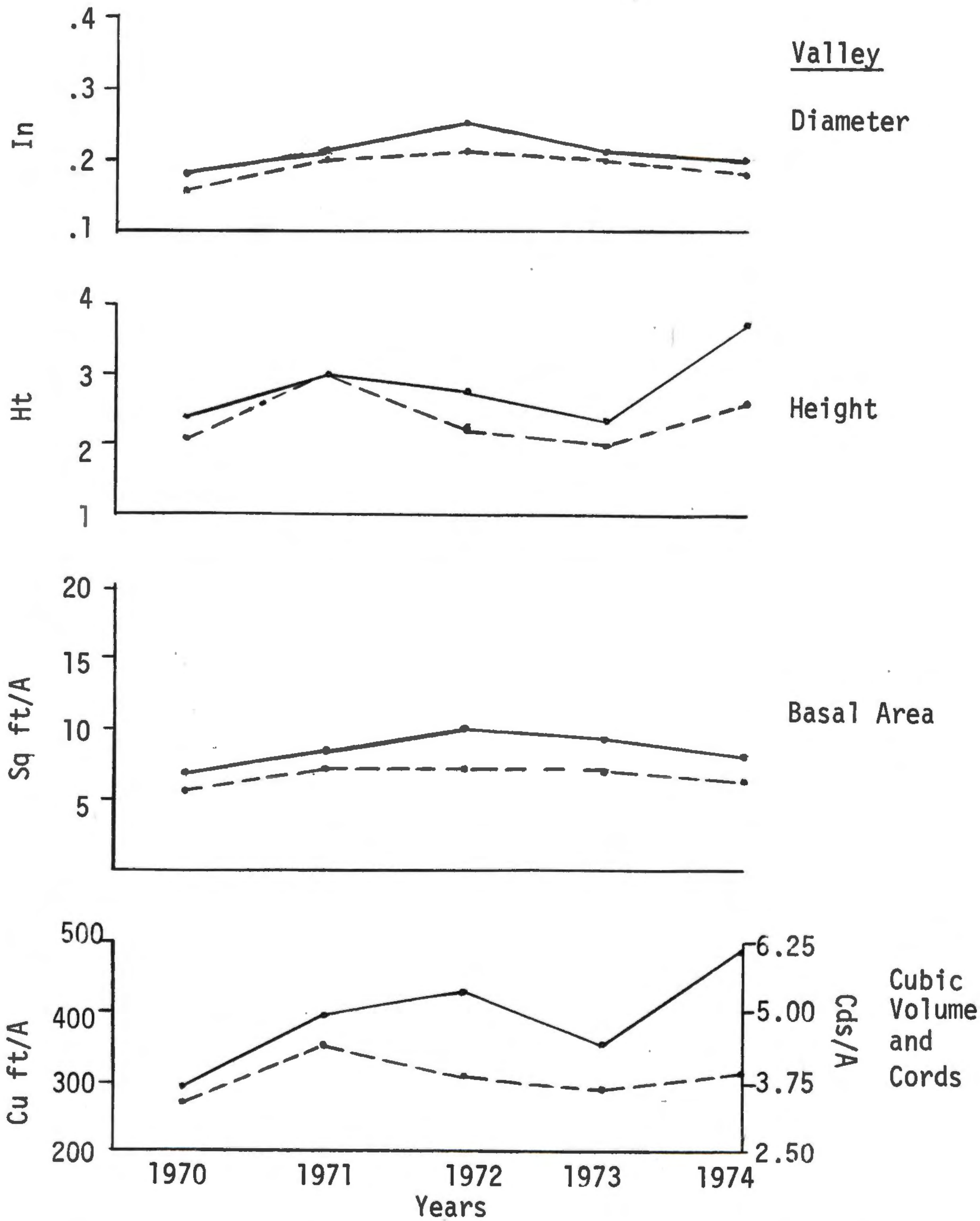

FIGURE B-23. Diameter, height, basal area and volume growth over 5 years for 150-70-100 treatment (——) as compared to control (---).

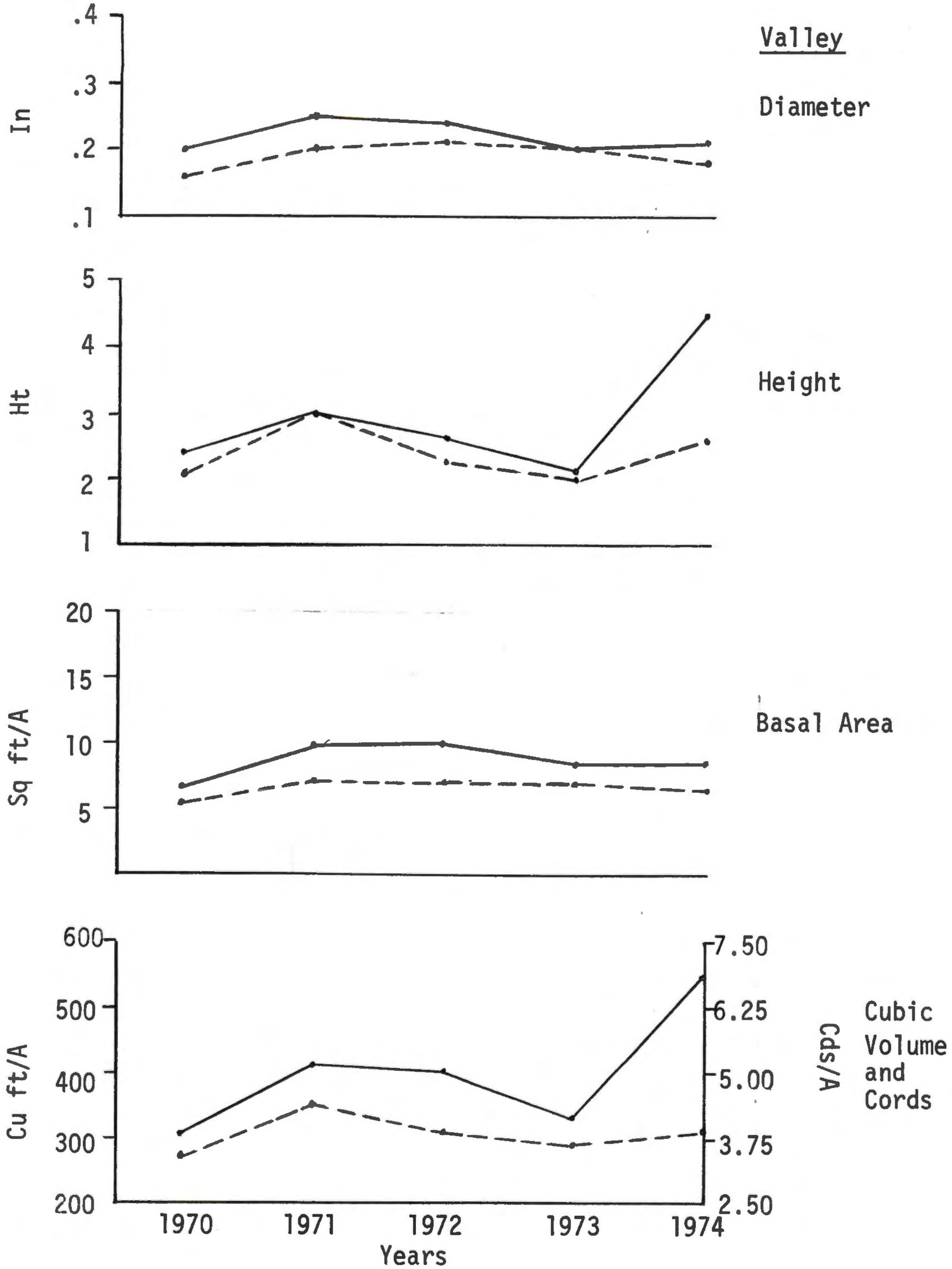

FIGURE B-24. Diameter, height, basal area and volume growth over 5 years for 150-35-0 treatment (——) as compared to control (---).

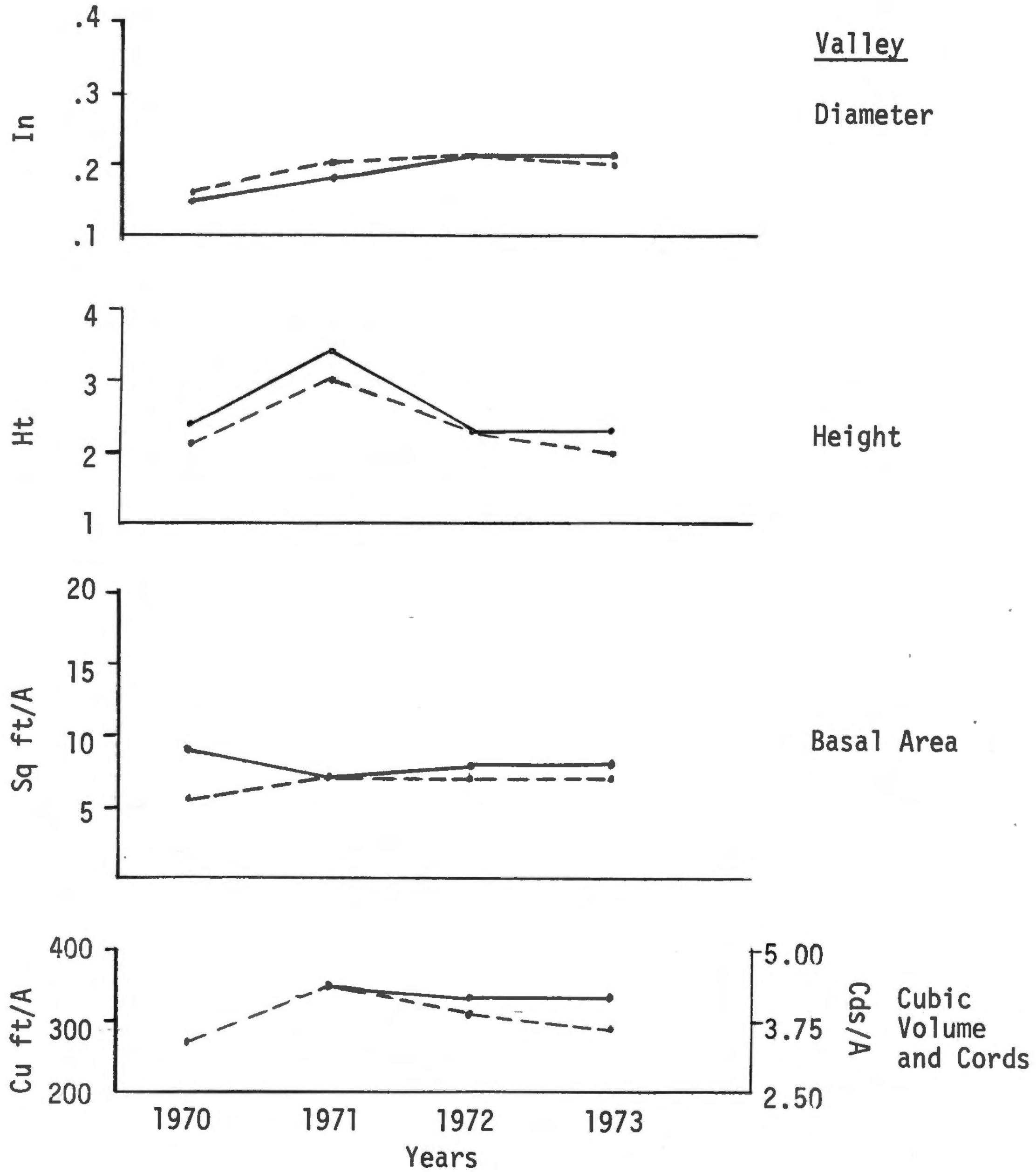

FIGURE B-25. Diameter, height, basal area and volume growth over 4 years for 50# N/A sludge treatment (——) as compared to control (---).

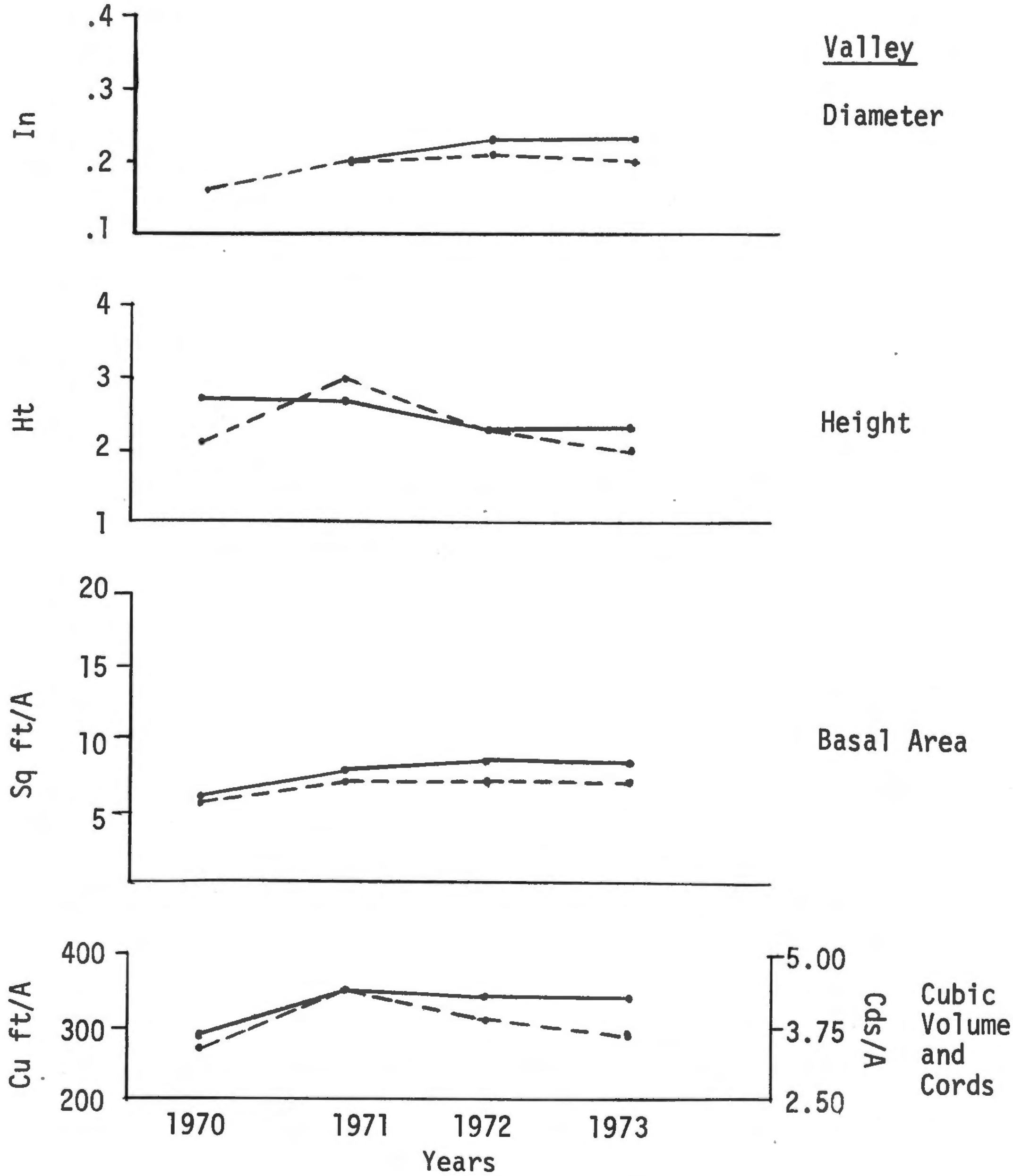

FIGURE B-26. Diameter, height, basal area and volume growth over 4 years for 100# N/A sludge treatment (——) as compared to control (---).

APPENDIX C

STATISTICAL ANALYSIS

TABLE C-1. Analysis of variance for five seasons' growth at the three locations for diameter, height, basal area and cubic volume.

Location	Diameter	Height	Basal Area	Cubic Volume
Plateau	**[a]	*[b]	NS[c]	NS
Satellite	*	NS	NS	NS
Valley	NS	NS	**	**

[a]Significant at the .01 level.

[b]Significant at the .05 level.

[c]Not significant.

TABLE C-2. Ranking of treatments according to decreasing diameter growth over five seasons at the three sites.

Location	Rank	Mean (In)	Change Over Control (%)	Duncan Test	No.	Treatment Description
Plateau	1	1.55	41		6	150-35-100-HC
	2	1.43	30		16	150-35-0
	3	1.40	27		15	150-70-100
	4	1.39	26		2	Hardwood Control (HC)
	5	1.38	25		14	150-0-100
	6	1.38	25		10	150(Urea)-35-100
	7	1.37	24		5	150-35-100-Basic
	8	1.34	21		13	300-35-100
	9	1.33	21		9	150-35-100-Micro
	10	1.27	15		12	75-35-100
	11	1.10	-		1	Control (C)
Satellite	1	1.55	18		5	150-35-100-Basic
	2	1.55	18		13	300-35-100
	3	1.31	-		1	Control (C)
Valley	1	1.23	26		7	150-35-100-T
	2	1.17	21		9	150-35-100-Micro
	3	1.15	19		3	Thinning (T)
	4	1.15	19		13	300-35-100
	5	1.12	16		5	150-35-100
	6	1.10	14		10	150(Urea)-35-100
	7	1.09	13		16	150-35-0
	8	1.09	13		12	75-35-100
	9	1.05	8		15	150-70-100
	10	0.99	2		14	150-0-100
	11	0.97	-		1	Control (C)

TABLE C-3. Ranking of treatments according to decreasing height growth over five years at the three locations.

Location	Rank	Mean (Ft)	Change Over Control (%)	Duncan Test	No.	Treatment Description
Plateau	1	12.6	28		15	150-70-100
	2	12.4	27		10	150(Urea)-35-100
	3	12.2	24		2	Hardwood Control (HC)
	4	12.2	24		5	150-35-100
	5	12.2	24		16	150-35-0
	6	12.1	23		13	300-35-100
	7	12.0	22		9	150-35-100-Micro
	8	11.8	19		6	150-35-100-HC
	9	11.4	16		12	75-35-100
	10	10.9	11		14	150-0-100
	11	9.8	-		1	Control (C)
Satellite	1	12.0	8		5	150-35-100
	2	11.3	-		1	300-35-100
	3	11.0	-3		13	Control
Valley	1	14.7	21		16	150-35-0
	2	14.3	18		10	150(Urea)-35-100
	3	14.2	17		12	75-35-100
	4	14.2	17		15	150-70-100
	5	14.1	16		5	150-35-100-Basic
	6	14.0	15		13	300-35-100
	7	13.7	13		9	150-35-100-Micro
	8	13.0	7		7	150-35-100-T
	9	12.8	5		14	150-0-100
	10	12.4	-		1	Control
	11	12.1	-2		3	Thinning (T)

TABLE C-4. Ranking of treatments according to decreasing basal area growth on 1/10 acre measurement plots over five seasons at three locations. (Multiply means by 10 to place on a per acre basis.)

Location	Rank	Mean (Sq Ft)	Change Over Control (%)	Duncan Test	No.	Treatment Description
Plateau	1	4.75	39		16	150-35-0
	2	4.68	36		10	150(Urea)-35-100
	3	4.68	36		9	150-35-100-Micro
	4	4.41	28		15	150-70-100
	5	4.39	28		6	150-35-100-HC
	6	4.27	25		14	150-0-100
	7	4.16	21		13	300-35-100
	8	4.07	19		12	75-35-100
	9	4.04	18		5	150-35-100
	10	3.94	15		2	Hardwood Control (HC)
	11	3.43	-		1	Control (C)
Satellite	1	3.92	23		5	150-35-100
	2	3.54	11		13	300-35-100
	3	3.19	-		1	Control
Valley	1	4.44	31		16	150-35-0
	2	4.42	30		5	150-35-100
	3	4.21	24		14	150-0-100
	4	4.14	22		15	150-70-100
	5	4.12	21		13	300-35-100
	6	4.07	20		10	150(Urea)-35-100
	7	4.05	19		7	150-35-100
	8	3.90	15		9	150-35-100-Micro
	9	3.84	13		12	75-35-100
	10	3.40	-		1	Control
	11	3.11	-8		3	Thinning (T)

TABLE C-5. Ranking of treatments according to decreasing cubic volume growth on 1/10 acre measurement plots over five seasons at three locations. (Multiply means by 10 to place on a per acre basis.)

Location	Rank	Mean (Cu Ft)	Change Over Control (%)	Volume Change Over Control (Cds/A)	Duncan Test	No.	Treatment Description
Plateau	1	133.49	51	5.63		10	150(Urea)-35-100
	2	126.13	42	4.71		9	150-35-100-Micro
	3	124.77	41	4.54		16	150-35-0
	4	121.65	37	4.15		6	150-35-100-HC
	5	120.89	37	4.05		13	300-35-100
	6	119.57	35	3.89		15	150-70-100
	7	116.84	32	3.55		12	75-35-100
	8	116.05	31	3.45		14	150-0-100
	9	113.19	28	3.09		2	Hardwood Control (HC)
	10	109.48	24	2.62		5	150-35-100-Basic
	11	88.49	-	-		1	Control (C)
Satellite	1	77.40	14	1.22		5	150-35-100
	2	67.69	-	-		1	Control
	3	61.38	-9	-0.79		13	300-35-100
Valley	1	203.56	32	6.22		5	150-35-100
	2	199.85	30	5.75		16	150-35-0
	3	196.61	28	5.35		15	150-70-100
	4	188.75	23	4.36		12	75-35-100
	5	187.86	22	4.25		14	150-0-100
	6	185.12	20	3.91		13	300-35-100
	7	184.86	20	3.88		10	150(Urea)-35-100
	8	174.48	13	1.95		9	150-35-100-Micro
	9	173.16	12	2.41		7	150-35-100-T
	10	153.88	-	-		1	Control
	11	127.55	-17	-3.29		3	Thinning (T)

APPENDIX D

ECONOMIC ANALYSIS

TABLE D-1. Internal rate of return for the Plateau site for: three response periods (10, 15, 20 years), followed by liquidation; two spreading costs--(1) 7¢/lb and $2/A administration, (2) 3¢/lb and $1.75/A administration; and two returns ($10/cord and $15/cord).

No.	Treatment Description	Material lbs/A	Response Period	Increase Over C (Cds/A)	7¢/lb & $2/A Cost $/A	7¢/lb & $2/A Revenue $10/cd	7¢/lb & $2/A Revenue $15/cd	3¢/lb & $1.75/A Cost $/A	3¢/lb & $1.75/A Revenue $10/cd	3¢/lb & $1.75/A Revenue $15/cd
5	150-35-100	810	10	4.3	112.13	-	-	79.48	-	-
			15	7.0		-	-		-	1.9
			20	12.0		.3	2.4		2.1	4.2
6	150-35-100-HC	810	10	5.3*	112.13	-	-	79.48	-	-
			15	7.9*		-	.4		-	2.7
			20	11.9*		.3	2.4		2.0	4.1
9	150-35-100-Micro	1060	10	7.6	157.13	-	-	114.48	-	-
			15	11.7		-	.7		.2	2.9
			20	20.6		1.4	3.5		3.0	5.1
10	150(Urea)-35-100	705	10	9.1	101.17	-	3.0	72.72	2.3	6.5
			15	14.7		2.5	5.3		4.8	7.7
			20	24.6		4.5	6.7		6.3	8.5
12	75-35-100	592.5	10	6.0	81.90	-	.9	57.95	.3	4.5
			15	9.6		1.1	3.8		3.4	6.2
			20	16.2		3.5	5.6		5.3	7.4
13	300-35-100	1245	10	6.4	172.60	-	-	122.55	-	-
			15	8.3		-	-		-	.1
14	150-0-100	635	10	4.7	86.06	-	-	60.41	-	1.5
			15	6.9		-	1.3		.9	3.7
15	150-70-100	985	10	6.5	138.18	-	-	98.53	-	-
			15	10.6		-	.9		.5	3.3
			20	18.2		1.4	3.5		3.1	5.2
16	150-35-0	610	10	6.9	88.53	-	1.6	63.88	.8	5.0
			15	10.0		.8	3.6		3.0	5.9
			20	17.3		3.4	5.5		5.1	7.3

*Increase over Treatment #2 (Hardwood Control).

NOTE: Dash (-) = costs greater than benefit.

TABLE D-2. Internal rate of return for the Valley site for: three response periods (10, 15, 20 years), followed by liquidation; two spreading costs--(1) 7¢/lb and $2 administration, (2) 3¢/lb and $1.75 administration; and two returns ($10/cord and $15/cord).

No.	Treatment Description	Material lbs/A	Response Period	Increase Over C (Cds/A)	7¢/lb & $2/A Cost $/A	7¢/lb & $2/A Revenue $10/cd	7¢/lb & $2/A Revenue $15/cd	3¢/lb & $1.75/A Cost $/A	3¢/lb & $1.75/A Revenue $10/cd	3¢/lb & $1.75/A Revenue $15/cd
5	150-35-100	810	10	11.2	112.13	-	4.1	79.48	3.5	7.8
			15	18.7		3.5	6.3		5.9	8.8
			20	36.4		6.1	8.2		7.9	10.1
7	150-35-100-T	810	10	8.0*	112.13	2.6	4.3	79.48	6.0	7.9
			15	12.6*		2.9	3.8		5.2	6.0
			20	20.0*		3.8	4.0		5.6	5.7
9	150-35-100-Micro	1060	10	4.9	157.13	-	-	114.48	-	-
			15	7.8		-	-		-	.2
			20	13.7		-	1.3		.9	3.0
10	150(Urea)-35-100	705	10	7.5	101.17	-	1.1	72.72	.3	4.5
			15	12.1		1.2	4.0		3.5	6.3
			20	21.3		3.8	5.9		5.5	7.7
12	75-35-100	592.5	10	8.1	81.90	-	4.0	57.95	3.4	7.7
			15	12.2		2.7	5.5		5.1	8.0
			20	20.3		4.6	6.8		6.5	8.6
13	300-35-100	1245	10	7.5	172.60	-	-	122.55	-	-
			15	12.1		-	.3		-	2.7
			20	19.9		.7	2.8		2.5	4.6
14	150-0-100	635	10	7.9	86.06	-	3.2	60.41	2.7	7.0
			15	12.7		2.6	5.4		5.1	8.0
			20	20.2		4.4	6.5		6.2	8.4
15	150-70-100	985	10	10.6	138.18	-	1.4	98.53	.7	4.9
			15	16.8		1.3	4.1		3.6	6.5
			20	27.7		3.6	5.7		5.3	7.5
16	150-35-0	610	10	11.3	88.53	2.5	6.7	63.88	5.9	10.2
			20	31.2		6.5	8.7		8.3	10.5

*Increase over Treatment #3 (Thinning).

NOTE: Dash (-) = costs greater than benefit.

TABLE D-3. Cost-price analysis for the Plateau site for: three response periods (10, 15, 20 years), followed by liquidation; two spreading costs--(1)7¢/lb and $2 administration, (2) 3¢/lb and $1.75 administration; and two interest rates (6% and 10%).

No.	Treatment Description	Material lbs/A	Planning Period	Increase Over C (Cds/A)	7¢/lb & $2/A Cost $/A	7¢/lb & $2/A Return 6%	7¢/lb & $2/A Return 10%	3¢/lb & $1.75/A Cost $/A	3¢/lb & $1.75/A Return 6%	3¢/lb & $1.75/A Return 10%
5	150-35-100	810	10	4.3	$112.13	$46.68	$67.54	$ 79.48	$33.09	$47.87
			15	7.0		38.44	66.96		27.25	47.46
			20	12.0		29.99	62.89		21.26	44.57
6	150-35-100-HC	810	10	5.3*	112.13	37.87	54.80	79.48	26.84	38.84
			15	7.9*		34.06	59.33		24.14	42.05
			20	11.9*		30.25	63.41		21.44	44.95
9	150-35-100-Micro	1060	10	7.6	157.13	37.01	53.55	114.48	26.96	39.01
			15	11.7		32.23	56.14		23.48	40.90
			20	20.6		24.48	51.33		17.84	37.40
10	150(Urea)-35-100	705	10	9.1	101.17	19.90	28.79	72.72	14.30	20.70
			15	14.7		16.52	28.77		11.87	20.68
			20	24.6		13.20	27.68		9.49	19.98
12	75-35-100	592.5	10	6.0	81.90	24.43	35.35	57.95	17.29	25.01
			15	9.6		20.47	35.66		14.49	25.23
			20	16.2		16.22	34.02		11.48	24.07
13	300-35-100	1245	10	6.4	172.60	48.27	69.85	122.55	34.27	49.59
			15	8.3		49.91	86.92		35.44	61.72
14	150-0-100	625	10	4.7	86.06	32.78	47.42	60.41	23.01	33.29
			15	6.9		29.93	52.13		21.01	36.60
15	150-70-100	985	10	6.5	138.18	38.05	55.06	98.53	27.13	39.26
			15	10.6		31.29	54.49		22.31	38.85
			20	18.2		24.37	51.10		17.38	36.43
16	150-35-0	610	10	6.9	88.53	27.97	33.23	63.88	16.57	23.98
			15	10.0		21.25	37.00		15.33	26.70
			20	17.3		16.43	34.44		11.85	24.85

*Increase over Treatment #2 (Hardwood Control).

TABLE D-4. Cost-price analysis for the Valley site for: three response periods (10, 15, 20 years), followed by liquidation; two spreading costs--(1) 7¢/lb and $2 administration, (2) 3¢/lb and $1.75 administration; and two interest rates (6% and 10%).

					7¢/lb & $2/A			3¢/lb & $1.75/A		
				Increase	Cost	Revenue		Cost	Revenue	
No.	Treatment Description	Material lbs/A	Planning Period	Over C (Cds/A)	$/A	6%	10%	$/A	6%	10%
5	150-35-100	810	10	11.2	$112.13	$17.92	$25.93	$ 79.48	$12.70	$18.38
			15	18.7		14.39	25.06		10.20	17.77
			20	36.4		9.89	20.73		7.01	14.69
7	150-35-100-T	810	10	80.0*	112.13	25.09	36.30	79.48	17.78	25.73
			15	12.6*		21.36	37.20		15.14	26.37
			20	20.0*		18.00	37.73		12.76	26.74
9	150-35-100-Micro	1060	10	4.9	157.13	57.40	83.05	114.48	41.82	60.51
			15	7.8		48.35	84.20		35.22	61.35
			20	13.7		36.82	77.19		26.82	56.24
10	150(Urea)-35-100	705	10	7.5	101.17	24.14	34.94	72.72	17.36	25.11
			15	12.1		20.02	34.95		14.42	25.12
			20	21.3		15.25	31.97		10.96	22.98
12	75-35-100	592.5	10	8.1	81.90	18.10	26.19	57.95	12.81	18.53
			15	12.2		16.11	28.06		11.40	19.85
			20	20.3		12.95	27.15		9.16	19.21
13	300-35-100	1245	10	7.5	172.60	41.19	59.60	122.55	29.25	42.32
			15	12.1		34.23	59.63		24.31	42.33
			20	19.9		27.84	58.37		19.77	41.44
14	150-0-100	635	10	7.9	86.06	19.50	28.21	60.41	13.69	19.80
			15	12.7		16.26	28.32		11.32	19.88
			20	20.2		13.68	28.67		9.60	20.13
15	150-70-100	985	10	10.6	138.18	23.33	33.76	98.53	16.64	24.07
			15	16.8		19.74	34.38		14.08	24.51
			20	27.7		16.01	33.57		11.42	23.94
16	150-35-0	610	10	11.3	88.53	14.02	20.29	63.88	10.12	14.64
			15	18.3		11.61	20.22		8.38	14.59
			20	31.2		9.11	19.09		6.57	13.78

*Increase over Treatment #3 (Thinning).

APPENDIX E

CLIMATIC DATA

TABLE E-1. Mean 1970, 1971, 1972, 1973 and 1974 monthly temperatures and precipitation for Crossville (Plateau) and Dayton (Valley).

Year	Statistics	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Monthly Average	Yearly Total
Crossville															
1970	Temp.	27.2	35.1	44.4	57.5	64.1	68.2	72.0	73.3	71.4	57.2	43.7	40.8	54.6	
	Precip.	1.94	4.81	4.48	11.26	1.57	6.88	2.85	8.99	3.77	4.03	1.76	4.82	4.76	57.12
1971	Temp.	33.8	35.6	39.7	54.6	59.5	71.9	71.7	71.8	69.3	62.0	45.0	47.1	55.2	
	Precip.	6.53	6.00	4.15	3.65	7.77	3.14	4.62	5.75	2.30	2.08	1.80	6.91	4.56	54.70
1972	Temp.	38.7	36.9	44.7	59.7	61.1	66.7	71.0	72.2	69.2	54.3	43.9	43.1	55.1	
	Precip.	8.53	4.79	6.52	5.53	4.57	5.74	3.41	0.91	7.03	6.28	5.03	9.58	5.66	67.92
1973	Temp.	34.8	36.9	54.0	52.9	59.1	71.9	74.3	72.4	70.2	59.3	50.6	38.2	56.2	
	Precip.	4.41	4.17	11.71	5.00	10.64	5.34	8.24	1.80	6.04	2.53	8.42	6.41	6.22	74.71
1974	Temp.	45.6	39.8	52.5	55.5	64.5	66.0	73.6	70.8	61.4	52.7	46.0	38.9	55.6	
	Precip.	10.10	6.14	6.03	2.62	8.08	1.48	2.94	3.36	3.96	2.26	6.15	5.73	4.90	58.85
Avg.	Temp.	36.0	36.9	47.0	56.0	61.7	68.9	72.5	72.1	68.3	57.1	45.8	41.6		
	Precip.	6.30	5.18	6.58	5.61	6.53	4.52	4.41	4.16	4.62	3.44	4.63	6.69		

TABLE E-1. (Continued)

Year	Statistics	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Monthly Average	Yearly Total
Dayton															
1970	Temp.	31.2	39.9	49.0	60.3	67.6	72.8	76.6	76.7	74.8	62.0	46.6	43.5	58.4	
	Precip.	3.20	2.82	4.71	7.51	2.76	4.51	3.34	3.82	1.71	7.23	1.75	5.80	5.10	49.16
1971	Temp.	31.4	40.1	45.1	58.1	64.1	75.8	75.5	65.4	73.6	64.8	48.3	48.4	58.4	
	Precip.	4.94	7.26	6.43	1.95	4.85	3.62	6.05	2.55	4.20	2.60	2.02	8.70	4.60	55.17
1972	Temp.	42.8	39.7	48.5	55.7	65.4	71.2	76.0	76.0	72.8	58.3	46.7	44.1	58.1	
	Precip.	7.59	3.56	7.13	3.40	6.46	3.82	5.25	1.83	5.20	5.76	5.38	9.25	5.39	64.63
1973	Temp.	38.0	39.1	55.5	56.0	63.6	74.6	77.3	75.4	73.3	62.6	52.1	40.6	59.0	
	Precip.	5.81	3.66	13.56	5.04	8.91	5.80	7.15	1.46	4.93	2.57	7.10	10.90	6.41	76.89
1974	Temp.	48.0	42.5	55.2	59.0	67.9	69.9	76.8	75.2	68.0	57.1	48.7	40.8	59.1	
	Precip.	9.45	6.68	5.92	6.80	8.70	1.73	2.26	6.88	4.12	2.07	5.19	6.20	5.50	66.0
Avg.	Temp.	38.3	40.3	50.7	57.8	65.7	72.9	76.4	75.7	72.5	61.0	48.5	43.5		
	Precip.	6.20	4.80	7.55	4.9	6.34	3.90	4.81	3.31	4.03	4.05	4.29	8.17		

SOURCE: "Climatological Data, Tennessee," U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. Monthly Summaries.

TABLE E-2. A-horizon soil analysis (pH, P and K) for 1972, 1973 and 1974 arranged by treatments for the three study sites.

No.	Treatment Description	pH 1972	pH 1973	pH 1974	P(lbs/A) 1972	P(lbs/A) 1973	P(lbs/A) 1974	K(lbs/A) 1972	K(lbs/A) 1973	K(lbs/A) 1974
Plateau										
1	Control	4.8	4.9	4.8	6	7	3	105	110	88
2	Hardwood Control	5.0	4.9	5.1	6	7	3	97	110	78
5	150-35-100	4.7	4.8	4.6	18	15	12	113	120	79
6	150-35-100-HC	4.9	4.8	4.8	16	15	11	126	120	85
9	150-35-100-Micro	4.9	4.8	4.8	13	15	8	125	120	87
10	150(Urea)-35-100	4.9	4.9	4.9	10	10	5	130	130	110
11	0-35-100	4.9	4.9	4.7	17	16	5	133	140	92
12	75-35-100	5.0	5.2	5.0	8	9	6	120	120	90
13	300-35-100	4.8	4.9	4.8	11	10	5	95	100	85
14	150-0-100	4.8	4.8	4.7	7	8	3	110	110	85
15	150-70-100	4.9	4.9	4.9	46	40	29	130	140	90
16	150-35-0	5.0	5.1	4.7	14	12	7	103	90	87
Satellite										
1	Control	4.7	4.9	4.3	7	9	5	115	120	87
5	150-35-100	4.9	5.0	4.5	25	21	7	120	120	82
13	300-35-100	4.9	5.0	4.4	13	15	7	105	100	80

TABLE E-2. (Continued)

No.	Treatment Description	pH 1972	pH 1973	pH 1974	P/lbs/A) 1972	P/lbs/A) 1973	P/lbs/A) 1974	K(lbs/A) 1972	K(lbs/A) 1973	K(lbs/A) 1974
Valley										
1	Control	4.6	4.7	4.3	5	6	3	65	60	57
3	Thinning (T)	4.5	4.7	4.5	7	6	3	55	60	45
5	150-35-100	4.5	4.8	4.5	27	21	17	77	70	47
7	150-35-100-T	4.5	4.8	4.4	21	21	9	57	70	45
9	150-35-100-Micro	4.5	4.8	4.5	17	21	13	63	70	52
10	150(Urea)-35-100	4.5	4.7	4.5	19	21	10	83	80	60
11	0-35-100	4.6	4.8	4.4	19	20	13	67	80	62
12	75-35-100	4.6	4.8	4.4	18	16	8	97	100	57
13	300-35-100	4.5	4.7	4.5	21	21	8	63	70	47
14	150-0-100	4.3	4.5	4.3	5	6	3	55	60	52
15	150-10-100	4.6	4.7	4.4	80	65	24	57	70	62
16	150-35-0	4.4	4.6	4.4	18	17	19	45	50	47
17	Sludge @ 50# N/A	4.5	4.7	4.4	7	6	4	57	60	55
18	Sludge @ 100# N/A	4.2	4.5	4.3	7	7	4	55	50	47

VITA

Jerry L. Richeson was born in Athens, Tennessee, on June 25, 1951. He attended City Park Elementary School in Athens and graduated from McMinn County High School in June, 1969. During September, 1969, he entered The University of Tennessee and received a Bachelor of Science degree in Forestry in August, 1973. In September, 1973, he accepted a research assistantship with The University of Tennessee Forestry Department and began study toward a Master of Science degree.

He has been employed by the Washington State Department of Natural Resources since November, 1975, and received his Master's degree in June, 1976.

He is a member of the Society of American Foresters and Xi Sigma Pi.

He has been married to the former Andrea D. Tessler of Chicago, Illinois since September, 1972.