THE EFFECTS OF FERTILIZATION ON DIAMETER GROWTH IN DENSE STANDS OF PONDEROSA PINE IN ARIZONA

by

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ABSTRACT

In 1961, fifty 1/50-acre plots were established near Blue Mountain in Arizona by Professor R. F. Wagle for the purpose of testing a selected group of fertilizers, a herbicide and a growth hormone in overcoming stagnation in Ponderosa pine stands. Thirteen treatments were applied at random on the plots.

Nitrogen, phosphorus, potassium, fenuron, gibberellic acid, along with a selected group of microelements were applied on the plots.

Tree growth was measured at the end of each growing season by use of a dendrometer or growth band. The growth band measured circumference growth to 0.01 inches. Diameter measurements were made in 1961 and 1973 using a diameter tape. Diameter measurements were estimated to 0.01 inches.

The data were analyzed using Student-Newman-Kuels' test. The analyses were performed at the 95% confidence level. The results indicated that stagnation cannot be broken using fertilizers without thinning when the stand and site characteristics of the type present in this study exist.

INTRODUCTION

Many pole-sized stands of ponderosa pine in the Southwest are highly overstocked by several thousand trees per acre, which has resulted in severely reduced growth. From the timber production point of view, these slow-growing or stagnated stands are worthless. Because ponderosa pine is the most important timber species in the Southwest, (U. S. Dept. of Agr., 1949) growth stagnation results in economic loss in timber and forage production and wildlife and watershed values.

Many agencies have been thinning these dense stands by mechanical and chemical means. The primary objective of thinning is to open up the stand and move the growth from many individuals to fewer individuals. First, undesirable individuals (poorly formed, damaged, large limbs, etc.) are removed according to spacing requirements, priorities and size.

The objective of this study was to test the ability of selected fertilizers, a herbicide and a growth hormone to assist the pine stands in overcoming stagnation.

Chemical, hand and mechanical thinning procedures were not a part of this study.

If growth stagnation can be broken by methods other than chemical or mechanical, tremendous savings in thinning costs and increased profits might be realized by federal, state, and private agencies. If growth stagnation can be overcome by fertilization in ponderosa pine stands, similar or modified techniques may be applicable to other stands with species exhibiting similar growth characteristics.

Overcoming growth stagnation through fertilizing, herbicides or growth stimulants should be far better and cheaper than the current methods which involve high labor and machine costs. Hundreds of acres could easily be treated in a day by aerial application. Whereas, by current methods, chemical or mechanical procedures, a crew can only treat a few acres in a day, with the attendant high labor costs.

LITERATURE REVIEW

In the southwestern United States, many dense stands of ponderosa pine (*Pinus ponderosa* Laws.) were regenerated after the logging operations of the 1880's. The majority were established around 1919 (Gaines and Kotok, 1954) following an extremely large seed crop and favorable growing conditions. Many of these stands have become stagnant, and presently are nearly worthless for timber production.

Around 1920, some interest was developed in thinning these dense ponderosa pine thickets. The first studies were made in the forests of Arizona and New Mexico; however, these were primarily small scale and academic in nature until 1933 when the Civilian Conservation Corps made it possible to test large scale thinning theories (Gaines and Kotok, 1954).

Numerous thinning studies have been conducted on many of the major timber species while forest nutrient studies have been largely confined to tree nurseries. Very little work has been done on forest thinning and nutrients in combination (Beasley, 1966).

In the past, a controversy centered around the factors which cause trees to grow faster following thinning (Krauch, 1924; Meyer, 1931; Curtis and Lynch, 1957; and Barrett, 1963). All agree that increases in tree growth are due more to increases in available soil moisture rather than to increases in light. Krauch (1924:39,40) working in the Southwest in ponderosa pine stands which had been partially logged about 28 years prior to the study found that ". . . the growth of large trees becomes greatly accelerated after part of the stand has been cut. . . . The data were obtained from 106 trees ranging between 15 and 26 inches in diameter and around 200 years. . ." old. His results also showed that growth response is due more to reduction in competition for soil moisture than the effects of increase in light. Meyer (1931:1127) in studies on 174 ponderosa pine trees released 20 to 40 years ago on ten different areas in Washington and Oregon found that "... the effect of moisture is of paramount significance, while that of light is only of secondary importance."

Meyers (1958) working in the Black Hills of South Dakota, tested three degrees of thinning on three age classes 28-40- and 55-year-old trees. The 28- and 40-year-old trees exhibited the best growth. Curtis and Lynch (1957) stated that increase in the growth of ponderosa pine were due primarily to increases in soil moisture following thinning rather than to the expansion of the crowns. Barrett (1963) studied the release of mature ponderosa pine in central Oregon, wherein all dominant trees were numbered and tagged, and all subordinate trees were removed on each of five randomly selected 1/10 acre plots, and five unthinned plots served as controls. The study showed that dominant trees do respond to thinning, thereby disproving the adage that dominant trees grow faster simply because they receive full sunlight.

Forest thinning studies in the past have been mostly concerned with increases in available moisture or light as primary causal agents in increasing tree growth. It is the author's opinion that this approach is too narrow. Interacting agents, including light, available moisture, nutrients, soil texture, structure, depth, microbial activity, and numerous other factors, can all influence tree growth.

Mace and Wagle (1964), working in stagnated stands of ponderosa pine in Arizona increased tree growth slightly by artificially increasing soil moisture beyond natural precipitation levels but found that the greatest growth occurred during periods of high relative humidity. This indicates that atmospheric moisture may have a greater influence on growth than any one of the other interrelating factors.

Staebler (1956:339), studying young Douglas fir (Pseudotsuga menziesii (Mirb.) Franco) stands in the Pacific Northwest found a significant reduction in height growth following thinning. The reduction was most evident the third year after thinning (p.339). "The reduction in height growth is considered to be evidence of shock." Dahms (1960), working with ponderosa pine in the Pacific Northwest observed that seedlings responded to thinning by quickly developing full crowns; however, height growth was slow at first but gradually increased to about one foot per year. Barrett (1963), working on dominant ponderosa pine poles found that during the first six years after thinning, the major response to release was in diameter increments with no clear-cut increases in height growth.

Beasley (1966) and Wagle and Beasley (1968), using thinning and nutrient-thinning combinations on young ponderosa pine stands near McNary, Arizona, obtained significant increases in diameter growth and basal area at the end of the second growing season from most of the treatments used. Height and diameter growth were reduced significantly in some treatments over the two-year period.

Teeguarden and Gordon (1964) found that ponderosa pine and Jeffrey pine seedlings in Northern California grew three times faster in thinned stands and height growth was 67% greater than in unthinned stands. It was also noted that pine trees required a minimum of two years before released trees showed increases in height growth. They also presented data that showed trees of advanced age responded to thinning. Pearson (1936), in ponderosa pine studies over a ten-year period on the Prescott National Forest of Arizona, observed that trees on thinned plots grew more in diameter and had a greater basal area than trees on unthinned plots. Krauch (1949) found only small differences in basal area growth between the same thinned and unthinned plots but height growth was greater on the thinned plots. Hornibrook (1936) found the growth of crop trees growing on the Coconino National Forest in plots thinned to a wide spacing was significantly higher than on crop trees on plots thinned to a narrow spacing. Trees with narrow spacing did not grow significantly faster in diameter than trees growing on non-thinned plots. There were no significant differences in tree heights for trees growing on the differently treated plots. Gaines and Kotok (1954), showed that thinning dense ponderosa pine stands in varied locations in Arizona and New Mexico increased the diameter growth on the remaining trees 10 to 35 percent. The fastest growth occurred on the plots with the lowest basal area per acre.

Pearson and Follweiler (1927), found that the bole form of trees in thinned mature ponderosa pine stands growing in Arizona changed very little from breast height to the top of the second log when the growth form of the remaining trees was computed following logging operations. However, in thinned immature ponderosa pine stands tree bole form changed steadily from breast height to the top of the second log. The growth increment of the bole changed with different heights above the ground following cutting. This study also showed that large trees unhampered by competition, often put on as much annual growth as smaller trees.

It is the author's belief that it takes a period of time after thinning for trees to respond to release and become wind firm. During this period, the tree strengthens both its bole and root system. The root system grows the fastest to occupy the released spaces thereby enabling the tree to better withstand increased wind stress which results from opening up the stand. Crown increases through foliage and twig growth is probably also a necessary prelude to rapid main stem growth and this also takes some time. This time period may vary with species, tree size, and environment and could explain many of the differences reported in the literature as to the length of time required for growth increases from thinning to become apparent.

Nutrient studies in forest stands were first made in Europe in planted stands. Ebermayer (1876), indicated that the majority of nutrients in a tree were contained within the leaves and branches. Therefore, if logging slash is left in the forest following cutting, only small amounts of nutrients (those contained within the harvested portion) would need replacing (Beasley, 1966). Meyer and Krapol (1956), and Laatsch (1957), found that nitrogen applications increased tree growth in European conifers. Galoux (1954), fertilized scotch pine seedlings (Pinus sylvestris L.) in Belgium using lime and phosphorus observed that one fertilization of newly planted scotch pine seedlings resulted in increased growth which was maintained for long periods of time.

In Southeastern U.S., Allen and Maki (1955) established that longleaf pine (Pinus palustris Mill.) seedlings responded best to nitrogen, phosphorus, and potassium fertilizer. Seedlings receiving only one or two nutrients did not respond as well as seedlings receiving all three nutrients. Walker and Youngberg (1962) applied nitrogen and phosphorus separately and then together on slash pine (Pinus elloittii Engelm. var. elliottii) in southern Georgia. They observed increased growth in all cases, which, however, lasted only three years.

Several workers were able to increase the growth of larger forest trees by applying fertilizers. Gessel and Shareeff (1957), applied nitrogen to a 30-year old Douglas fir stand and increased growth in both diameter and volume. Heilman and Gessel (1963), stated that the effects of nitrogen on growth were still evident in mature Douglas fir stands ten years after application. Zahner (1959) applied nitrogen, phosphorus, and potassium to loblolly pine in southern Arkansas and substantially increased growth rates over non-fertilized trees for two years. Hoekstra and Asher (1962) working with slash pine in Florida were able to increase growth with applications of nitrogen, phosphorus, and potassium. Significant results were evident the first year after application.

Wilde (1961:346), stated that the laws governing nutrition of nursery and forest stands are basically the same, but"... they differ radically in their quantitative demands for nutrients and in the drain which they exert on soil fertility." Care must be taken in interpreting results of nursery fertilization experiments and applying these results to forest stands. The major differences influencing the nutrient availability between nursery seedlings and forest stands are the number of trees per acre and the rooting depth. The number of individuals in a nursery may reach millions of trees per acre, whereas forest stands usually have less than 2,000 trees per acre. Seedlings in nurseries are rooted primarily in the upper twelve inches of soil, while forest stands derive their nutrients from much larger volumes of soil. Nurseries have relatively small amounts of nutrients recycling through needle fall, while forest stands have large quantities of nutrient recycling. Adams and Dickson (1973:35), studying the nutrition of sitka spruce (*Picea sitchsensis* (Bong.) Carr.) found that with low soil fertility "... tree nutrition depends to a large extent upon nutrient cycling via litter fall. Large accumulations of organic matter on the forest floor break the cycle and are therefore undesirable."

Additional problems of forest fertilization were discussed by Pritchett and Robertson (1960). They found the roots of young slash pine, two-, three- and five-years old, will reach out horizontally nineteen, twenty-five and thirty-two feet respectively with root grafts occurring in trees five years and older. Except for short-term nutrient studies, they stated plot size should be about 1/4- to 1/2-acre in size. Gessel, Walker and Haddock (1950) improved the appearance and nutrient content of Douglas fir needles by applying fertilizer to nutrient deficient stands. They used superphosphate, ammonium nitrate, ammonium sulfate, potassium sulphate, and lime and concluded that a program of fertilizing forest stands with nitrogen would result in faster growth of second growth stands. Heiberg and White (1950), obtained significant height growth increases in a variety of pine stands in Northern New York fertilizing with sodium nitrate and potassium. Height growth was increased as much as 104% with potassium. Mergen and Voigt (1960) using five rates of nitrogen, phosphorus, and potassium fertilizer application on two age classes of slash pine, increased growth by 32% in the 22-year-old age class trees.

Farmer, Snow and Curlin (1970), applied nitrogen and phosphorus to young yellow poplar (Liriodendron tulififera L.) in southern Michigan and increased the growth for two years after planting. Phosphorus was only effective when used in combination with nitrogen.

By fertilizing slash pine in the Florida sand hills Baker (1973) caused a shift in the tree height class distribution toward a larger height class. Brix (1971), in treating Douglas fir found that the greatest response in tree diameter growth occurred in the early part of the growing season--April and May.

The only studies found in the literature on the effect of combinations of thinning and fertilizer on tree growth were made by Curlin (1963), Beasley (1966), and Wagle and Beasley (1968). Curlin (1963:234) applied nitrogen and phosphorus to young short leaf pine (Pinus echinata, Mill.) trees in Tennessee, "... singly and in combination on both thinned and unthinned plots." At the end of four years, growth in basal area had increased as much as 300% over growth in the unthinned control plots. Trees growing in the thinned plots receiving only nitrogen increased basal area by 40%. Beasley (1966), and Wagle and Beasley (1968), using thinning and fertilizer treatments on second growth ponderosa pine near McNary, Arizona, increased growth in basal area 20.5% in two years for all treatments over trees growing in unthinned-unfertilized plots. The trees on the thinned-fertilized plots, increased in basal area 55.7% the first year and 29.9% the second year over the unthinned-unfertilized plots. The greatest growth differences occurred between the trees growing on the thinned-fertilized, and those growing on the unthinned-unfertilized plots; this difference was 174.7% the first year and 192.0% the second year.

Most researchers generally agree that gibberellic acid (GBA) positively effects forest tree growth. Marth, Audia and Mitchell (1956), Nelson (1957) and Westing (1959) have reported GBA to be of only limited value for forestry use. Conifer seedlings require high concentrations of GBA before response becomes evident. It is also pointed out by Jensen and Dochinger (1972) that several applications of GBA at high concentration resulted in more growth than using weaker concentrations in either more or fewer applications. The GBA treatments also increased the period over which rapid elongation or terminal stem growth occurred.

Marth, Audia and Mitchell (1956) found that coniferous species are less responsive than most hardwood species to GBA applications. Virginia pine (Pinus virginiana Mill.) gave the greatest increase in height growth of all of the pines tested.

Bilan and Kemp (1960) stated that both the method of treatment and the concentration of gibberellic in solution were highly significant factors. As the GBA concentration was increased, the height growth of loblolly pine seedlings (Pinus taeda L.) increased proportionately. These authors also found that GBA applications to the shoots result in considerably less increase in height growth than root applications. They assumed that this difference may arise from the fact that the stems were actively growing at the time of application. Therefore, for gibberellin to influence growth, it must enter into living cells or tissue.

Several pertinent facts can be summarized from the literature review:

1. Thinning dense tree stands will ultimately increase the growth rate on the remaining stock. A growth increase can be detected in many species regardless of age.

2. Thinnings combined with fertilizer treatments usually result in greater growth increases than would

have normally occurred had the treatments been applied separately.

3. Application of fertilizers may or may not increase tree growth, depending on existing environmental conditions.

4. A highly erratic response period usually results for both diameter and height growth following thinning or nutrient applications.

DESCRIPTION OF THE STUDY AREA

Location

The site on which the study was made is located five miles east of McNary, Arizona, near Blue Mountain in the northeast corner of the Fort Apache Indian Reservation. The legal description is as follows: the NW1/4, SW1/4, Sec. 26, T. 8N. R. 24E. Gila and Salt River Base and Meridian. The elevation is 7,683 feet[1] above mean sea level.

Soil

In general, the area has a gentle slope of 1% with a southwest exposure.

The soil description, given in its entirety in the Appendix, was made by S.W. Buol[2] of The University of Arizona. Soil profiles, which formed the basis of Buol's description, were obtained from pits located near Plot 46. (see Figures A1, A2 in Appendix.) Generally, the soils were relatively uniform

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1. Elevation obtained from a USGS bench mark near the starting point of the plot transect.

2. Buol, S.W. Ph.D. Assist. Professor of Agri. Chem. and Soils; Assist. Agri. Chemist, Agri. Exp. Sta.; University of Arizona, Tucson, Arizona.

throughout the area--immature and originating from volcanic cinders.

Vegetation

The predominant vegetation was second growth ponderosa pine which was growing in pure, dense, even-aged sapling thickets ranging in size from 1/4-acre to several acres. Large, mature and over-mature pine were scattered throughout the area. A great majority of the sapling thickets became established after a devasting forest fire in 1904 which destroyed 60,000 acres of timber (Kallander, 1969). Seeds from the survivors fell on an excellent seed bed resulting from the fire.

The stand averages 875 trees per acre with an average basal area of 156 square feet per acre. Average basal area per tree is 0.178 square feet or an average tree diameter of 5.7 inches DBH for the stand.[3]

The crowns form a moderately dense closed canopy. The closed canopy, together with the build-up of surface litter results in almost no surface vegetation in the

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3. From data collected on August 13, 1974 by the Continuous Forest Inventory crew under the supervision of Richard E.A. Lyon, Forester, Fort Apache Indian Reservation, Arizona. Special permission has been granted for the use of the above information.

stands. A large variety of grasses, forbs, etc., only reach significant quantities in the more open areas.

A doghair, or sapling thicket, may be described as a stand of small trees generally less than 5.0 inches in diameter, and densities are such that diameter and height growth are very slow and have often been described as stagnated. A stand may remain in a stagnated condition for several decades. However, through growth and mortality, dominance may eventually be asserted naturally over time and stagnation may be overcome thereby permitting a more normal stand to develop. The time involved in expressing dominance under these conditions is so great that the timber production potential of the land occupied by these dense stands is almost non-existent.

Climate

Data from the McNary weather station were utilized to determine mean annual temperature and precipitation values. The mean annual daily maximum temperature is 62.3°F. with a mean annual daily minimum of 30.8°F. Maximum temperatures occur during July and August and minimum temperatures occurred in January and February.

The mean annual precipitation is 24.70 inches with 80% occurring in the three summer and four winter months.

The summer precipitation usually comes from high intensity convective thunder storms. The summer storms are characteristically localized and of short duration. The summer storms are the result of warm moist air moving up from the Bermuda high pressure zone situated in the Gulf of Mexico.

Winter precipitation is cyclonic in nature and characterized by storms of longer duration, lower intensity which cover wide areas. These winter storms come in from the Pacific coast. About 80% of the winter precipitation occurs as snow (Sellers, 1960).

METHOD OF STUDY

In the summer of 1961, three macro nutrients, a herbicide and a growth hormone were applied to fifty 1/50-acre plots which were established along a 2,325-foot transect. Criteria used in locating the plots were that they be fairly uniform in tree density and trees were of the same approximate age class. An effort was also made to locate the plots removed from the influences of mature and over-mature trees.

Other factors such as soil types, slope, topography and aspect were relatively uniform throughout the area. Even though the plot areas were the same, the plot widths and lengths were varied to obtain more uniformity between the densities, heights, age classes, etc. of the trees included.

Ten trees were selected in each plot for measurement and these were arbitrarily classed as crop trees. They were selected on the basis of crown vigor, DBH and the likelihood of surviving to final harvest. However, an effort was made to include dominants, codominants and some intermediates in the selections.

Eight fertilizer and five miscellaneous treatments were applied randomly prior to the summer rainy season.

To avoid an edge effect between the treated and untreated areas, a 15-foot wide buffer zone around each plot received the same treatment as the study plot.

The treatments and nutrient combinations applied to the plots are given in Table I. All treatments were applied only once.

Selective and non-selective refers to the method in which macro nutrients, micro nutrients, fenuron, and gibberellic acid (GBA) were applied.

Selective application of NPK(S) and micro elements means these nutrients were only applied to the base of crop trees. In contrast, selective application of fenuron means that fenuron was selectively applied to the crowns and bole of non-crop trees. Non-selective nutrient or fenuron applications means that the nutrients or fenuron were applied as evenly as possible over the plot without regard to crop trees. The selective fenuron treatment was used to encourage mortality selectively in the non-crop trees and the non-selective fenuron treatment was used to determine if fenuron would cause the most mortality in the weakest trees and thus

Table I. Treatments and nutrient combinations applied to the Blue Mountain study plots.

Plot Numbers	Regular Treatments
5, 9, 11, 12, 13, 15, 25, 27, 37, 40, 50	control
1, 20, 38, 44	partial treatment N,P,K (S) and no micro nutrients
6, 22, 24, 26	full treatment N,P,K (S)+ micro nutrients
3, 8, 48, 49	partial treatment P,K (S)-n+ micro nutrients
2, 4, 31, 32	partial treatment N,K (S)-p+ micro nutrients
19, 23, 45, 47	partial treatment N,P,K (S)+ micro nutrients
18, 33, 39, 46	no litter. all litter removed and added to double litter.
7, 30, 36, 42	double litter
	Miscellaneous Treatments
17, 21, 41	sel N,P,K (S) + micro elements
16, 28	sel fen
29, 43	non-sel-fen
10, 34	sel GBA
14, 35	sel GBA + N,P,K (S) + micro elements

Terminology

N = nitrogen	S = sulfur	GBA = gibberellic acid
P = phosphorus	Fen = fenuron	Sel = selective
K = potassium		Non sel = non selective

The 50 plots are located near Blue Mountain, east of McNary, Arizona.

encourage the remaining trees to assert dominance over a shorter period of time. GBA was only applied to the crown of selected crop trees in which increased height growth or assertion of dominance was desired. All nutrients were hand broadcast around selected trees and over the plot and buffer zone as evenly as possible. The chelated microelements; Copper, Iron, Zinc, Boron, and Manganese, in a common solution, were applied in the amounts per acre shown in Table II. The microelement chelates were applied to the plots with a hand sprayer after being mixed with distilled water. Fenuron, in the form of pellets with 25% active ingredient was also broadcast at a rate of 16 lbs active ingredient per acre. Gibberellic acid was mixed with 1.5 gallons of distilled water, 50 ml. of glycerin and a heaping teaspoon of detergent and applied with a hand sprayer to the foliage of the trees designated as crop trees.

The nutrients, their acre equivalents and the chemical compounds in which they were applied on the plots are shown in Table II.

At the time of the initial plot measurement, the diameter at breast height, 4.5 feet above the ground, was measured to the nearest 0.01 inch.

Table II. Nutrients applied to ponderosa pine on Blue Mountain study plots.

			Acre Equivalent	
Fertilizer	Compound	Compound LBS/AC	Nutrient	Nutrient LBS/AC
Nitrogen (N)	NH4 NO_3	215.54	N	75.00
Phosphorus (P)	$CaH_2(PO_4)$+$2H_2$	266.40	P_2O_5	150.00
Potassium (K)	K_2 SO_4	92.50	K_2O	50.00
Sulfur (S)	K_2 SO_4	92.50	S	15.00 (approx.)
Micro element Chelate Dow M 1761				
Iron (Fe)				5.00
Zinc (Z)				2.50
Manganese (Mn)				2.50
Copper (CU)				1.25
Boron (Bo)				2.50
Fenuron				16 lb a.i./ acre
Gibberellic acid				50 g/acre

To measure growth over a long period of time, a growth band with a vernier (dendrometer) (Fig. 1) was installed at DBH on the ten crop trees in each plot (Liming, 1957). The vernier data were collected to detect dramatic growth changes on a year-to-year basis. The initial growth band readings were recorded at the time of installation. By means of the vernier, growth increases in circumference as little as 0.01 inch could be measured. Growth measurements were recorded annually after tree growth had stopped for the season. An example of the raw data is given in the appendix in Table A1.

A summary of growth occurring over the twelve year study period is shown in Table III, and in Figure 2.

DHB measurements were taken again with a diameter tape in 1973 and estimated to 0.0 inch. Both diameter and vernier measurements were taken at the same location on the tree.

To ensure that all plots had a common basis of measurement, the square feet basal area values were calculated. Basal area measurements were used because larger trees have more basal area growth with a given diameter increase than do smaller trees. This method is the most common measurement in modern forestry for discussing stand densities

Figure 1. A Growth Band Installed On A Small Tree Stem.

The vernier is 1.34 inches. Subsequent changes in this reading when added to the initial measurement will give the growth in circumference over specific periods of time.

Table III. Total average growth per tree by treatment in diameter and basal area.

Treatment Number	Treatment*	Diameter Growth in Inches	Basal Area Growth in Square Feet
1	No Litter	3.10	.0523
2	Control	3.06	.0510
3	Non-Sel Fen	3.37	.0618
4	Sel-GBA	3.22	.0567
5	NK(S)-P+Me	2.62	.0373
6	PK(S)-N+Me	3.04	.0504
7	Double Litter	2.88	.0453
8	Sel-Fen	3.03	.0500
9	NPK(S)-Me	3.40	.0632
10	NPK(S)+Me	3.54	.0683
11	NP-K(S)+Me	3.35	.0613
12	Sel-NPK(S)+Me	3.73	.0758
13	Sel-GBA+NPK(S)+Me	3.90	.0830

*Non-Sel-Fen = nonselective fenuron

(S) = Sulfur

Sel-GBA = selective gibberellic acid

K = Potassium

N = Nitrogen

Me = micro elements

P = Phosphorus

Sel = selective

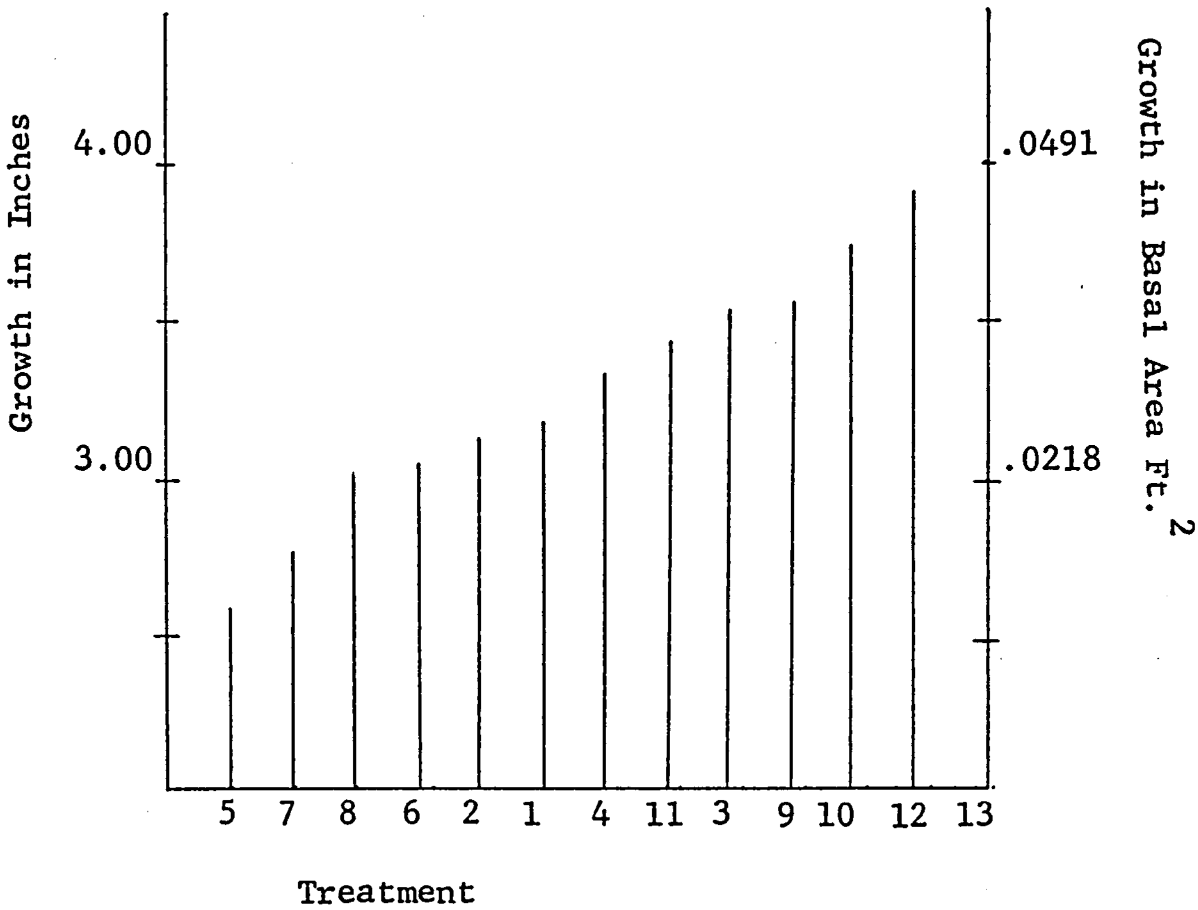

Figure 2. Growth Relationships Between Treatments

and volume. The original diameter values were averaged by plot (Appendix, Table AIII) and converted to mean square feet basal area, and mean circumference. The vernier values for each plot were averaged by year and converted to basal area (Appendix, Table AII). The increases recorded by the growth bands represented increases in tree circumference. The annual differences in the growth band readings were then added to the circumference which gave the mean circumference of the plots by year. The circumference was then converted to diameter and basal area. The basal areas were calculated using the following formula:

$$\text{Basal area Ft.}^2 = \frac{\pi D^2}{4 \times 144} = .00545415\ D^2$$

D = diameter in inches

An example of the procedure is described in Table AIV of the appendix. (The above description was utilized in the Student Newman-Kuels' analysis.)

If a tree died during the measurement period, or inconsistencies such as incorrect DBH in 1961, or erratic vernier readings existed due to measurement errors, that tree would be dropped from the analysis. A total of 29 trees was dropped for one or more of the reasons stated.

The basal area means were calculated from Table AIII of the Appendix and were then grouped according to treatment and punched onto computer cards. The analysis of variance was performed by the University of Arizona Agricultural Experiment Station Statistics, computer CDC 6400. The data were then analyzed using the Student-Newman-Kuels' procedure as described by Steel and Torrie (1960:111) at the 95% confidence level. The Student-Newman-Kuels' method was selected because "... it takes into account the number of treatments in the experiment; it is a multiple-range test for judging the significance of a set of differences; it permits decisions as to which differences are significant and which are not; it is a range test procedure and the error rate applies at each stage to tests involving the same number of means." The Student-Newman-Kuels' test was designed to detect significant differences between treatment means. The treatment means were ranked according to size and are presented in the Results and Discussion section in Table IV.

RESULTS AND DISCUSSION

Basal area growth was calculated from thirteen years of data by use of growth bands. The growth band measures increases in tree circumference. The growth band data were then converted to basal areas.

The analysis of variance (Table IV) showed that the shortest significant range between treatment means was 2.87 $Ft.^2$. As can be seen from the ranked treatment presented in Table IV the maximum difference for the 1961 date is 0.0448 $Ft.^2$ (NK(S)-P+Me and Sel NPK(S)+Me), and 0.0876 $Ft.^2$ (NK(S)-P+Me and Sel GBA+NPK(S)+Me) for the 1973 data. Therefore, there were no significant differences detected at the 95% confidence level at the start of the experiment in 1961, and no significant differences had developed between treatments at the conclusion of the experiment in 1973.

In a study conducted west of McNary, Arizona, in 1965 by Beasley, significant differences were detected between the unthinned-fertilized plots one year after treatments were applied. This portion of Beasley's and Wagle's and Beasley's study was identical to the author's Blue Mountain study. The author believes that differences observed between

Table IV. Analysis of variance for the Student-Newman-Kuels' Test for the diameter data presented in Table AIII of the Appendix

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	F prob.*
1961:					
Between treatments	12	.0110	.0009	1.00	.418
Within treatments	37	.0318	.0009		
Total	49	.0428			
1973:					
Between treatments	12	.0287	.0024	1.60	.152
Within treatments	37	.0573	.0015		
Total	49	.0859			

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Ranges for the 95% confidence level for 1961 and 1973:

Number of treatments P:	2	3	4	5	6	7
Ranges for the mean:	2.87	3.45	3.80	4.05	4.25	4.41 ..
	8	9	10	11	12	13
	.. 4.45	4.66	4.66	4.85	4.93	5.06

* F prob. The probability of a difference between two treatment means being declared significant.

Table IV. (continued)

1961
Means presented in Table AII of the Appendix

Treatment number:		5	8	1	2	6	10
Treatment mean:		.1331	.1338	.1361	.1460	.1473	.1476..
	7	9	4	3	11	13	12
	.. .1481	.1531	.1720	.1725	.1700	.1750	.1779

1973
Means presented in Table AII of the Appendix

Treatment number:		5	8	1	7	2	6
Treatment mean:		.1704	.1838	.1884	.1934	.1970	.1977..
	10	9	4	3	11	12	13
	.. .2159	.2163	.2287	.2343	.2383	.2537	.2580

No pair of treatments have means that differ by more than the shortest significant range of a subset of that size.

Using the 1961 data a difference between means two apart (treatments 5 and 8, 8 and 1, etc.) must be at least 2.87 for the difference to be significant. Likewise, the difference between means (such as treatments 5 and 13, 8 and 11, 1 and 12) must be at least 4.85 for the difference to be significant. All means underlined by the same solid line are not significant (no significance found).

Beasley's study and the Blue Mountain study arose from variations due mainly to differing tree densities and soil characteristics of the two study areas.

The following differences and similarities between the Blue Mountain site and the study site used by Beasley should be noted. The two areas were approximately eight miles apart. Slope, temperature, annual precipitation and aspect were all relatively constant. It should also be mentioned again that a portion of the fertilizer treatments of Beasley and Wagle, and Beasley were the same for both studies. There is an elevation difference of two to three hundred feet between the two areas.

The major differences between the sites were in tree density, size and distribution of sapling thickets and soil type.

Basal area on the Blue Mountain plots ranged from 140 to 180 square-feet per acre, while in Beasley's study the basal area averaged about 100 square-feet per acre.[4]

The Blue Mountain site had larger sapling thickets with a more compact aerial distribution of thickets.

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4. Personal interview with Richard E.A. Lyons, Forester, Fort Apache Indian Reservation, Arizona. Dec. 11, 1974.

The soils of the Blue Mountain study area were older, deeper and better developed than those found on Beasley's site. In addition to this, certain areas around Beasley's site were noted for having a perched water table.[5]

When the results of Beasley's unthinned-unfertilized and unthinned-fertilized plots were compared with the results obtained from the Blue Mountain study site, it became apparent that stagnation in pine stands could be overcome if tree densities were not above a predetermined maximum dictated by site characteristics. This assumption was made with reservations, however, because Beasley's study was a short term project covering a period of two years.

The results of this study show that fertilizer, herbicide and growth stimulant applications cannot overcome stagnation with tree densities of the magnitude presented here. This follows the results of numerous researchers who have achieved significant increases in growth through varying degrees of thinning and thinning-fertilizer combination.

With the exception of a portion of the Beasley, and Beasley and Wagle study, the literature contained no

5. Personal interview with Richard E.A. Lyons, Forester, Fort Apache Indian Reservation, Sept. 12, 1974.

information on overcoming stand stagnation in natural forest stands without the aid of thinning. However, there are several pieces of literature which cite significant growth increases on less than stagnated or in overstocked stand conditions (Gessel and Shareeff, 1957; Zahner, 1959; Hoekstra and Asher, 1962) to mention a few. This supports the theory that there may be a critical density dictated by site conditions, and beyond which it is impossible to break stagnation without thinning.

However, it should be remembered that the quantities of nutrients applied were small and only one application was made. Further testing seems to be indicated which would involve the applications of larger quantities of nutrients and/or periodic applications.

CONCLUSION

As previously stated significant differences could not be detected by the Student-Newman-Kuels' analysis at the 95% level thirteen years following the treatment applications. With densities of 156 square-feet per acre under the existing site conditions, stagnation was not broken by using fertilizers in the amounts applied in this study. Either a reduction in the number of trees per acre or more fertilizer may be required to bring about significant growth responses in these stands.

SUMMARY

In 1961 a study site east of McNary was established in a stagnated stand of ponderosa pine to test the ability of a selected group of fertilizers in breaking stagnation. Thirteen treatments were randomly applied to a total of fifty 1/50-acre plots with ten selected trees per plot.

Using the Student-Newman-Kuels' analysis, the following conclusion was reached: fertilizer, herbicide and growth stimulant applications did not overcome stagnation. A reduction in the number of trees per acre or the application of more fertilizer is needed to overcome stagnation in dense pine thickets with site and vegetation condition which were presented in this study.

APPENDIX

SOIL DESCRIPTION OF AREA IN WHICH THE FERTILIZER PLOTS WERE LOCATED

Watershed Management Plots in the Whiteriver Apache Indian Reservation, Arizona

By S. W. Buol

Area 1:

Soils in this area are silt loam in texture developed from pumic material under a multi-aged stand of Ponderosa pine at an elevation of approximately 7,500 feet. Pumic particles, ranging from 1" - 3" in diameter are distributed throughout the profile and into the clay loam textured lower strata that is apparently the result of a different lithologic deposition or a paleosalic B horizon. The presence of clay skin development would tend to support the theory of a paleosalic development. However, since no C horizon could be detected in the present profile there exists good evidence that the clay skin may be presently forming. The profiles appear to be quite uniform in the four pits examined. The range of depth to the clay loam textured lithologic layer was observed to range from 33 to 20 inches from the surface. This layer has a definite influence on the subsurface drainage, as shown by presence of mottling. Of the morphological characteristics in the profiles of the area it is probable that the depth to the clay loam layer would have the greatest influence on the growth of the ponderosa pine and should be examined locally in comparative plots.

The following are field descriptions of two pits in the area.

Soil Profile		Area Pit 1 (Plot 6)
A_{oo}-A_o	1/2" - 0"	Partially decomposed ponderosa pine needles, A_o portion pH 5.0.
A_1	0 - 2"	Dark reddish brown (5YR 2/2 moist) silt loam, weak find platy structure, moderately acid (pH 5.5); clear smooth boundary.

Soil Profile		Area 1 Pit 1 (Plot 6)
A_3	2" - 10"	Dark reddish brown (5YR 3/2 moits) silt loam, very friable fine granular structure, (pH 5.5), gradual lower boundary.
B_1	10" - 19"	Same as A_3 horizon except having a very friable, weak fine to medium subangular blocky structure that breaks to fine granular structure.
B_2	19" - 33"	Dark reddish brown (5YR 3/3 moist) silt loam, slightly heavier than the B_1 horizon, moderate blocky and subangular blocky structure breaking to fine granular structure; (pH 5.5); abrupt wavy boundary.
IIB_2	33" +	Dark reddish brown (5YR 3/2 moist) clay loam, medium and fine subangular blocky structure with common fine reddish brown (4YR 4/4 moist) Mottles; pH 5.5.
		Area 1 (Plot 46)
A_o-A_{oo}	1/2" - 0	Partially decomposed ponderosa pine needles.
A_1	0 - 2"	Dark reddish brown (5YR 3/2 moist) silt loam, very weak medium granular structure moderately acid (pH 5.4); clear smooth boundary.
A_3	2" - 9"	Same as the A_1 horizon except friable blocky and subangular blocky structure breaking easily to granular structure; gradual boundary. White micelia common in this layer.
B_1	9" - 16"	Same as the A_3 horizon except medium subangular blocky structure breaking to a medium granular structure.

Soil Profile Area 1 (Plot 46)

B_2	16" - 20"	Same as B_1 horizon except having a more firm structure that breaks to fine subangular blocky and contains a few fine yellowish red mottles (5YR 4/6 moist); pH 5.5 abrupt wavy boundary.
II B_2	20" - 27"	Dark reddish brown (5YR 3/4 moist) clay loam, firm medium subangular blocky structure having a few fine mottles like the B_2 horizon; ph 5.5, gradual lower boundary.
II B_{23}	27" +	Similar to the II B_2 horizon except less mottling.

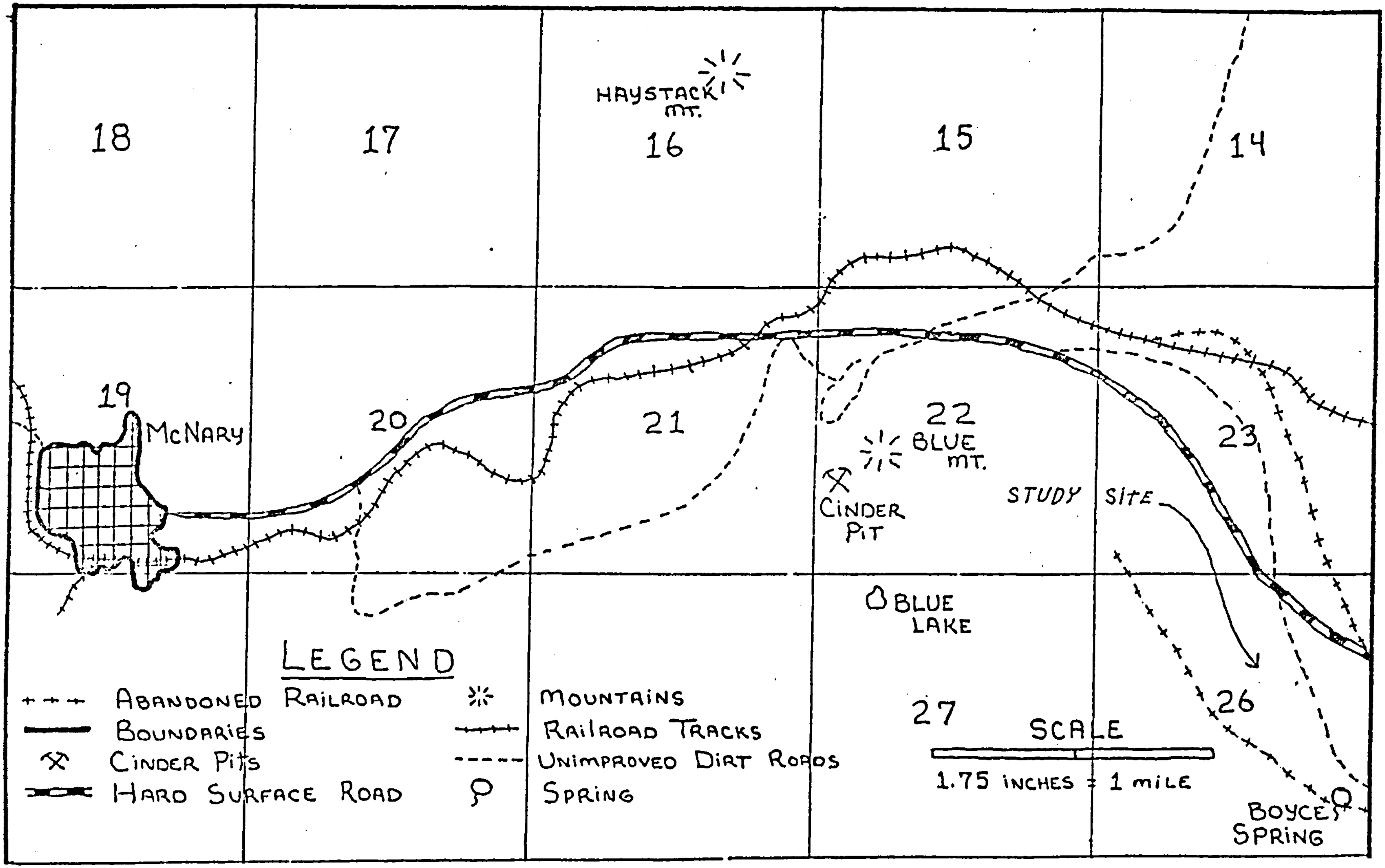

Figure A1. Location of Study Site

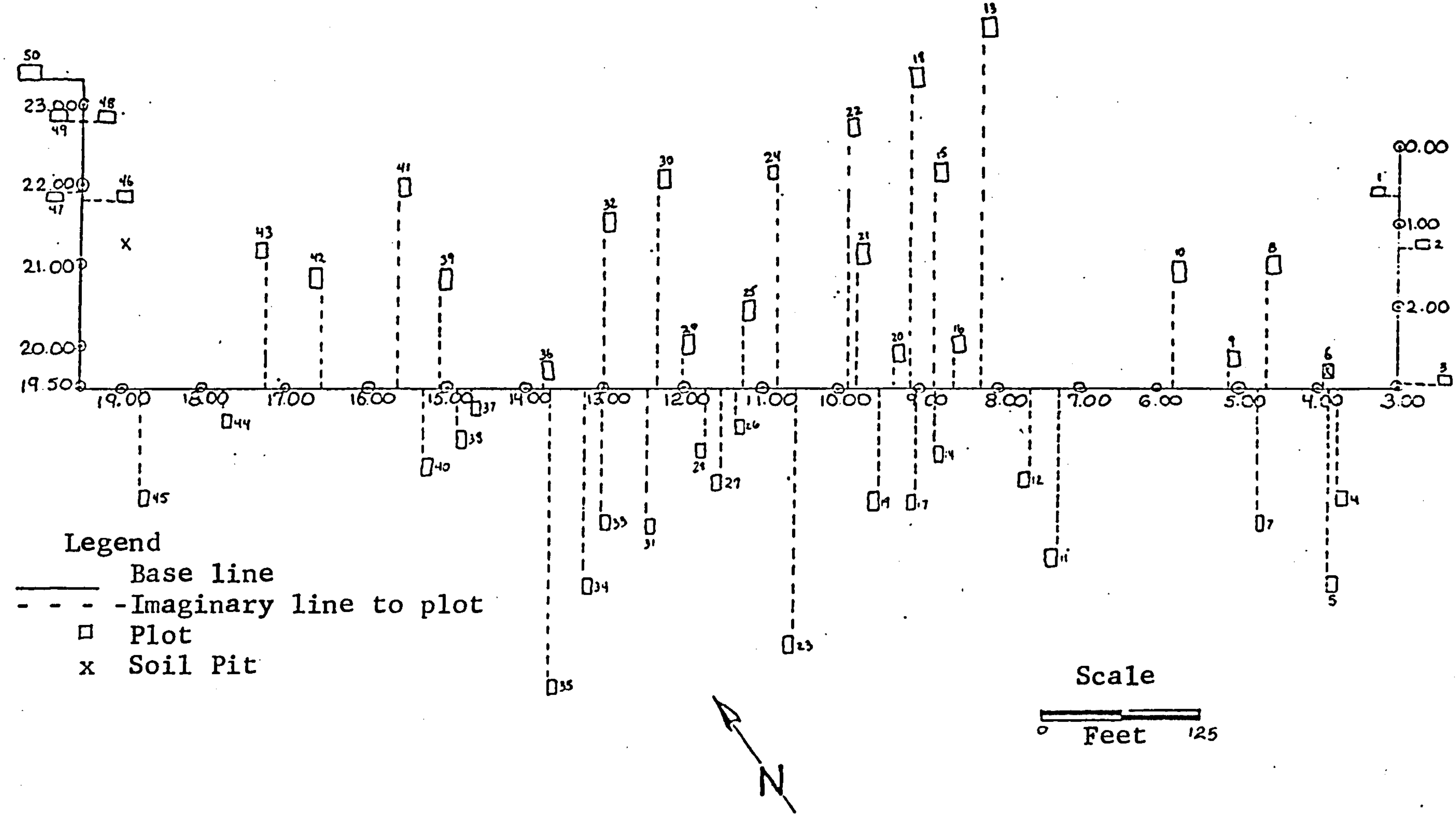

Figure A2. Blue Mountain Study Plots

Table AI. Raw data for plot number 42

Plot No. 42
Treatment: Double Litter

Starting Diameter	1961	1962	Vernier 1963	1964	1965	1966	1967	1968	1971	1972	Diameter 1973
6.46	0.80	0.80	0.99	1.00	1.29	1.56	2.19	2.16	2.34	2.43	7.52
4.61	0.70	0.73	0.90	0.93	1.16	1.30	1.40	1.70	0.96	1.12	5.28
8.16	0.73	0.76	1.08	0.08	1.39	1.62	2.05	2.30	2.03	2.40	9.15
5.31	0.76	0.76	0.76	0.76	0.92	0.93	1.03	1.03	1.01	1.01	5.40
5.75	0.97	1.02	1.35	1.41	1.75	2.00	2.35	2.47	1.70	2.01	6.70
4.40	0.70	0.76	0.88	0.92	1.22	1.52	1.96	2.34	1.32	1.74	5.50
3.45	0.78	0.78	0.78	0.78	0.85	0.92	0.96	0.96	0.96	0.96	3.44
4.88	0.70	1.19	1.39	1.40	1.70	2.02	2.10	2.33	1.68	1.70	5.70
4.42	0.80	0.80	1.04	1.12	1.47	1.74	2.09	2.36	1.78	2.27	5.40
4.71	0.73	0.73	0.84	0.84	1.06	1.15	1.30	1.37	1.56	1.65	5.00

Example of Raw Data Blue Mt. Study Site

Table AII. Mean basal areas by year

Treatment	Treatment Number	Number Plots per Treatment	Basal Area by Treatment		Vernier averages by treatment				by year converted to Ft^2 basal area				
			1961	1973	1962	1963	1964	1965	1966	1967	1968	1971	1972
			mean	mean	mean	mean	mean	mean	mean	mean	mean	mean	mean
No litter	1	4	.1361	.1884	.1405	.1430	.1435	.1485	.1520	.1572	.1612	.1847	.1857
Control	2	11	.1460	.1970	.1465	.1490	.1502	.1542	.1595	.1636	.1681	.1865	.1931
Non-Sel-Fen	3	2	.1725	.2343	.1725	.1760	.1765	.1815	.1870	.1930	.1980	.2260	.2300
Sel GBA	4	2	.1720	.2287	.1730	.1765	.1775	.1835	.1890	.1940	.2010	.2200	.2240
NK(S)-P+Me	5	4	.1331	.1704	.1337	.1375	.1387	.1425	.1465	.1517	.1545	.1640	.1615
PK(S)-N+Me	6	4	.1473	.1977	.1480	.1507	.1517	.1560	.1592	.1667	.1702	.1867	.1937
Double litter	7	4	.1481	.1934	.1485	.1520	.1527	.1585	.1622	.1677	.1727	.1830	.1915
Sel-Fen	8	2	.1338	.1838	.1345	.1370	.1385	.1435	.1485	.1555	.1595	.1785	.1830
NPK(S)-Me	9	4	.1531	.2163	.1545	.1582	.1595	.1640	.1695	.1757	.1817	.2012	.2057
NPK(S)+Me	10	4	.1476	.2159	.1492	.1535	.1540	.1605	.1667	.1712	.1762	.2043	.2102
NP-K(S)+Me	11	4	.1770	.2383	.1785	.1837	.1842	.1907	.1952	.2037	.2085	.2287	.2340
Sel-PK(S)+Me	12	3	.1779	.2537	.1813	.1877	.1887	.1957	.2023	.2100	.2147	.2423	.2470
Sel GBA+NK(S)+Me	13	2	.1750	.2580	.1770	.1845	.1860	.1940	.2015	.2090	.2140	.2470	.2525
		50	.1523	.2084	.1536	.1573	.1583	.1634	.1684	.1742	.1787	.1986	.2040

Non-Sel-Fen= nonselective fenuron
Sel GBA = selective gibberellic acid
N = nitrogen
P= Phosphorus
(S)= Sulfur
K= Potassium
ME= Micro elements
Sel= Selective

Table AIII. Mean diameter by plots grouped by treatments

Treatment 1 - No Litter			Treatment 2 - Control		
	Diameter-inches			Diameter-inches	
Plot Number	1961	1973	Plot Number	1961	1973
18	4.66	5.43	05	5.54	6.23
33	5.26	6.56	09	4.44	5.53
39	5.10	5.78	11	5.56	6.29
46	4.97	5.68	12	5.22	5.57
Mean	4.99	5.88	13	4.79	6.37
			15	5.61	6.54
			25	5.66	6.37
			27	5.47	6.12
			37	4.69	5.53
			40	5.32	6.14
			50	4.57	5.39

Treatment 3 - Non Sel Fen			Treatment 4 - Sel GBA		
	Diameter-inches			Diameter-inches	
Plot Number	1961	1973	Plot Number	1961	1973
29	5.38	6.45	10	6.12	7.02
43	5.88	6.67	34	4.93	5.73
Mean	5.63	6.56	Mean	5.62	6.47

Table AIII. (continued)

Treatment 5 - NK(S)-P+Me

Plot Number	Diameter-inches 1961	1973
02	4.94	5.81
04	4.83	4.87
31	4.67	5.29
32	5.33	6.39
Mean	4.94	5.59

Treatment 6 - PK(S)-N+Me

Plot Number	Diameter-inches 1961	1973
03	5.58	6.62
08	4.65	5.46
48	5.89	6.59
49	4.68	5.41
Mean	5.20	6.02

Treatment 7 - Double Litter

Plot Number	Diameter-inches 1961	1973
07	5.45	6.02
30	5.08	5.89
36	5.09	5.97
42	5.22	5.92
Mean	5.21	5.95

Treatment 8 - Sel-Fen

Plot Number	Diameter-inches 1961	1973
16	4.57	5.30
28	5.33	6.30
Mean	4.95	5.80

Treatment 9 - NPK(S)-Me

Plot Number	Diameter-inches 1961	1973
01	4.44	5.61
20	5.55	6.61
38	5.88	6.63
44	5.33	6.35
Mean	5.30	6.30

Table AIII. (continued)

Treatment 10 - NPK(S)+Me		
Diameter-inches		
Plot Number	1961	1973
06	5.27	6.50
22	5.38	6.43
24	5.05	6.40
26	5.12	5.83
Mean	5.20	6.29

Treatment 11 - NP-K(S)+Me		
Diameter-inches		
Plot Number	1961	1973
19	5.18	6.22
23	5.81	6.78
45	6.12	6.90
47	5.75	6.54
Mean	5.71	6.61

Treatment 12		
Diameter-inches		
Plot Number	1961	1973
17	6.34	7.41
21	6.06	7.21
41	4.75	5.84
Mean	5.71	6.82

Treatment 13		
Diameter-inches		
Plot Number	1961	1973
14	5.66	7.09
35	5.67	6.79
Mean	5.66	6.88

Table AIV. Converting circumference growth to diameter growth

1. Original diameter of trees $\times \pi$ = original circumference.

2. $$\frac{\text{Original circumference} + \text{First Year's circumference growth}}{\pi} - \text{original diameter} = \text{diameter growth.}$$

3. Original diameter + First Year's diameter growth $\times \pi$ = second year beginning circumference.

4. $$\frac{\text{Second year beginning circumference} + \text{Circumference increment}}{\pi} - \left(\begin{array}{l}\text{Original diameter} + \\ \text{First year diameter growth}\end{array}\right) = \text{Second year diameter growth}$$

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