THE INFLUENCE OF PLANTING DENSITY ON THE EARLY GROWTH OF RED PINE

Thesis for the Degree of M. S.
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DANIEL GEORGE NEARY
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ABSTRACT

THE INFLUENCE OF PLANTING DENSITY ON
THE EARLY GROWTH OF RED PINE

By

Daniel George Neary

This study examined the impact of planting density on the early growth of red pine (*Pinus resinosa* Ait.) in northern Michigan. The influences of five densities (500, 750, 1000, 1500, and 2000 trees/hectare) were evaluated in terms of (1) changes in red pine growth, (2) root competition and distribution, (3) biomass and nutrient distribution, and (4) intensity of snow damage. The observations, made over a three-year period, were concluded when the plantation was nine years old.

Stem and crown growth during the period of 1969-1971 indicated that more growth had occurred in the lower density plots. The DBH of trees in plots with 500 trees/hectare was significantly greater than the DBH of trees in plots with 2000 trees/hectare. A DBH greater than 5.1 cm (2 inches) was observed in 77 percent of the trees in the 500 trees/hectare plots and in only 28 percent of the trees in the 2000 trees/hectare plots.

There were no significant stem height differences. Needle lengths were significantly longer in the 500 trees/hectare plots.

Root competition was studied by means of soil moisture determinations and excavation of red pine root systems. No significant moisture variations attributable to tree density were observed. Root excavations revealed an unequal distribution of roots in the growing space allotted to each tree. About 45 percent of the horizontal root system showed a distinct tendency to become oriented along the planting furrow. Evidence indicating root competition far in advance of crown closure was observed.

Trees sampled in 1968 and 1971 were separated into needle, branch, stem, and root components, weighed, and analyzed for nutrient content. No significant differences were noted between the component parts and the stand densities.

The amount of snow damage in the plantation was related to the stocking level. Plots with 2000 trees/hectare suffered three to four times as much damage as those with 500 trees/hectare. Most of the injury was concentrated on the fourth whorl from the top of the tree at about 75 cm above the ground. Trees in plots with 1000, 1500, and 2000 trees/hectare lost 30 to 40 percent of the branches in that whorl compared to 15 to 30 percent for the 500 and 750 trees/hectare plots.

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Daniel George Neary

A THESIS

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in partial fulfillment of the requirements
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CHAPTER I

INTRODUCTION

Within its natural range, red pine (*Pinus resinosa* Ait.) was once most abundant in the northern regions of Minnesota, Wisconsin, and Michigan. Following extensive logging operations, settlement clearing, and a series of catastrophic fires in the latter half of the 19th century, red pine stands in this region were considerably reduced. In the past 70 years red pine has made a comeback under the impetus of abundant natural regeneration and widespread planting programs.

When a plantation is to be established, an important management decision involved is that of the number of trees to plant per hectare. Since the initial stocking density may have significant and lasting effects on the growth of the stand, this decision is an important one. Many plantations of red pine in northern Michigan have been established at close spacings that necessitate precommercial thinning. Part of the rationale is that maximum plant productivity results only when a stocking level is reached that fully utilizes the site. Related to this is the theory that competition between two individuals in a stand does not occur until crown closure. Furthermore, it has been believed desirable to maintain an adequate stocking surplus from the beginning of the rotation to cover losses due to insect and disease attacks. However, with the recent emphasis on the economics of forest operations, the amount of capital investment in plantation establishment has begun to exert considerable influence on the initial spacing decision.

It is generally recognized that the periodic thinning of red pine plantations is a desirable silvicultural practice for obtaining maximum economic returns. However, most thinning studies have been established in stands of relatively high density where trees have often reached merchantable size. The effects of the initial stocking density on the early development of the trees, and on the subsequent results obtained by thinning are not taken into account. The objective of this study is to determine the most silviculturally desirable initial density level for red pine in northern Michigan.

CHAPTER II

REVIEW OF LITERATURE

The choice of the proper spacing in a red pine plantation requires careful consideration of the wide array of environmental factors influencing growth and development. The interactions of these factors with spacing result in either advantageous or disadvantageous conditions for tree growth. The pros and cons of wide spacing in conifer plantations have been enumerated by Morrow (1964) and Wilde (1964). They stressed that the choice of spacing be based upon such factors as the nature of the soil, composition and density of competing vegetation, species growth patterns, climate, moisture regime, insect and disease hazards, the type of wood product desired, and financial feasibility.

Growth responses to wide spacings have been documented by several thinning studies conducted in natural and planted stands. Eyre and Zehngraff (1947) reported that a 23-year-old natural red pine stand thinned to a spacing of 3.0 x 3.0 meters (1080 stems/hectare)[1]

[1]Refer to Appendix Table 14 for the English system equivalents for these and subsequent measurements.

stimulated more diameter growth, suffered less from glaze damage, and had significantly more trees in larger diameter classes than narrower spacings. In Canada, Berry (1965) pointed out that a 4.3 x 4.3 meter spacing (550 stems/hectare) established in a 13-year-old red pine plantation resulted in greater diameter growth, increased taper, larger average basal area growth, more than double the volume growth per tree, and little difference in height growth in comparison with the original spacing of 2.1 x 2.1 meters. A subsequent study by Berry (1969) showed that height growth in the 4.3 x 4.3 meter spacing decreased for four years following the thinning operation before returning to normal.

Barrett (1965) reported that a dense stand of ponderosa pine (*Pinus ponderosa* Laws.) thinned to five densities ranging from 150 to 2470 stems/hectare resulted in twice as much diameter increment and total height growth on the widest spacing as on the closest spacing. In plots with the competing understory vegetation removed, diameter growth in the wider spacings was even greater.

While thinning studies enable delineation of some of the advantages and disadvantages of wide spacings, they do not consider growth response differences resulting from initial planting spacing. Consequently, several research projects have been conducted to analyze the growth of red pine over a range of initial spacings.

Byrnes and Bramble (1965) reported the results of a 30-year-old red pine stand originally planted at spacings of 1.5 x 1.5, 1.8 x 1.8, 1.8 x 2.4, and 3.0 x 3.0 meters (4310, 2990, 2240, and 1081 trees/hectare). In comparison to the 1.5 x 1.5 spacing, the 3.0 x 3.0 meter-spaced trees were approximately 7.5 centimeters larger in DBH (diameter at 1.37 meters), 1.65 meters taller, more wind-firm, and maintained the greatest rate of volume increase in addition to suffering no losses from mortality factors. The 3.0 x 3.0 meter-spaced plots had six times as many trees and contained seven times the volume of wood in trees classed 18 cm or greater in DBH than the 1.5 x 1.5 meter-spaced plots.

The growth and yield of 25-year-old red pine planted in three different spacings in southern Michigan were summarized by Lemmien and Rudolph (1959). A 3.0 x 3.0 meter spacing was superior to either a 1.8 x 1.8 or 2.4 x 2.4 meter spacing since it produced nearly as much volume per hectare in larger, more merchantable trees. Also, thinnings were more easily applied, the access for cultural operations improved, and establishment costs lowered.

One of the most extensive studies on the growth of red pine planted at different densities was reported by Stiell (1964) in Ontario. The experiment measured the growth of seedlings planted in furrows 2.1 x 2.1, 3.0 x 3.0, and 3.7 x 3.7 meters apart (220, 1080, and 750 stems/hectare). After 20 years, the 3.7 x 3.7 spacing resulted in the greatest stem diameter growth, the largest average branch diameter, the fastest rate of volume growth per tree, the longest crown length, and the greatest foliage weight. Height growth and the number of branches per whorl appeared to be independent of spacing. Both total basal area and basal area increment were greatest in the closest spacing. Stiell concluded that the 3.7 x 3.7 meter spacing probably offered the best opportunity for shortening the rotation of red pine and increasing net economic returns.

Berry (1970) reviewed the growth of 16-year-old red pine planted in five spacings ranging from 1.2 x 1.2 to 4.3 x 4.3 meters (6730 to 550 stems/hectare). He noted that as spacing increased, the average DBH was increased 47 percent. However, while height growth was unrelated to spacing, a trend for closely spaced trees to have smaller stem diameters and narrower crowns existed. Crown closure and subsequent competition probably reduced radial growth throughout the entire length of the stem.

The environmental factors responsible for the growth responses of red pine have been under study by a number of forest scientists. Such aspects of red pine growth as root distribution, precipitation and temperature effects, soil moisture and temperature effects, growth patterns, and snowfall effects have been examined. While Rudolf (1957) reviewed the general silvical characteristics of red pine, basic physiological and phenological information has been provided by Krenholz (1934), Duff and Nolan (1953), Kozlowski and Ward (1957), and Kozlowski and Peterson (1962). Richards _et al_. (1962) discussed stand development and site index for red pine plantations in New York. DeMent and Stone (1968) examined the influences of soil type and soil physical properties on red pine growth. Tree growth and development as a function of soil moisture, soil temperature, and soil nutrients have been investigated recently by Leaf _et al_. (1970) in red pine plantations.

The root system of red pine, its distribution, and its association with other tree roots has been discussed by Day (1941), Garin (1942), Brown and Lacate (1961), and Stiell (1970). Root growth responses have also been studied in some detail by Krenholz (1934), White and Wood (1958), and Merritt (1968).

Considerable research interest has centered around the interrelationships between rainfall, soil moisture, and tree growth. Early work on the effects of precipitation on red pine growth was done by Motley (1949), Stoeckeler and Limstrom (1950), and Dils and Day (1952). They showed the close relationship between radial growth and rainfall. Della-Bianca and Dils (1960), Bay (1963), and Bay and Boelter (1963) observed the effects of stand density on soil moisture and radial growth. Zahner and Donnelly (1967) studied the correlations of water deficits with radial growth in young red pine. The effects of ground vegetation on red pine growth was investigated by Shaw _et al_. (1968), and Wilde _et al_. (1968). They noticed a reduction in tree growth with depletion in soil moisture caused by high rates of weed species transpiration. Clements (1965, 1970), by correlating rainfall with radial growth in red pine, pointed out how moisture conditions during the formation of buds in one year significantly affected shoot growth the following year. Buds with an adequate moisture supply were larger, produced more needle primordia, broke dormancy earlier, and provided a greater needle photosynthetic surface that resulted in greater radial growth than those with a moisture deficit.

Heavy snow accumulations, characteristic of Michigan's upper peninsula, prompted several studies to be conducted that dealt with the effects of stand density on snow buildup and damage. Red pine proved to be the least susceptible to snow damage of all the native conifers of the region following a late fall snow storm containing wet snow and high winds (U.S. Forest Service, 1939). Stoeckeler and Rudolf (1949) and Godman and

Omstead (1962) showed greater snow damage in closely spaced Lake States conifer stands than in widely spaced stands. However, with wider spacings, snow accumulation increases were directly proportional to soil moisture increases as reported by Dils and Arend (1956), Weitzman and Bay (1959), and Hansen (1969).

CHAPTER III

THE STUDY AREA

Location and Soils

The study area of about 22 hectares in size is located in the eastern end of Michigan's upper peninsula approximately 48 kilometers south of Sault Ste. Marie on the Munuscong State Forest. It is situated in the N 1/2, SE 1/4, Section 35, Township 43 North, Range 1 West, Michigan Meridian.

The tract containing the study plots lies on a nearly level portion of an east-west oriented ridge at 244 to 247 meters above sea level. The ridge consists of Engadine Dolomite and Manistique Dolomite overtopped with varying depths of glacial debris. The soil that formed from the glacier deposited material is classified as Kalkaska. It is a well-drained typic haplorthod that has developed in deep sands containing little or no calcareous material. While the soil does contain stray chunks of dolomite, the bulk of the parent material originated from igneous rocks of the Canadian Shield. The textural range of the Kalkaska Series grades from sand to loamy sand. The solum ranges in depth from 51 to 114 cm with occasional weak cementation of the upper B horizon. The textural characteristics of this soil result in slow runoff, rapid permeability, and excellent drainage. Consequently, the Kalkaska tends to be drouthy during dry spells. Productivity is low to high for hardwoods, and medium to high for conifers (Soil Conservation Service, 1965).

Regional Climate

The general climate of the upper peninsula of Michigan is marked by low to moderate rainfall with cool to warm summers and cold winters. For the record period of 1931 to 1960 the weather in the study area was characterized by an average annual temperature of 5.5 degrees Centigrade. The average January temperature was -9.4 degrees while the average July temperature was 18.9 degrees. The growing season averaged 120 to 130 days for the period involved. Annual precipitation has averaged between 69 and 71 cm with an annual snowfall of 203 to 229 cm contributing one-third of the moisture (Senninger, 1963).

Past History

The original vegetation of the area was primarily northern hardwoods. Around 1885, a 22-hectare tract was homesteaded by the Morrison family of Pickford, Michigan.

Old growth hardwoods were felled and burned. Evidence of this burning still exists in charcoal deposits found at the bottom of the A_p soil horizon. Corn, potatoes, various vegetables, and livestock forage crops were grown on the cleared land. The farm was abandoned in the early 1900's and the fields left fallow.[1] During the 1930's the state of Michigan acquired this land in lieu of delinquent taxes and turned over its administration to the Department of Natural Resources. In the fall of 1962, two portions of the old Morrison farm were planted with 3-0 red pine nursery stock using a T6 tractor with a Killifer plow followed by a DNR planting machine with a 23 cm planting shoe.

Study Design

The original stocking level of 2000 to 2250 trees/hectare was altered by an intermediate thinning in the spring of 1968 in order to study the effects on subsequent growth by simulating a range of initial stocking densities. The red pine at that time had grown for five summers in the plantation and were about 1.5 meters tall. The experimental design was a randomized block design consisting of five treatments in each of four blocks (Figure 1). Treatments of 500, 750, 1000, 1500, and 2000 trees/hectare were selected, and 20 plots, each 1/25th

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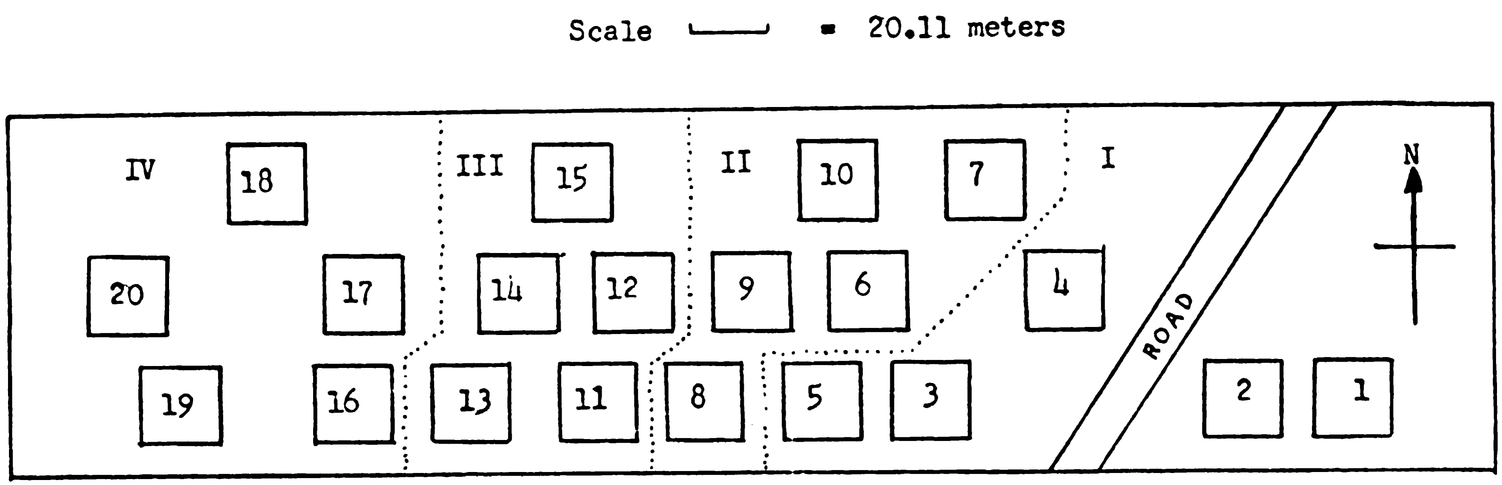
[1]Personal recollection of Mr. Clayton Morrison of Pickford.



Stems/Hectare	Plots
500	2, 6, 12, 19
750	5, 7, 14, 18
1000	1, 9, 11, 16
1500	4,10, 13, 20
2000	3, 8, 15, 17

Figure 1. Plot map for the red pine spacing study in the N 1/2, SE 1/4, T43N, R1W, Michigan meridian.

hectare in size, were established. The randomized block design was used to eliminate as a source of error an observed east-west gradient in tree height and ground vegetation. Every effort was made to keep the plots uniform in terms of tree height and ground vegetation.

CHAPTER IV

FIELD PROCEDURES

A wide variety of study methods were used to evaluate the influences of climate, soils, and vegetation on red pine growth.

Climate

Climatic factors have been measured since 1969. At weekly intervals during the growing season of that year, air temperature and rainfall were recorded at 30.5 cm above ground. Both minimum-maximum thermometers and small bucket-type rain gages were installed in plots 6, 9, 8, 20, and 18. During the summer of 1970 the thermometers and rain gages were located in plots 1, 9, 11, and 16. In 1971 the minimum-maximum thermometers were placed in plots 1, 9, 11, and 16 at 30.5 and 152.4 cm above the ground, and in plots 2, 3, 6, and 8 at 30.5 cm above the ground. Rain gages were located in plots 14, 1, and 19. Previous records showed little precipitation variation in the plantation. A pyrheliometer and hygrothermograph were installed on plot 14, the plot designated as the main weather station. The pyrheliometer was placed on the ground in an open area subject to minimal shading. The hygrothermograph was set in a ventilated, double-roofed shelter with the temperature sensor 30.5 cm above the ground. Temperature and precipitation recordings were made daily except Saturday and Sunday from June 18 to September 5, 1971. The solar radiation and relative humidity recordings were continuous during the same period.

In addition to the plot weather records, weather summaries from Dunbar Forest Experiment Station, Detour, and Kincheloe Air Force Base were obtained to put the study area within the perspective of the general climate pattern of the eastern end of Michigan's upper peninsula. These weather stations are, respectively, 21 kilometers northeast, 39 kilometers eastsoutheast, and 21 kilometers northwest of the plantation.

Soils

Soil descriptions were made in August of 1968. Profiles of the soil were exposed and described in plots 7 and 10 since these two locations proved to contain the modal soil characteristics of all the plots. At weekly intervals during the 1969 growing season, gravimetric soil moisture samples were taken at designated points in plots 6, 9, 8, 20, and 18 from the top 15 cm of the soil.

In the summer of 1971 gravimetric soil moisture determinations were again made in all plots for the 0 to 15 cm depth, and in plots, 1, 2, 3, 4, and 5 (Block I) and 16, 17, 18, 19, and 20 (Block IV) for the 15 to 30 cm depth. Sampling points were located in the furrows at an intermediate distance from the surrounding trees. Weekly samples were spaced at least 150 cm apart to eliminate variations in soil moisture due to previous sampling holes.

Ground Vegetation

A detailed ground vegetation survey was made by subdividing each of the 20 plots into nine square subplots. A one meter square quadrat was then located at the center of each subplot or in the nearest open area from the center of the subplot. Each species group was rated on a scale of 0 to 10 according to the percent of the surface area covered. A preliminary examination of the 20 plots resulted in the selection of the following thirteen categories for use in the survey:

1. *Polytrichum* s.p.--Hair Cap Moss
2. *Rumex acetosella* L.--Dock
3. *Hieracium florentinum* All.--Kingdevil
4. *Hieracium aurantiacum* L.--Orange Hawkweed
5. *Euphorbia esula* L.--Leafy spurge
6. *Fragaria vesca* L.--Strawberry
7. *Rubus idaeus* L.--Raspberry
8. *Poa* spp.--Grasses
9. *Agropyron repens* (L.) Beauv.--Quack Grass
10. Lichen
11. *Asclepias syriaca* L.--Milkweed
12. *Pteris aquilinum* (L.) Kumn.--Bracken Fern
13. Bare Ground

Red Pine Measurements

Stem and Crown Growth

Needle length and length of the current terminal shoot were measured at one- or two-week intervals in 1969, 1970, and 1971 on three sample trees within each plot. The average needle length was measured at the base of the year's current shoot. The terminal shoot length was taken from the topmost whorl to the base of the terminal bud. In 1971 one representative tree on the edge of each of the 20 plots was chosen for monitoring with a circumference dendrometer. An aluminum band was placed at the DBH mark on each tree on June 16. Each band was measured for increase in circumference at weekly intervals.

Root Development

The root system was examined for three representative red pine trees of the 500 and 2000 stems/hectare densities and one of the 1000 stems/hectare density. A 1.2 x 1.2 meter area was established around each tree, and a 0.3 meter wide trench was dug to a depth of about 0.6 meters around the central 1.2 x 1.2 meter block. Care was taken to ensure that the roots were not removed from the trench along with the soil material. Following excavation, the root patterns were mapped along both the vertical and cross-sectional views from each face of the block around the tree. The roots were labelled according to four diameter classes:

1. 0.0 to 6.3 mm
2. 6.4 to 12.6 mm
3. 12.7 to 18.9 mm
4. 19.0 mm +

After the mapping was completed, the block of soil remaining around each tree was excavated to trace the roots found in the trenches back to their tree of origin. Each tree was then cut at ground line and sectioned into stem, branches, needles, and roots for biomass analysis. No attempt was made to obtain that portion of the root system outside of the original excavation area.

Snow Damage

As the result of unusual winter weather conditions during the study period, one additional set of measurements was made. Three successive winters of heavy snow accumulation resulted in extensive snow damage to the plantation. A damage survey was undertaken to determine if the extent of injury could be related to the various densities used in the spacing study. The survey included measuring the upper six whorls in each tree in every plot for the following:

1. Number of branches in the whorl
2. Height of the whorl from the ground

3. Number of branches damaged in the 1970-1971 winter

4. The percentage damage from the 1970-1971 winter

   (a) 90-100%: Branches killed or about to die

   (b) 50-90%: Branches more than 50% pulled from their sockets and still alive

   (c) Less than 50%: Branches lightly damaged

5. Average diameter of recently damaged branches

6. Damage from the winters of 1968-1969 and 1969-1970

   (a) Total number of branches damaged

   (b) Estimate of the number of branches in the whorl before any damage occurred

   (c) Number of intact branches

   (d) Number of damaged branches

   (e) Number of missing branches

Biomass

In 1969 a number of trees were collected for biomass analysis. Individual trees from plots 1 through 5 and representative trees from Blocks II through IV were obtained. The trees were then separated into stem, branches, and foliage for determination of oven dry weight and nutrient content. The nutrient analysis was ha

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handled by the Michigan State University Plant Analysis Lab. The same procedure was used in 1971 on the trees removed during the root study.

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CHAPTER V

RESULTS AND DISCUSSION

Climate

Temperature

The mean temperatures observed at 30.5 cm above the ground during the growing seasons of 1969 through 1971 were quite similar. A maximum mean temperature of about 20 degrees Centigrade usually occurred in mid or late July. Minimum temperatures in the plantation during the periods of record were generally in the 0- to 10-degree Centigrade range, while the maximums were characteristically in the 25- to 38-degree range. The normal pattern of hot days and cold nights during the months of June, July, and August occasionally resulted in temperatures below 0 and above 38 degrees. Temperatures recorded at the standard height of 152.4 cm (5 feet) above ground in 1971 were generally 1 to 4 degrees cooler. Those recorded in the open area outside the plantation averaged 0 to 3 degrees cooler because of increased air circulation.

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Precipitation

Rainfall in the eastern half of the upper peninsula during the summer months is uneven due to the sporadic thundershowers that provide most of the precipitation. Weekly oscillations of 0 to 8.5 cm of precipitation have been recorded in the course of the 1969-1971 growing seasons (Figures 3 and 4 on pages 29 and 30). Late summer and early fall rainfall appears to be the most important since it affects the development of the terminal bud, and ultimately the growth of the tree (Clements, 1970). This relationship is discussed in more detail in the section on shoot and crown growth.

Relative Humidity

The relative humidity in the plantation was continually monitored during the 1971 growing season. The normal daily pattern for the relative humidity resulted in a minimum reading of less than 40 percent in the early afternoon, and a maximum of 99 to 100 percent between midnight and dawn.

Solar Radiation

Incoming solar radiation during the growing season of 1971 averaged 408 langleys/day (gram-calories/cm^2/day). The week of maximum solar radiation (507 langleys/day) came as might be expected after the summer solstice.

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The maximum rate of insolation observed was 691 langleys/day while the minimum was 80 langleys/day.

Soils

Soil Profile

The modal soil profiles described in 1968 belong to the Kalkaska series. This series consists of well-drained typic haplorthods that have developed in deep sands containing little or no calcareous material. Occurring mainly in the lower peninsula, Kalkaska soils occupy about 216,000 hectares in Michigan. There are some small aggregates in the eastern half of the upper peninsula. This series is usually associated with the well-drained Rubicon, Karlin, Grayling, Graycalm, and Wallace soil series. Collectively, this group accounts for 1.6 million hectares of the 15 million hectare land area of Michigan.

Kalkaska soils are usually found on level and pitted plains, or on dry, bench land with low relief and short slopes. The original vegetation cover for this series was sugar maple (*Acer saccharum* Marsh.), beech (*Fagus grandifolia* Ehrh.), yellow birch (*Betula lutea* Michx. f.), hemlock (*Tsuga canadensis* (L.) Can.), red pine (*Pinus resinosa* Ait.), white pine (*Pinus strobus* L.), and occasionally jack pine (*Pinus banksiana* Lamb.).

The description of the Kalkaska modal profile is as follows:

The Kalkaska Series

SOIL PROFILE: KALKASKA SAND

02	05-00 cm	Black (10YR2/1) well-decomposed leaf litter with a high proportion of mineral soil; weak, medium, granular structure; very friable; many fine roots; very strongly acid; abrupt smooth boundary.
A2	00-23 cm	Sand; light brownish gray (10YR6/2); single grain, structureless loose; few fine roots; very strongly acid; abrupt irregular boundary. 10-31 cm thick.
B2ih	23-28 cm	Sand; dark reddish brown (5YR2/2); weak, medium, granular structure; massive in chunks; very friable with some strongly cemented chunks of ortstein occurring in the lower part of this horizon and the B22ir, B23ir, and the upper B3 horizon; many fine roots occurring the friable portion of the horizon, only a few roots penetrate the ortstein chunks; very strongly acid; abrupt irregular boundary. 5-25 cm thick.
B22ir	28-38 cm	Sand; dark brown (7.5YR3/2); very weak, coarse, granular to medium subangular, blocky structure; massive in chunks; very friable with strongly cemented chunks of ortstein, very strongly cemented; clear irregular boundary. 5-15 cm thick.
B23ir	38-58 cm	Sand; brown to dark brown (7.5YR4/4); very weak coarse to medium granular structure; very friable with a few weakly cemented chunks of ortstein; medium acid; clear irregular boundary. 10-38 cm thick.
B3	58-96 cm	Sand; yellowish brown (10YR5/4); very weak, coarse, granular structure; very friable; medium acid; gradual wavy boundary. 15-51 cm thick.
C1	58-96 cm	Sand; yellowish brown (10YR6/4); single grain structureless loose; medium acid.

[1]Soil Conservation Service, 1965, Kalkaska soil series description. National Cooperative Soil Survey, U.S. Department of Agriculture Soil Conservation Service.

Figure 2 presents the representative soil profile of the area as it was described in the original Soil Conservation Service field report in 1968. The legend for the abbreviations used in the description is shown below:

1. Boundary
   (a) as--abrupt smooth
   (b) ab--abrupt broken
   (c) ai--abrupt irregular
   (d) gi--gradual irregular
   (e) gw--gradual wavy

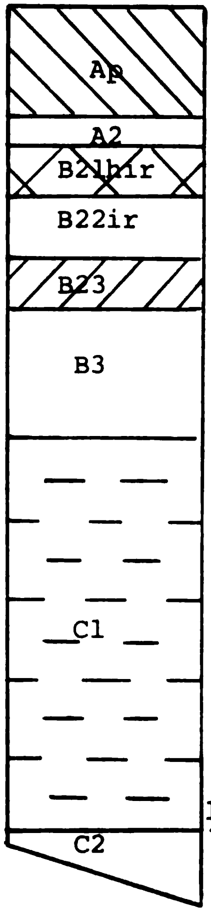
2. Structure
   (a) fsbk--fine subangular blocky
   (b) vfsbk--very fine subangular blocky
   (c) sg--single grain

3. Consistence
   (a) vfr--very friable
   (b) l--loose

Additional soil characteristics were also noted within the profile. Chunks of ortstein were common throughout the B horizon. The C2 horizon was found to contain colored bands about 0.6 to 1.5 cm thick and nearly 6 cm apart. Particles of charcoal, relicts of the original forest that was cut and burned, were evident at the bottom of the Ap horizon. Stray pieces of dolomite were noticeable at ground level and in the surface horizons.

Soil Moisture

Soil moisture in sandy soils is seldom adequate over the entire growing season for plant growth, and



Depth (cm)	Boundary	Color	Structure	Consistence	pH	Texture	NO_3 (ppm)	P	K	Ca	Mg
									(kg/ha)		
17.5	as	10YR4/1	fsbk	vfr	4.7	sand	6.0	8.0	17.1	164.2	28.5
22.5	ab	5YR5/2	fsbk	vfr	5.1	sand	4.0	4.6	5.7	164.2	28.5
30.0	ai	5YR2/2	vfsbk	vfr	5.0	sand	-	21.7	17.1	364.8	42.2
39.6	ai	5YR3/4	vfsbk	vfr	5.2	sand	-	27.4	11.4	164.2	28.5
47.5	ai	7.5YR4/4	vfsbk	vfr	5.2	sand	-	29.6	11.4	164.2	28.5
67.5	gi	10YR4/4	sg	l	5.3	sand	-	68.4	5.7	164.2	13.7
130.0	gw	10YR6/4	sg	l	5.4	sand	-	39.9	11.4	164.2	13.7
		10YR6/4	sg	l	5.3	sand	-	34.2	11.4	164.2	28.5

Figure 2. Soil horizon description for the modal Kalkaska sand profile within the study plantation.

thus often becomes a critically important factor in tree growth. The ability of well-drained soils to hold water is primarily a function of the silt and clay present in the profile. Sands normally have less than 7 percent of their profiles in the silt and clay fractions. Thus, their ability to hold water available for tree use is reduced. For soils of sand texture the mean range of available soil moisture is between 3 and 8 percent by weight (Broadfoot and Burke, 1958; Miller, 1970). Soil moisture levels in sandy soils are consequently influenced to a great extent by precipitation patterns.

The seasonal soil moisture pattern for 1969 in the 0 to 15 cm portion of the soil profile is shown in Figure 3. Two soil moisture trends are evident. The general decline in moisture over the summer reflects both soil moisture depletion due to evapo-transpiration and a decreasing frequency of rainfall in the latter part of the summer. Abrupt increases in soil moisture are a direct response to increased rainfall. The lack of large oscillations and the maintenance of high soil moisture levels can be directly tied to the abundant rainfall in June.

The soil moisture regime during the summer of 1971 in the 0 to 15 and the 15 to 30 cm of the soil is portrayed in Figures 4 and 5. No statistical differences are noted between spacing and soil moisture. Only

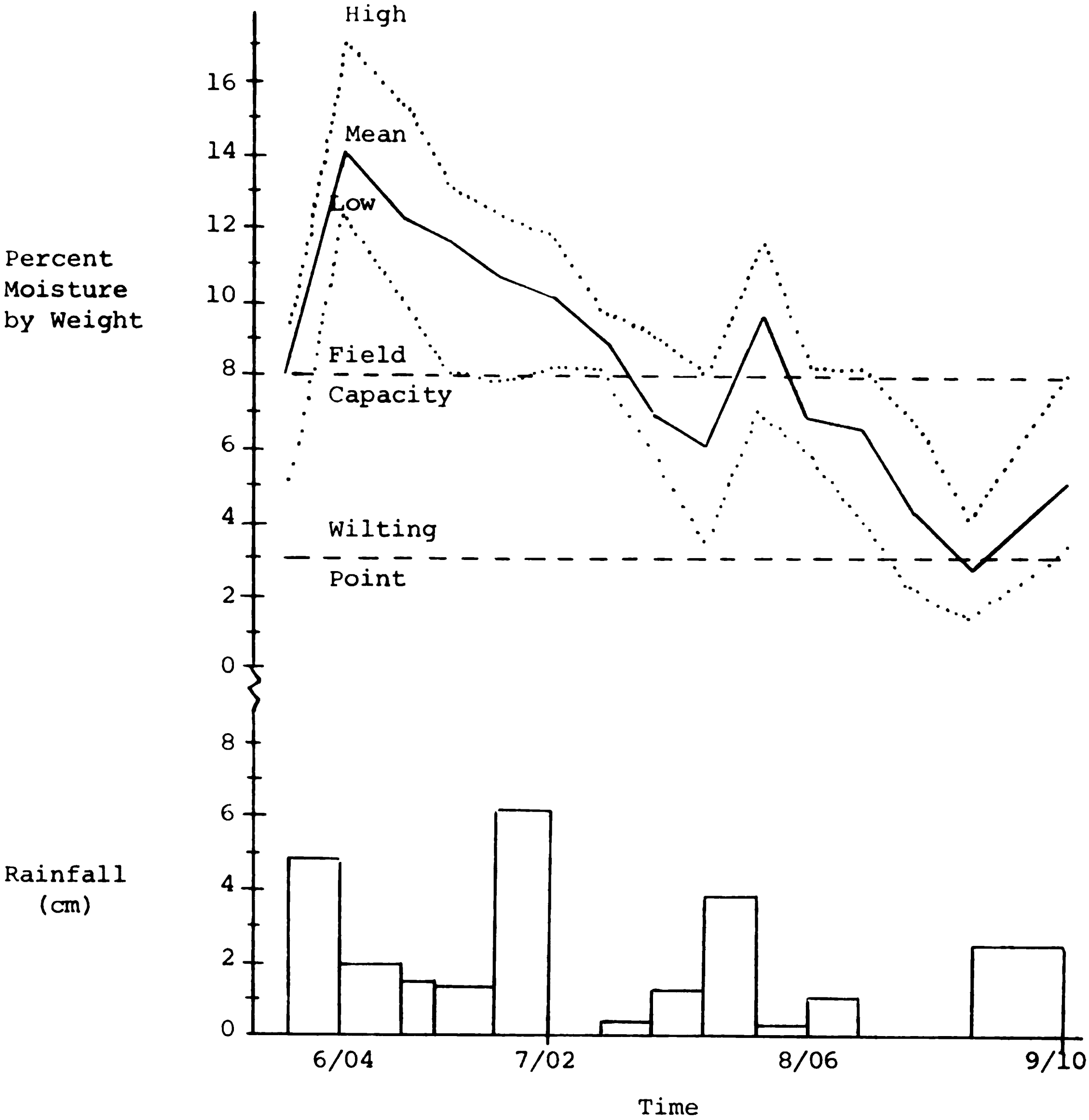


Figure 3. Soil moisture variations in the 0 to 15 centimeter depth of Kalkaska sand during the summer of 1969.

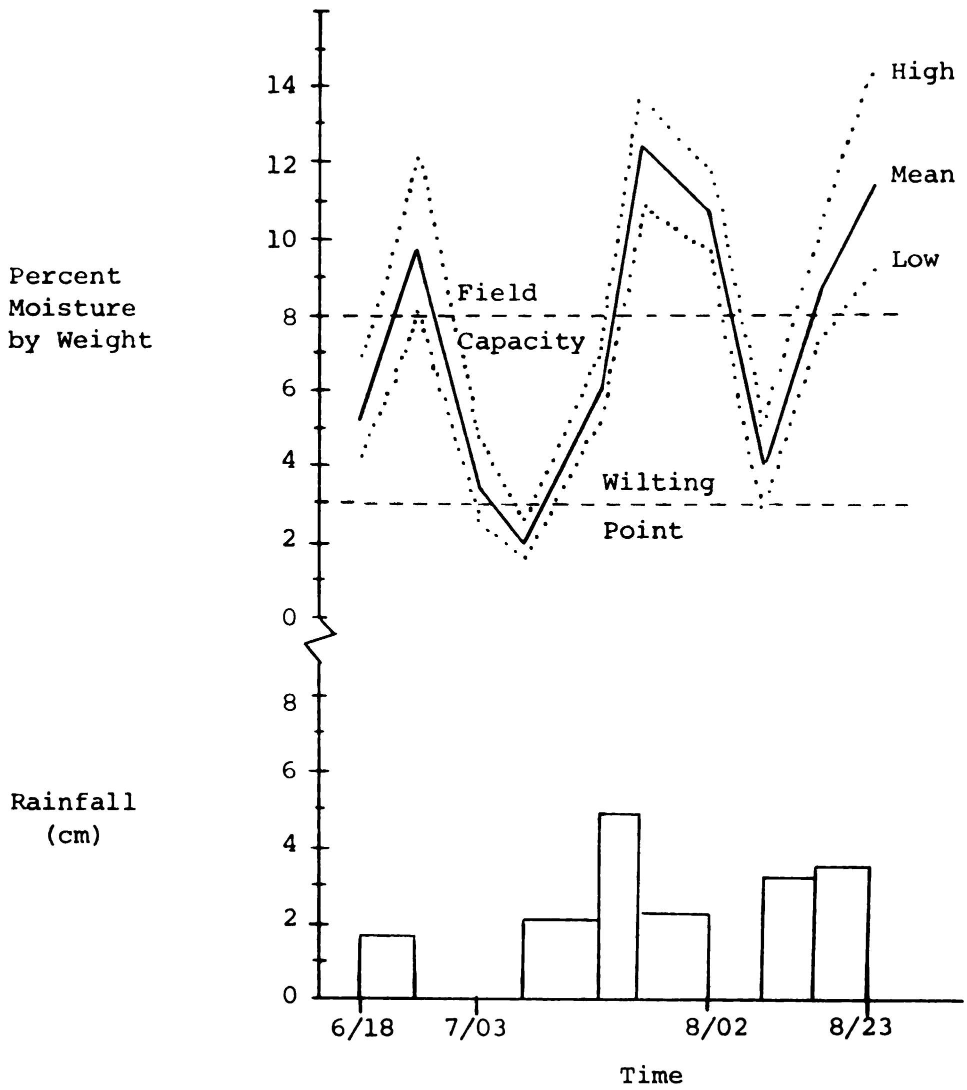


Figure 4. Soil moisture variations in the 0 to 15 centimeter depth of Kalkaska sand during the summer of 1971.

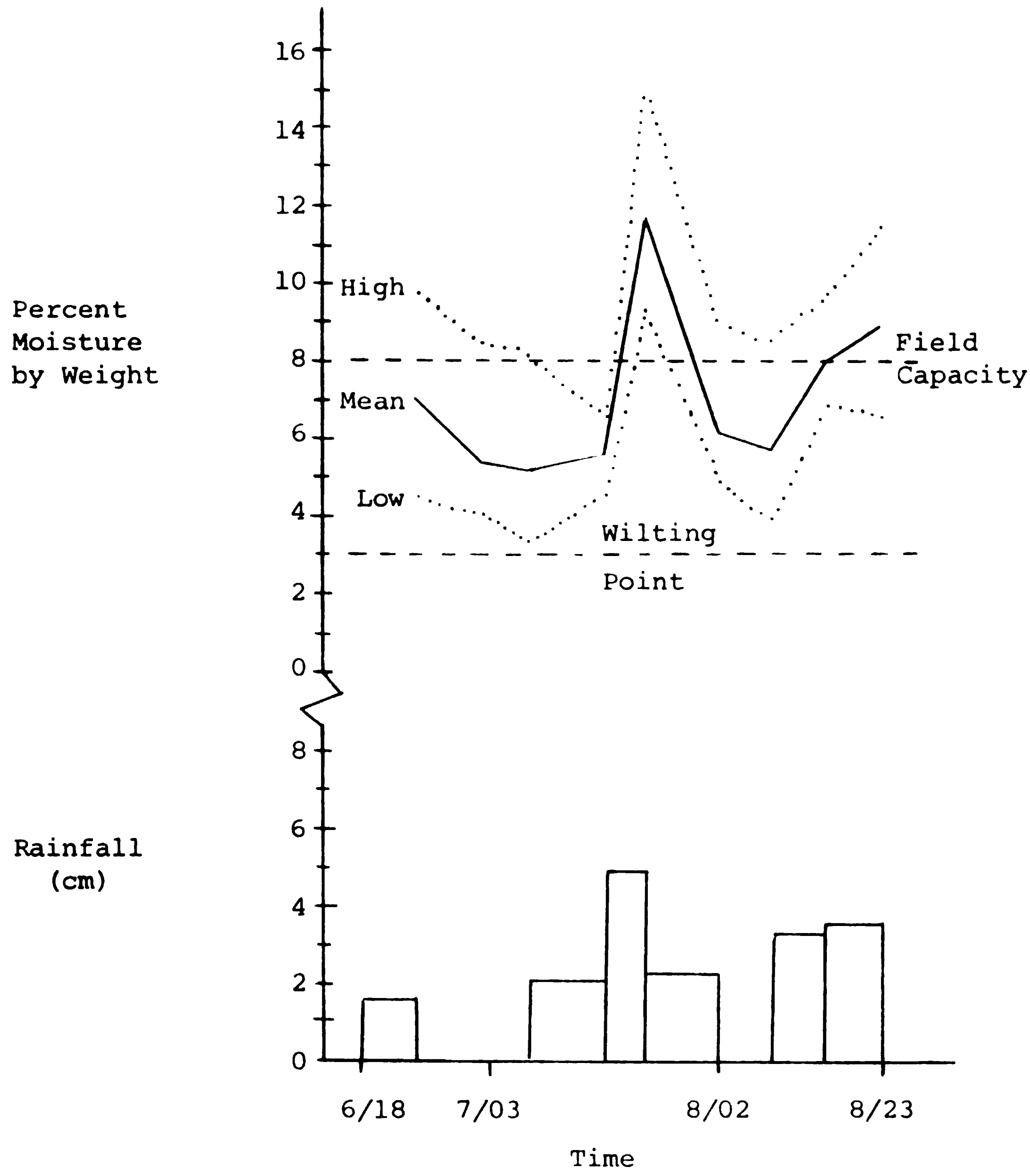


Figure 5. Soil moisture variations in the 15 to 30 centimeter depth of Kalkaska sand during the summer of 1971.

differences between weeks (due to variation in weekly rainfall) are significant. In comparison to the 0 to 15 cm depth, the 15 to 30 cm depth has similar moisture fluctuations but of lesser magnitude. The 1971 soil moisture pattern shows the trend of direct response to rainfall but does not show a gradual pattern of soil moisture depletion over the summer. The abundant rainfall that characterizes the early summer of 1969 is absent in 1971. Thus, soil moisture in the upper 15 cm of soil drops to below the wilting point in early July, recovers quickly with abundant rain, and drops suddenly again with the first dry period. Compared to 1969, 1971 is characterized by greater soil moisture stress at an earlier point in the growing season.

The failure to detect significant soil moisture differences between plots of different density in 1971 may have been due to both insufficient sampling points and/or sampling frequency. Although diameter and needle growth responses are directly influenced by moisture availability, and significant diameter and needle growth differences were observed, the methods employed to determine soil moisture were unable to detect any significant differences.

Ground Vegetation

The ground vegetation was studied to determine possible effects of herbaceous competition on tree growth. An observable east-west vegetation gradient was measured in the study area. It was recognized that tree density could be a significant factor influencing the establishment of several of the more competitive herbaceous plants.

A profile view of the vegetation present is contained in Figure 6. Proceeding from Block I through Block IV the percentage of the ground surface covered by hair cap moss drops from around 45 percent to less than 20 percent. Correspondingly, the percentage of the plot areas covered by the group consisting of orange hawkweed, grasses, kingdevil, and leafy spurge increases from approximately 20 percent in Block I to 40 percent within Block IV.

Table 1, summarizing the heights of all the trees by blocks, shows that as of 1971 both the average tree height and DBH of Block IV are significantly lower than those of Blocks I, II, and III. The reaction in tree growth in Block IV may reflect competition with herbaceous vegetation. Unfortunately, the percentage of ground surface covered by orange hawkweed, kingdevil, leafy spurge, and the grasses is misleading as it does not present an adequate picture of the soil volume occupied by the roots of those plants. Occupying a large portion of the surface horizons and, in the case of leafy spurge, often extending as deep as the red pine

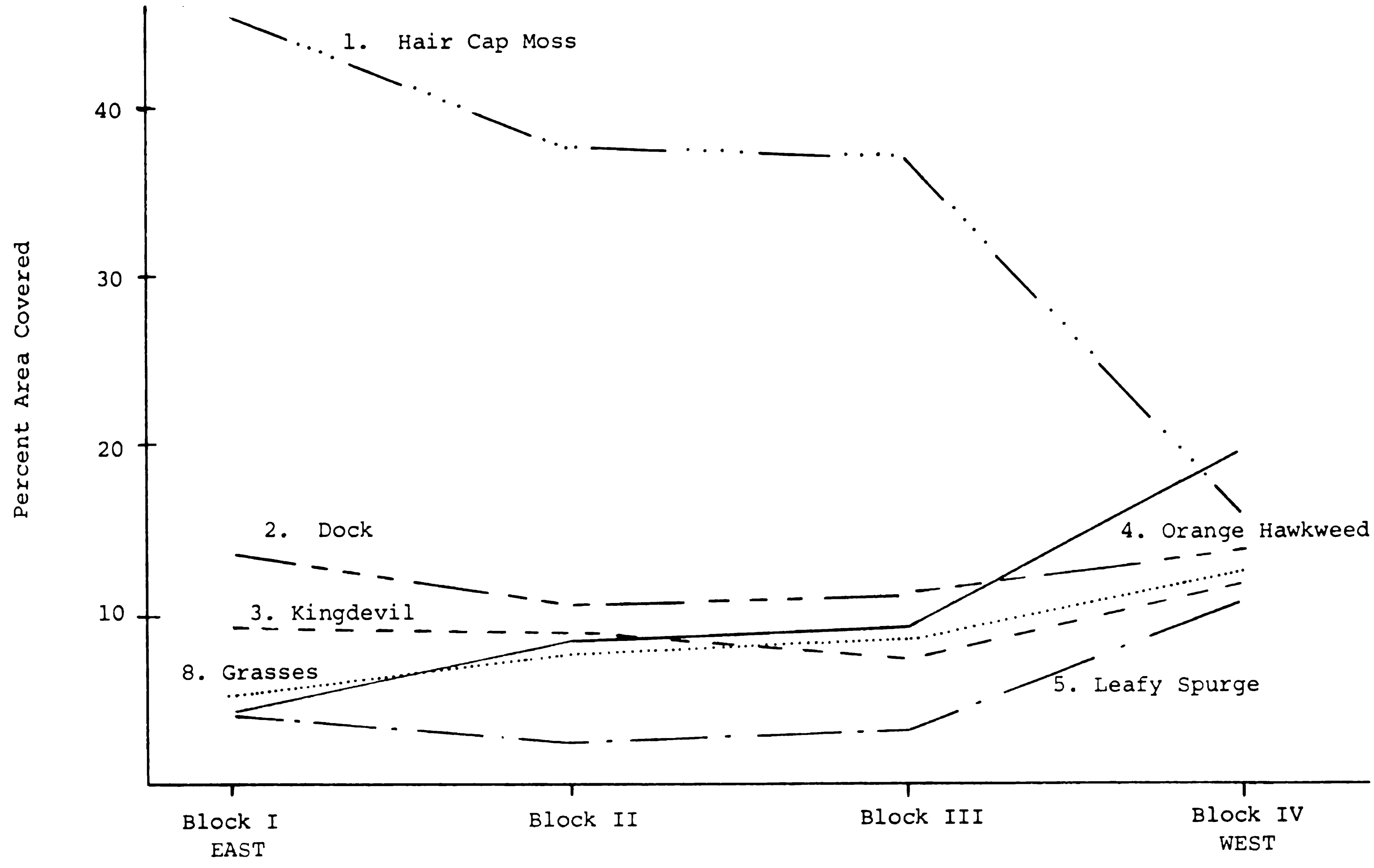


Figure 6. Change in ground vegetation from east to west within the plantation.

Table 1. Block comparison of total height and DBH of all trees, fall 1971.

Block	Height[1] (m)	DBH[1] (cm)
I	3.23 a	5.06 a
II	3.12 a	4.91 a
III	3.18 a	4.99 a
IV	2.92 b	4.30 b

[1]Means not followed by the same letter are significantly different at the 5 percent level (Tukey's test).

roots, such roots utilize a great deal of the limited available soil moisture. This increases the moisture stress potential which in turn results in tree growth reductions.

The herbaceous vegetation distribution showed no relationship to tree density. Thus it can be concluded that tree variations found in different spacings are due to factors other than herbaceous vegetation distribution.

Stem and Crown Growth

Stem Height Growth

The measurements of the terminal leader growth of the three sample trees on each plot over the last three growing seasons is summarized in Table 2 and illustrated in Figure 7. The 1969 growing season resulted in the 500 and 750 trees/hectare spacings having the least

Table 2. Mean annual terminal leader growth of the 12 sample red pine trees in each spacing.

Trees/Hectare	Growth[1]		
	1969	1970	1971
	(cm)		
500	48.33 b	56.08 a	62.85 a
750	48.67 ab	52.04 a	61.04 a
1000	55.67 ab	51.67 a	60.58 a
1500	60.34 a	51.71 a	59.38 a
2000	50.99 ab	48.17 a	56.62 a

[1]Means not followed by the same letter are significantly different at the 5 percent level (Tukey's test).

growth. This was the first year after the 1968 intermediate thinning operation which simulated the initial stocking levels. The slower growth of the trees in these two spacings is similar to that reported by Berry (1969). He noted that a ten-year-old red pine stand thinned from 2000 to about 500 stems/hectare suffered reduced height growth for three years following the thinning. The reduction in height growth was most likely due to increased root and branch growth as a response to expanded growing space. However, in this case the decrease in growth was much shorter in length.

In 1970 the situation changed considerably as height growth tapered off in the 1000, 1500, and 2000 trees/hectare plots and increased in the 500 and 750 trees/hectare plots. This reduction was probably the

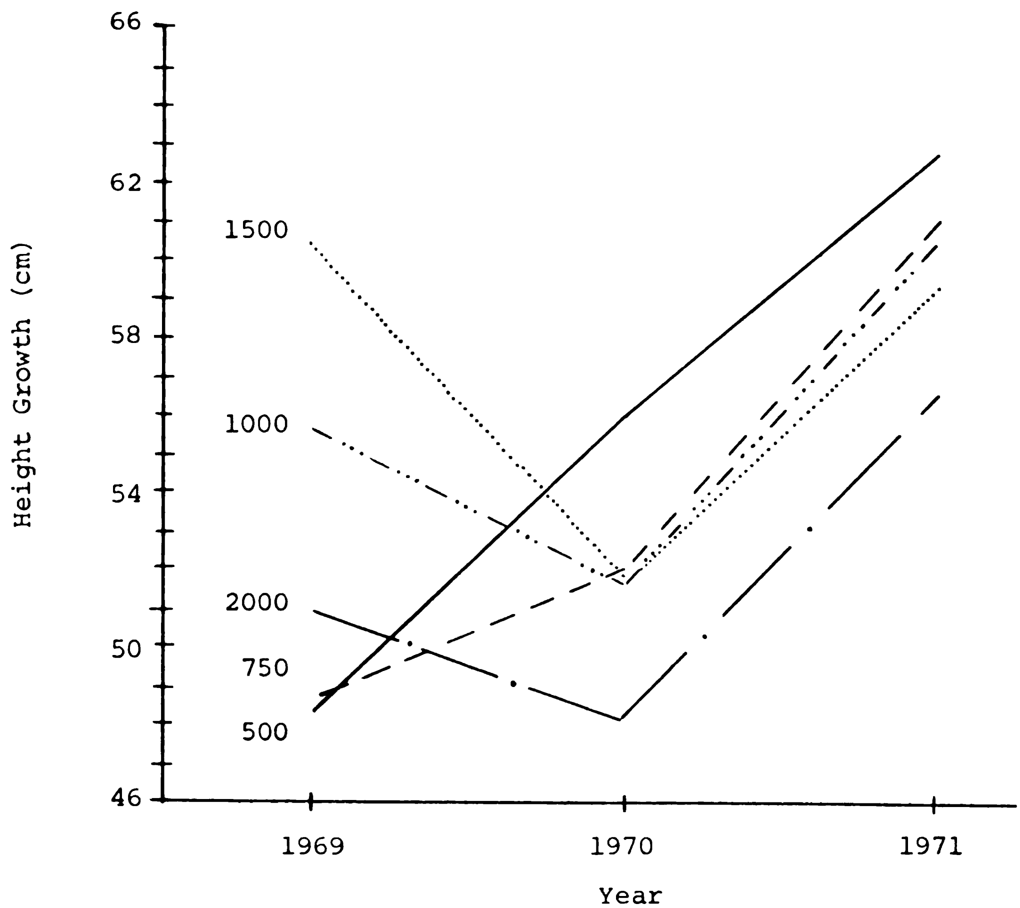


Figure 7. Three-year mean annual leader growth of 12 sample trees per spacing.

result of soil moisture deficiency. The 1970 growing season was characterized by less precipitation during the: (1) previous year's bud development period, (2) pre-growing season, and (3) shoot extension period (Table 3). A study by Clements (1970) showed that the amount of red pine shoot growth in one year is significantly affected by the available moisture during the period of bud development (July-September) of the previous year. Low amounts of moisture result in short terminal buds and consequently less leader growth the following summer. Also, severe soil moisture deficiency during any one summer will result in shoot growth reduction for that period (White, 1958). With rainfall during the bud development period of 1969 being 9 cm below normal and 17 cm less than that of the previous year, the amount of available soil moisture was most likely reduced. Competition in the 1000, 1500, and 2000 trees/hectare plots further limited the availability of soil water. Trees in the 500 and 750 stems/hectare plots were probably spaced far enough apart to avoid moisture competition. Consequently, the terminal buds produced in the three densest spacings resulted in 1970 leader growth that was less than that of the two widest spacings. Also, the low rainfall (2 cm below normal) during May and June of 1970 probably contributed to the reduced shoot growth in 1970.

Table 3. Yearly precipitation in the eastern end of the Upper Peninsula partitioned according to red pine growth phases.

Year	Pre-Growing Season Oct.-Apr.	Shoot Extension May-June	Bud Development July-Sep.
	(cm)		
Mean[1]	37.69	15.90	24.66
1968[2]	42.06	19.18	32.94
1969	46.08	23.62	15.54
1970	39.12	13.92	33.81
1971	44.15	14.40	26.39

[1]Mean for the years 1940-1969 using station data from Sault Ste. Marie, Dunbar Forest Experiment Station, Newberry, and Mackinac City.

[2]Average of Dunbar, Detour, and Kincheloe Air Force Base.

Growth of the terminal leader in 1971 increased for all the densities due to abundant rainfall in the bud development period of 1970. Indeed, the leader growth for 1971 was the best of the three years. The fastest growing sample tree in the plantation grew 76 cm.

The differences between the fastest growing and slowest growing trees each year were minimal until early or mid-July (Figure 8). In 1969 the leader growth in the 500 stems/hectare plots slowed down considerably after July 16th. The reduction in growth for that density was probably due to a shift toward root extension. The trees would use up a considerable amount of their

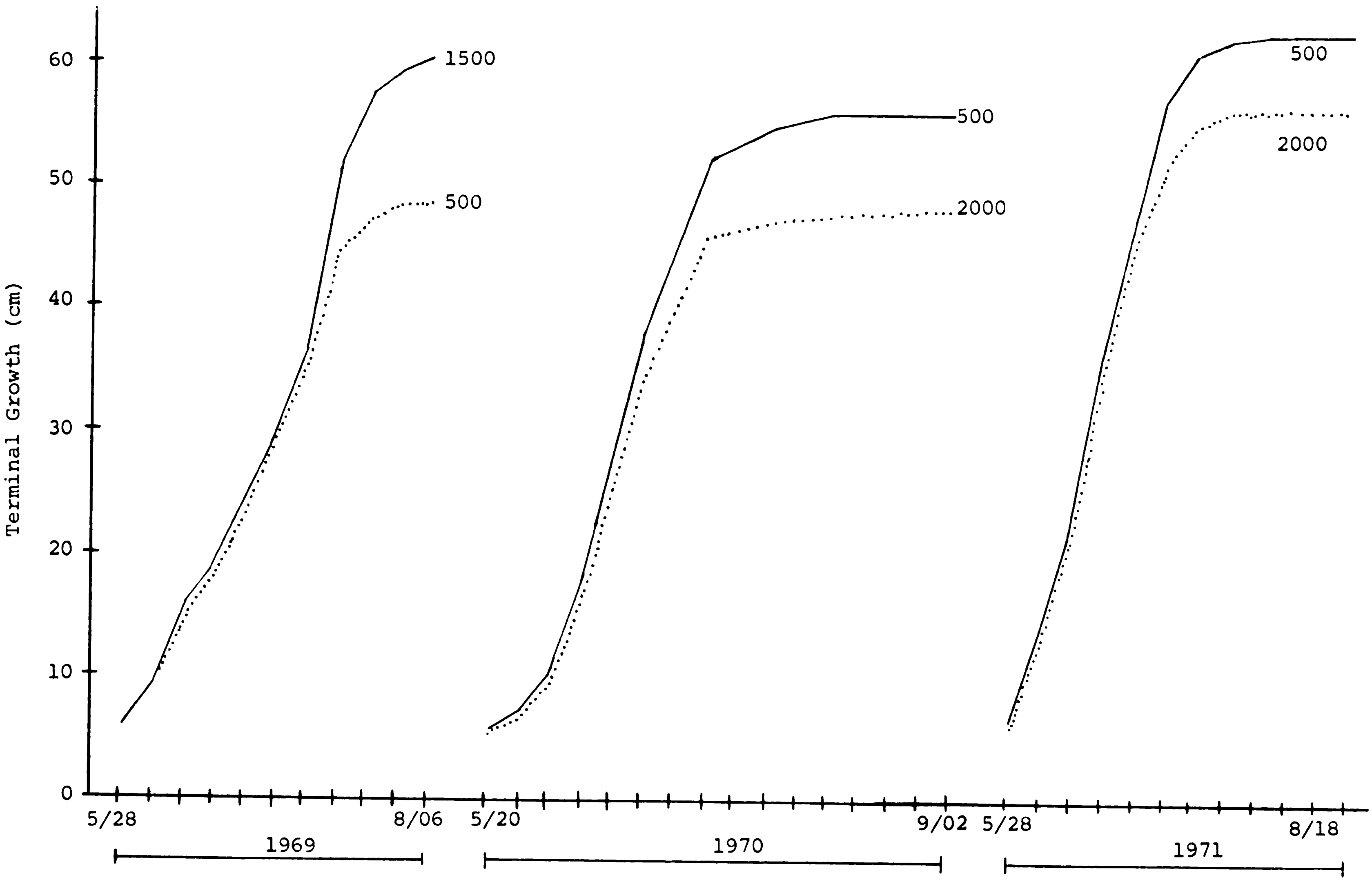


Figure 8. Maximum and minimum terminal growth of contrasting spacings over a three-year period.

photosynthetic products in expanding roots into adjacent soil areas from which competing trees were thinned (Shier, 1970). During the 1970 and 1971 growing seasons, the slowdown in the rate of terminal growth began in early July. This point occurred about mid-way into the growing season. It marked the completion of 90 percent of the leader growth and the initiation of bud formation.

The total height of the sample trees on each plot has been recorded for the past four years (Table 4). In 1968 the difference between the fastest and slowest growing plots was 8.8 cm. By 1971 this difference had increased to 25.1 cm. This coincides with results obtained by Stiell (1964) on a 20-year-old red pine. He found no more than 30 cm difference between the heights of trees in densities of 750 and 2200 trees/hectare. If the 500 trees/hectare plots continue at their present rate of increase they will have grown about 55 cm taller than the 2000 trees/hectare density at age 20 years.

Stem Diameter Growth

When DBH was first measureable in 1970, the 500 trees/hectare spacing averaged 0.7 cm greater in diameter than the 2000 trees/hectare spacing (Table 4). The following year this difference between the extremes of the spacing range increased to 1.0 cm. In both years, the DBH for the 500 trees/hectare plots was significantly greater than that of the 2000 trees/hectare plots. This

Table 4. Mean annual height and DBH of the sample trees for three growing seasons.

Trees/ Hectare	Total Height[1]				Total DBH[1]	
	1968	1969	1970	1971	1970	1971
	(m)				(cm)	
500	1.594 a	2.098 a	2.670 a	3.321 a	3.89 a	5.52 a
750	1.532 a	2.030 a	2.603 a	3.223 a	3.48 ab	5.01 ab
1000	1.575 a	2.077 a	2.588 a	3.213 a	3.58 ab	5.08 ab
1500	1.569 a	2.080 a	2.606 a	3.202 a	3.33 ab	4.93 ab
2000	1.506 a	2.008 a	2.489 a	3.070 a	3.18 b	4.54 b

[1]Means not followed by the same letter are significantly different at the 5 percent level (Tukey's test).

same trend of increasing diameter growth with a decrease in tree density has been noted by Stiell (1969), Berry (1970), and others.

The diameter distributions of all the trees by spacing is summarized in Table 5. In the 500 stems/hectare plots, 76.8 percent of the trees have a DBH greater than 5.1 cm. In the 2000 trees/hectare plots only 27.9 percent of the trees fall in this diameter class. While the densest spacing has four times as many trees/hectare as the lightest spacing, it has only one-third as many trees greater than 5.1 cm in DBH.

Weekly circumference growth was monitored in 1971 on four trees per spacing by means of a band dendrometer (Table 6). No significant differences were observed in the overall circumference growth by density level.

Table 5. Diameter distribution for all trees by spacing, below and above a DBH of 5.1 cm.

Trees/Hectare	DBH = < 5.1 cm		DBH = > 5.1 cm	
	No. of Trees	Percentage	No. of Trees	Percentage
500	20	23.2	67	76.8
750	37	43.0	59	57.1
1000	80	47.4	89	52.6
1500	128	51.6	120	48.4
2000	235	72.2	91	27.9

Table 6. Mean weekly circumference growth by density, 1971.

Date	Trees/Hectare				
	500	750	1000	1500	2000
	(mm)				
6/23	4.2	3.5	3.6	4.2	4.0
6/30	4.4	4.3	5.2	3.0	4.2
7/07	3.4	1.4	3.0	3.8	2.3
7/14	1.8	2.6	2.9	1.8	2.3
7/21	0.7	0.7	0.4	0.4	1.2
7/28	4.3	3.7	3.8	4.3	3.5
8/04	2.2	3.3	1.5	2.0	2.5
8/11	4.0	2.3	3.5	3.0	2.5
8/18	2.2	2.2	3.8	2.7	2.0
8/25	2.8	3.5	3.7	3.0	3.7
9/08	2.5	2.5	2.5	2.0	2.0
Total	32.5	30.0	32.0	30.2	30.2

However, a continuous growth decrease occurred over the first five measurement periods, followed by an equally steady increase in circumference during the remaining observational period. The diameter growth decline reflected a drought period between June 25th and July 9th. The combination of low rainfall, high solar radiation, and considerable evapo-transpiration resulted in the depletion of soil moisture below the wilting point (Figure 4, page 30). Heavy precipitation between July 19th and July 24th alleviated the soil moisture stress, and circumference growth resumed at a rate comparable to that observed on June 30th. Succeeding dry and wet periods accounted for the remaining fluctuations in growth.

Needle Growth

The measurements of needle length on the developing leader were made to evaluate differences in photosynthetic capability. Trees with longer needles would possess a larger photosynthetic surface area, and thus possess greater growth potential (Berry, 1965). Table 7 illustrates the needle length differences over a three-year period. The observable needle growth differences appear to parallel to some extent the changes in leader growth (Figure 9). Changes in the total needle length can be best explained in terms of the precipitation record. Studies by Clements (1970) and others have described

Table 7. Mean annual needle growth on 12 sample trees per spacing for three growing seasons.

Trees/Hectare[1]	1969	1970	1971
	(cm)		
500	12.67 ab	11.83 a	12.36 a
750	12.68 ab	11.50 a	11.96 ab
1000	13.00 a	11.50 a	11.27 ab
1500	13.00 a	11.42 a	11.09 b
2000	12.00 b	11.46 a	11.04 b

[1]Means not followed by the same letter are significantly different at the 5 percent level (Tukey's test).

the correlations of needle growth with moisture availability. Good needle growth in 1969 was the result of adequate rainfall during the bud development phase of 1968, and high pre-growing season and early summer rainfall (Table 3). The decrease in needle length in 1970 was the result of low rainfall during the bud formation period of 1969, the pre-growing season, and the shoot extension period. In 1971 abundant precipitation occurred in the previous year's bud development period and during the pre-growing season.

However, except for the 500 and 750 trees/hectare plots, overall needle length declined. This does not agree with the results obtained by Clements (1970). Perhaps the extensive snow damage which occurred in

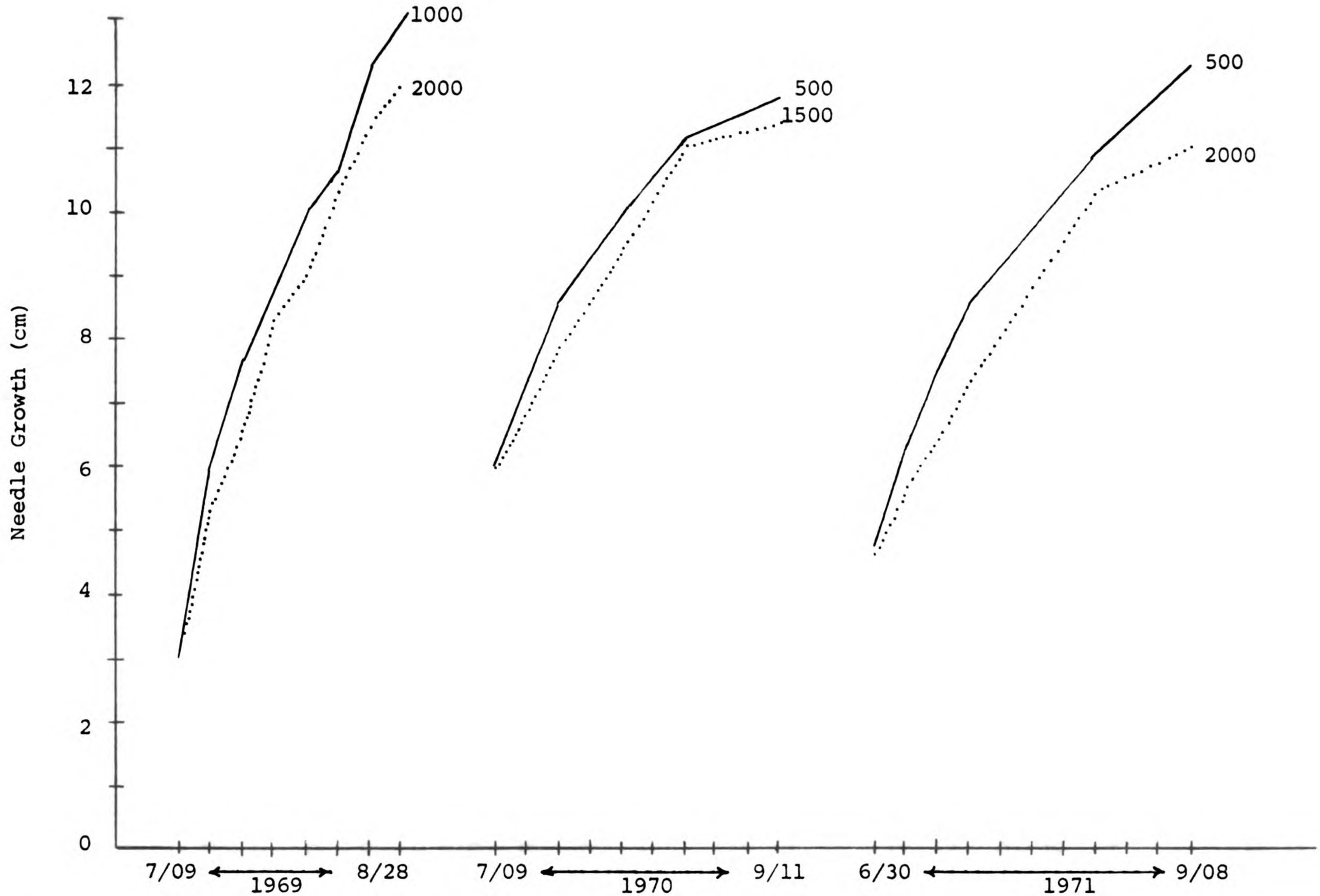


Figure 9. Maximum and minimum needle growth, by corresponding spacing, for a three-year period.

the three closest spacings reduced the physiologic vigor of the trees and consequently resulted in less needle growth.

Summary of Growth Responses

The growth responses of *Pinus resinosa* Ait. to different spacing levels are keyed to the availability of soil moisture. Significant height growth differences over the range of spacings occur only with limiting soil moisture levels. Diameter growth appears to be quite sensitive to the water status of the tree. With decreased competition in the wider spacings, greater diameter increases result. Needle lengths also exhibit a dependence upon soil moisture.

The plots with 500 and 750 trees/hectare are generally characterized by higher levels of soil moisture availability. Thus more significant growth responses can be expected in these than in the 1000, 1500, and 2000 trees/hectare plots. If the present trends continue, the wider-spaced plots will contain trees that are taller in height and greater in DBH at rotation age than the narrower-spaced plots (Stiell, 1964). Figures 10 and 11 illustrate the growth that has occurred in three growing seasons.

Root Development

An important phase of young red pine growth that is often overlooked is root development. Red pine saplings

Figure 10. 500 trees/ha. plot: (A) after the thinning in 1968 to simulate initial stocking level and (B) in 1971--Note: no crown closure.

A

B

Figure 11. 2000 trees/ha. plot: (A) after the thinning in 1968 to simulate initial stocking level and (B) in 1971--Note: crown closure.

A

B

usually possess an extensive system of lateral roots that occupies much of the upper 30 cm of the soil profile. These roots perform the important function of obtaining moisture from the surface soil horizons (Day, 1941).

It has often been assumed that tree competition between individuals in a stand is minimal until crown closure occurs. This is based on the theory that tree roots are widely dispersed and sufficiently separated to minimize competition before the crowns become closed. The occurrance of any competition between two young trees would thus depend on close root proximity, a large number of roots growing in close association, and dry soil moisture conditions.

The root excavation phase of this study was conducted to determine whether or not root associations were occurring which might lead to competition for minerals or water. Such competition would most likely affect the growth of the red pine before crown closure. Of the seven root systems excavated and mapped, Figure 12 presents a representative view.

The root systems of the excavated trees were typical of those characterized for red pine by Day (1941), and Brown and Lacate (1961). However, they also possessed a different trait, that of a marked tendency towards orientation and concentration within the furrow. In Figure 12 a distinct cluster of roots is noticeable running from

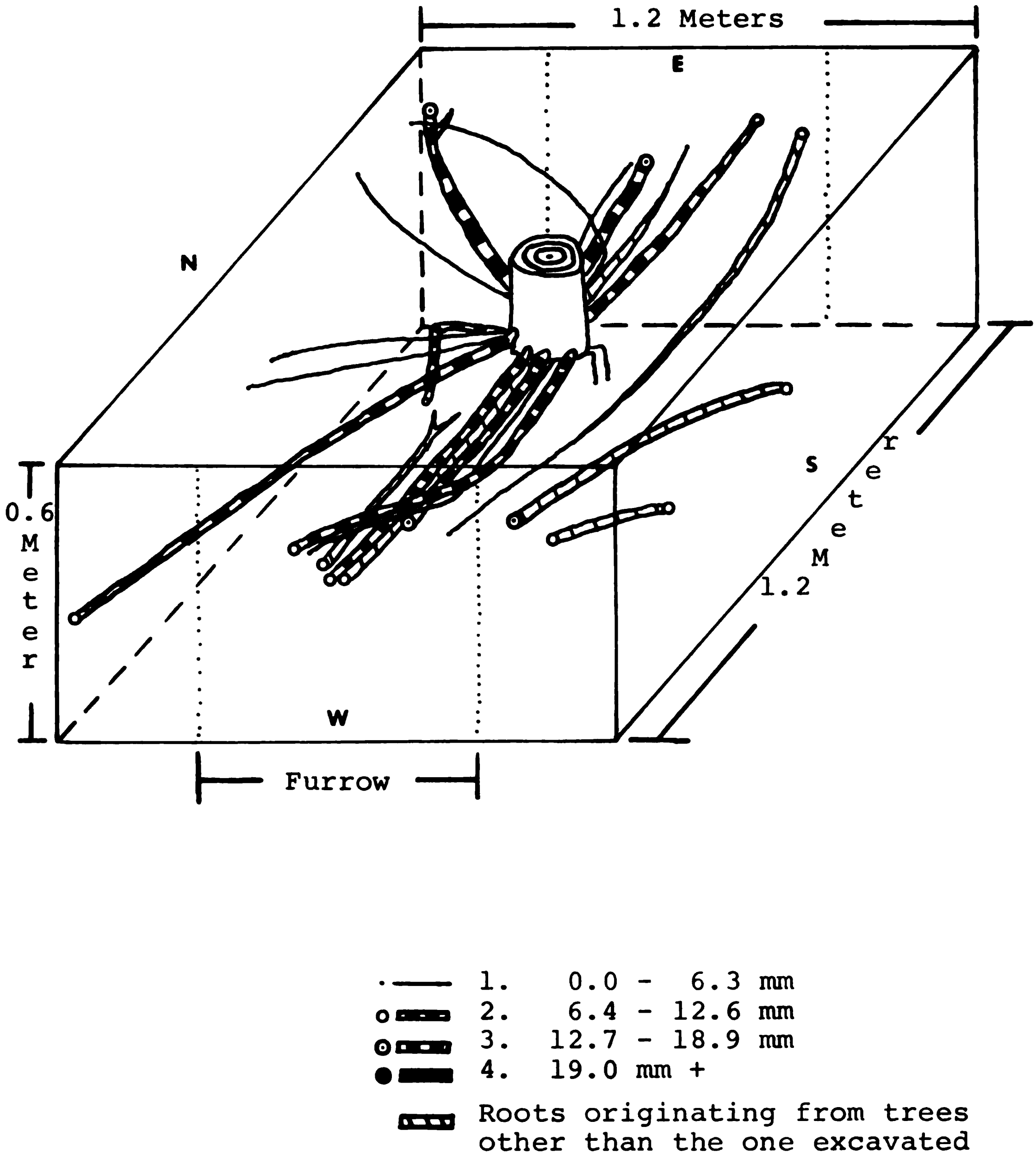


Figure 12. Three-dimensional distribution of red pine roots in .86 cubic meters of soil for tree No. 1, 2000 trees/hectare.

east to west. These roots are lined up directly along the planting furrow. The root originating from the tree immediately to the west and traversing under the excavated tree is quite prominent. Due to its alignment it is in direct competition with two or more trees to the east in the same row. Another item of interest is the nearly complete absence of root extension in a southerly direction from the root collar of the tree.

Quantifying these orientations presents a more precise picture of the root distribution that has taken place in all seven trees. Table 8 summarizes the percentage distribution of the root systems of the excavated trees in terms of their orientation to the planting furrow. The numbers of roots in each of the four diameter categories were tabulated according to their angle (0, 45, or 90 degree) with the furrow. The number of roots in each category was then weighted according to the respective cross-sectional area to give relative importance to the larger roots. The percentage distribution of the root system for each tree was thus determined by dividing the weighted sum for each angle classification by the overall weighted sum for the tree (see Appendix, Table 28).

The lack of uniform root distribution around the root collar results from furrow planting. As the planter proceeds along it plows open the furrow, parts the soil,

Table 8. Percentage distribution of the root systems according to the angle of the roots with the planting furrow.

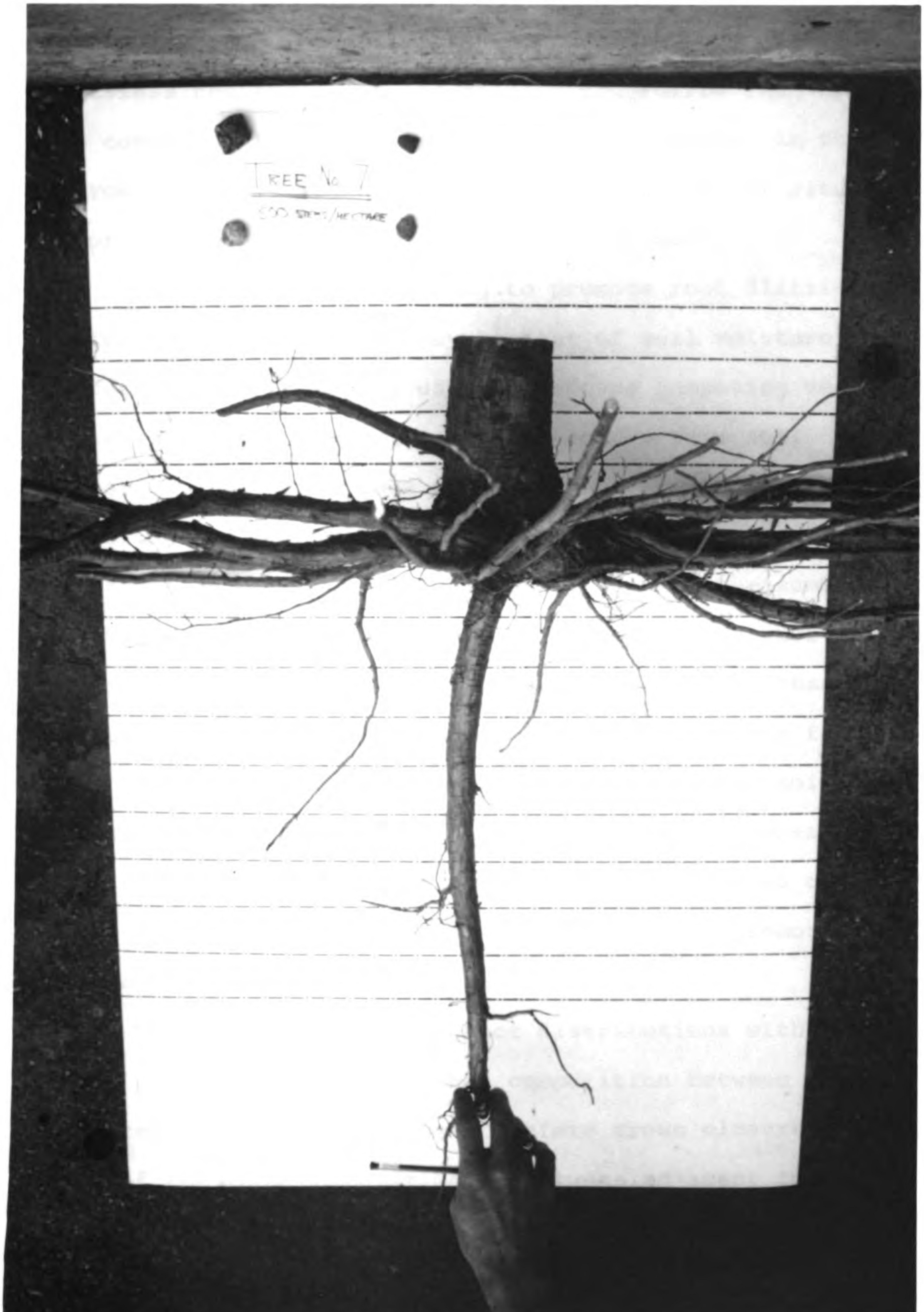
Tree No.	Root Angle		
	0	45	90
	%	%	%
1	56.0	28.0	16.0
2	41.8	29.1	29.1
3	45.0	40.0	15.0
4	50.0	46.9	4.1
5	31.2	59.4	9.4
6	44.4	36.1	19.5
7	48.6	34.3	17.1
Mean	45.2	39.1	15.7

and deposits the seedlings. When the seedlings are dropped from the moving planting machine, the roots contact the ground first and thus become strung out horizontally behind the stem. Evidence of this was often visible in the form of roots emerging from the collar at one point, being wrapped halfway around the root collar, and then extending out along the furrow line (see Figures 13 and 14).

The distinct root alignment along the furrow may also be due to compression of the soil by the planting machine. The physical process of parting the soil enough to position a seedling results in a certain amount of soil compaction on either side of the slit. Roots

Figure 13. Partially excavated root of red pine exhibiting orientation in the furrow.

Figure 14. Excavated root system representative of machine-planted red pine.


TREE No 7

developing from the newly planted seedling subsequently meet less resistance in the soil of the furrow than in the compacted furrow walls, and thus grow better in the furrow. Ferrill and Woods (1966) noted a similar situation in pines established with planting bars.

Another factor operating to promote root distribution within the furrow may be that of soil moisture differential. Furrowing usually removes competing vegetation from the planting strip and leaves bare soil exposed. The furrow thus acts as a zone relatively free of herbaceous species that compete for water. It also functions as a good water collector. During the summer of 1971 a slight droughty period was ended by a substantial rainfall. A few hours after the rain had begun, observations on moisture penetration into the soil were taken with a soil probe. On the bare soil furrows the moisture had permeated to a depth of 60 cm. On adjacent areas with herbaceous vegetation the rain had penetrated only 5 cm. These advantageous moisture conditions promote greater root development in the furrows.

These observations on root distributions within the study plantation indicate that competition between trees in a red pine stand does exist before crown closure occurs. Most of the root competition is between adjacent trees in the same row rather than between adjacent trees in different rows. It appears that greater initial spacing between trees may be required than above ground appearances might suggest.

Snow Damage Survey

Damage to the plantation from heavy snow accumulations during the three winters of 1969, 1970, and 1971 were assessed for intensity and distribution. The damage has been most apparent on lateral branches about 75 cm above the ground (Figure 15).

The general extent of the injury to the trees within the plantation is presented in Table 9. One apparent trend is the increasing amount of damage with increased tree density. Note that the number of whorls damaged per tree more than doubled from the 500 to 2000 trees/hectare spacing. The amount of old damage (1968-1969 and 1969-1970 winters) tripled over the range of spacings. The quantity of new damage (1970-1971 winter) increased by a factor of four as the density increases from 500 to 2000 trees/hectare. The statistical analysis of the old and new damage resulted in declaring fewer of the old damage means significantly different. This was a consequence of greater within-spacing variation in the old damage than in the new damage analysis of variance.

Of the recently injured branches, larger diameter branch damage occurred in the wider spacings. This was an obvious reflection of the spacing growth differences.

Table 9. Summary of the number of whorls and branches damaged during three winters on a per-tree basis, by spacing.

Trees/ Ha.	Injury Type[1]						
	Whorls Damaged		Old Damage		New Damage		Diameter
	No.	No./Tree (Branches)	No.	No./Tree (Branches)	No.	No./Tree (Branches)	(cm)
500	68	0.78 a	60	0.69 a	34	0.39 a	2.11 a
750	140	1.09 ab	126	0.98 ab	87	0.68 ab	1.80 ab
1000	242	1.43 bc	261	1.54 ab	174	1.03 bc	2.11 a
1500	389	1.57 bc	446	1.81 b	266	1.08 bc	1.80 ab
2000	595	1.82 c	663	2.02 b	529	1.62 c	1.75 b

[1]Means within each category not followed by the letter are significantly different at the 5 percent level (Tukey's test).

Absence of crown closure in the wider-spaced plots has allowed low branches to continue to grow in diameter (Stiell, 1964). Thus any damage to lower branches in the plots with fewer trees/hectare would automatically involve branches with greater diameters.

New Damage

The snow injury occurring during the winter of 1970-1971 was divided into three damage categories. Depending on the degree of vascular system disruption, the damage was assessed as 0-50, 50-90, and 90-100 percent (Table 10, Figure 16).

Figure 15. Snow damage "line" in 1971 at about 75 cm above the ground, 2000 trees/ha.

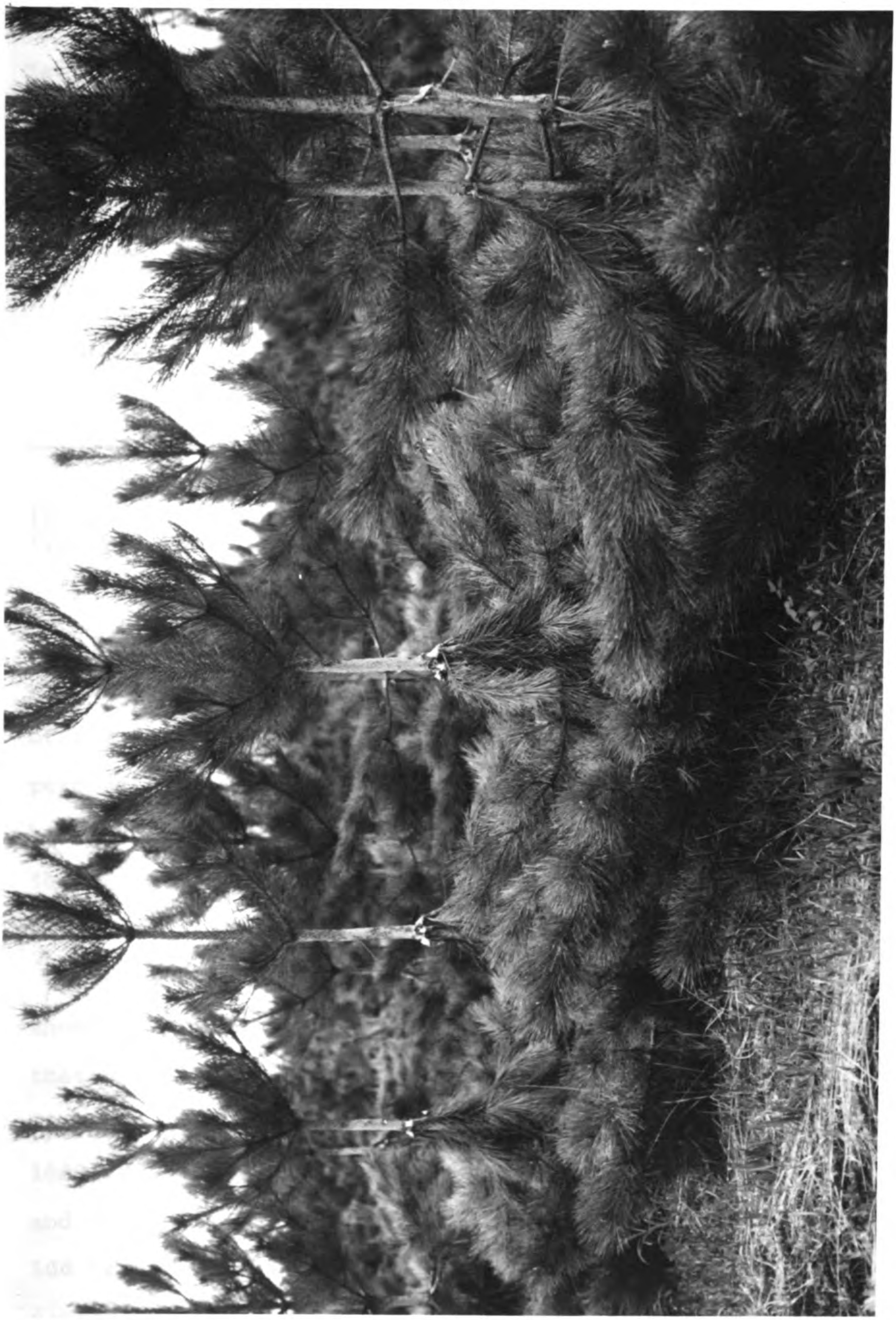


Table 10. Number of damaged branches/tree during the winter of 1970-1971 classified according to the percentage damage to the vascular system.

Trees/Hectare	Damaged Branches/Tree[1]		
	90-100%	50-90%	0-50%
500	0.18 a	0.20 a	0.01 a
750	0.42 ab	0.22 a	0.04 a
1000	0.74 bc	0.32 a	0.03 a
1500	0.76 bc	0.30 a	0.02 a
2000	1.17 c	0.38 a	0.07 a

[1]Means within each category not followed by the same letter are significantly different at the 5 percent level (Tukey's test).

Branches in the 90-100 percent damage class were either torn entirely off the tree or died in the course of the following growing season. Damage in the 50-90 percent class usually left the branch alive, but often hanging down onto a lower whorl. Branches with less than 50 percent damage were difficult to locate since they healed over quickly.

The types and distribution of the new damage are shown in Figure 11. It is quite evident from the graph that a majority of the branches damaged were in the 90-100 percent class. In that class, the 2000, 1500, and 1000 trees/hectare plots have respectively six, four, and four times as many branches killed per tree than the 500 trees/hectare plots. Also, while the amount of damage observed in the 500 trees/hectare plots was

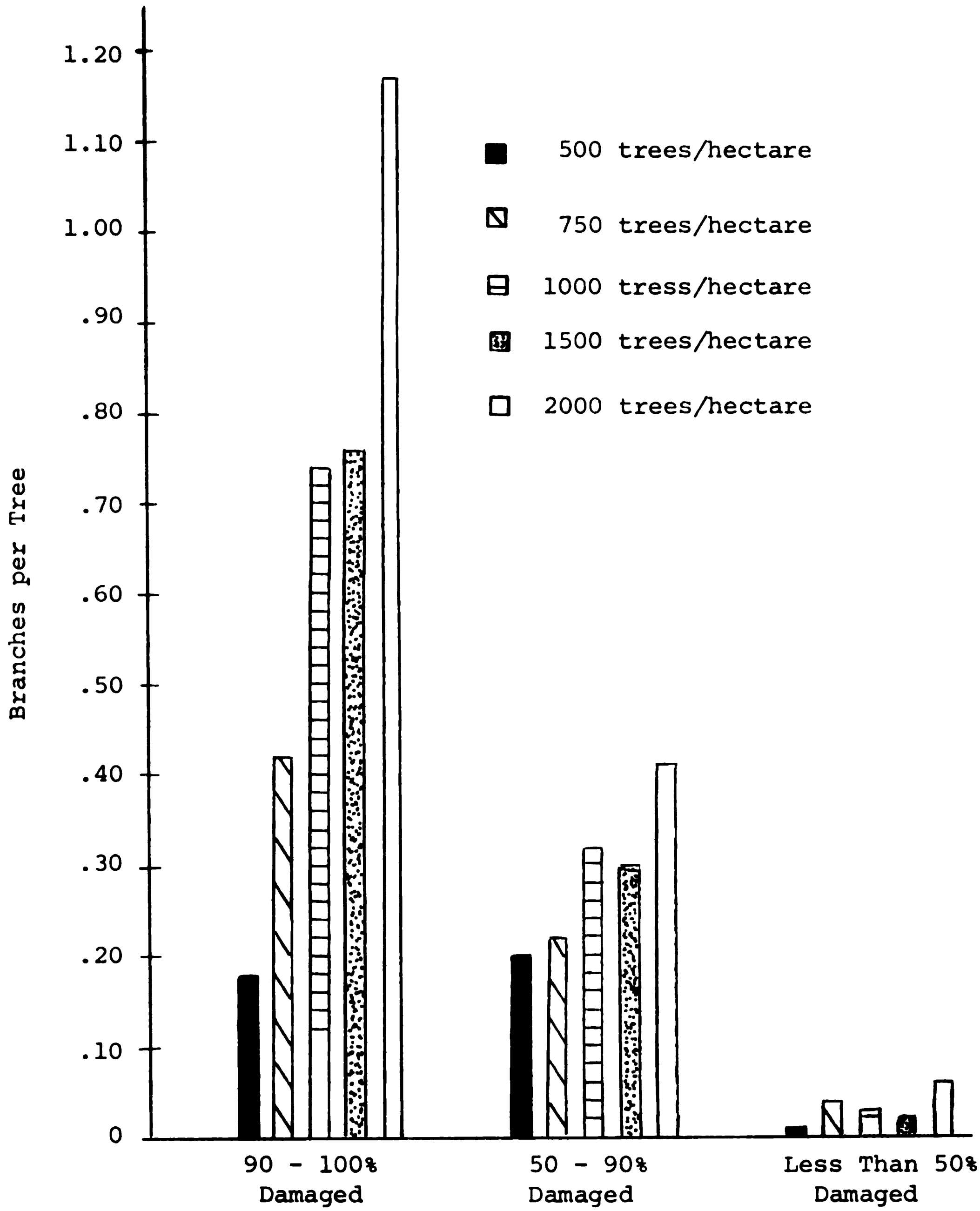


Figure 16. Branches per tree damaged and killed in the winter of 1970-1971 by density level.

equally distributed among the 90-100 and 50-90 percent damage categories, the more closely spaced plots contained an ever-increasing proportion of damage in the 90-100 percent category (Figure 17).

Old Damage

Branches damaged during the winters of 1968-1969 and 1969-1970 were recorded as either remaining on the tree or missing (Table 11). The branches remaining category contains branches once classified as 0-50 and 50-90 percent damaged, while those classes as missing fell into the category of 90-100 percent damaged. The most notable part of the old damage is again the trend toward an increasing amount of damage with increased tree density. The numbers of branches missing and remaining are approximately equal across the range of spacings. No differences in the branches missing category could be declared significant, even though the magnitude of the differences between the means is similar to that of the branch remaining category, because of large within-spacing variations.

Whorl Damage Profile

To obtain a better perspective of the snow injury, it is necessary to examine the height and whorl distribution of the damage (Table 12). This table presents the

Figure 17. Branch vascular cambial separation for the 90-100 percent snow damage category.

Table 11. Snow damage during the winters of 1968-1969 and 1969-1970 classified as either remaining branches or missing branches.

Trees/Hectare	Branches/Tree[1]	
	Remaining	Missing
500	0.36 a	0.44 a
750	0.53 ab	0.47 a
1000	0.75 bc	0.82 a
1500	0.90 bc	0.90 a
2000	0.95 c	1.07 a

[1]Means within each category not followed by the same letter are significantly different at the 5 percent level (Tukey's test).

Table 12. Distribution of snow damage during the last three winters by whorl and damage category.

Whorl	New Damage				Old Damage		
	Branches	90-100%	50-90%	0-50%	Branches	Branch Left	Branch Gone
I	2	2 (100%)	0 (0%)	0 (0%)	0	0 (0%)	0 (0%)
II	66	56 (85%)	2 (3%)	8 (12%)	7	0 (0%)	7 (100%)
III	357	289 (81%)	48 (13%)	20 (6%)	90	26 (29%)	64 (71%)
IV	468	343 (73%)	117 (25%)	8 (2%)	885	271 (31%)	614 (69%)
V	184	62 (32%)	127 (66%)	5 (3%)	557	448 (80%)	109 (20%)
VI	3	0 (0%)	3 (100%)	0 (0%)	17	14 (82%)	3 (18%)

old and new damage to the top six whorls of all the trees in the study plots. The tabulated whorl heights are:

Whorl	Average Height (m)
I	2.5
II	2.0
III	1.5
IV	0.7
V	0.5
VI	0.3

Starting with Whorl I (top whorl), the amount of injury increases from two branches, reaches a maximum in Whorl IV with 1,353 branches, and then decreases to 20 branches in Whorl VI. Damage to Whorl IV is twice that of Whorl V and three times that of Whorl III. Not only is the damage heaviest in Whorl IV, but 73 percent of the newly injured branches, and 69 percent of the previously injured branches are in categories implying death and/or complete removal from the stem. The danger of such a concentrated removal of branches lies in the possibilities of completely girdling the stem and thus killing the tree. While only two trees in the 20 plots were thus far killed outright by snow damage, many trees were observed to have a large portion of their xylem exposed at Whorl IV. It remains to be seen what further stand mortality occurs in the next few years as a result of reduction in tree vigor associated with this snow injury.

A closer view of the intense damage to Whorl IV is presented in Figure 18. Trees in plots with 2000 trees/hectare had 40 percent of their branches in Whorl IV damaged to some extent, while trees in plots of 500 trees/hectare suffered injury to only 15 percent of their branches. In terms of branches killed, the closer-spaced trees were hit three to four times as hard as the wider-spaced trees. Statistical analysis of the damaged and killed categories showed that the 500 and 750 stems/hectare densities had significantly lower incidences of injury than the other three densities.

Summary

The observed snow damage appears to be closely correlated to plantation density. The primary climatic mechanism resulting in this type of snow damage has a sequence of events beginning with the melting of the snowpack in the spring. Snow in the widely spaced and more exposed plots melts faster than the snow in the more closely spaced and shaded plots. Slowly melting snow retains much of the melt water in pore spaces, thus increasing its density by a factor of two to four times. It is this dense snow, bearing down on the branches, that causes the injury. The position of the damage on

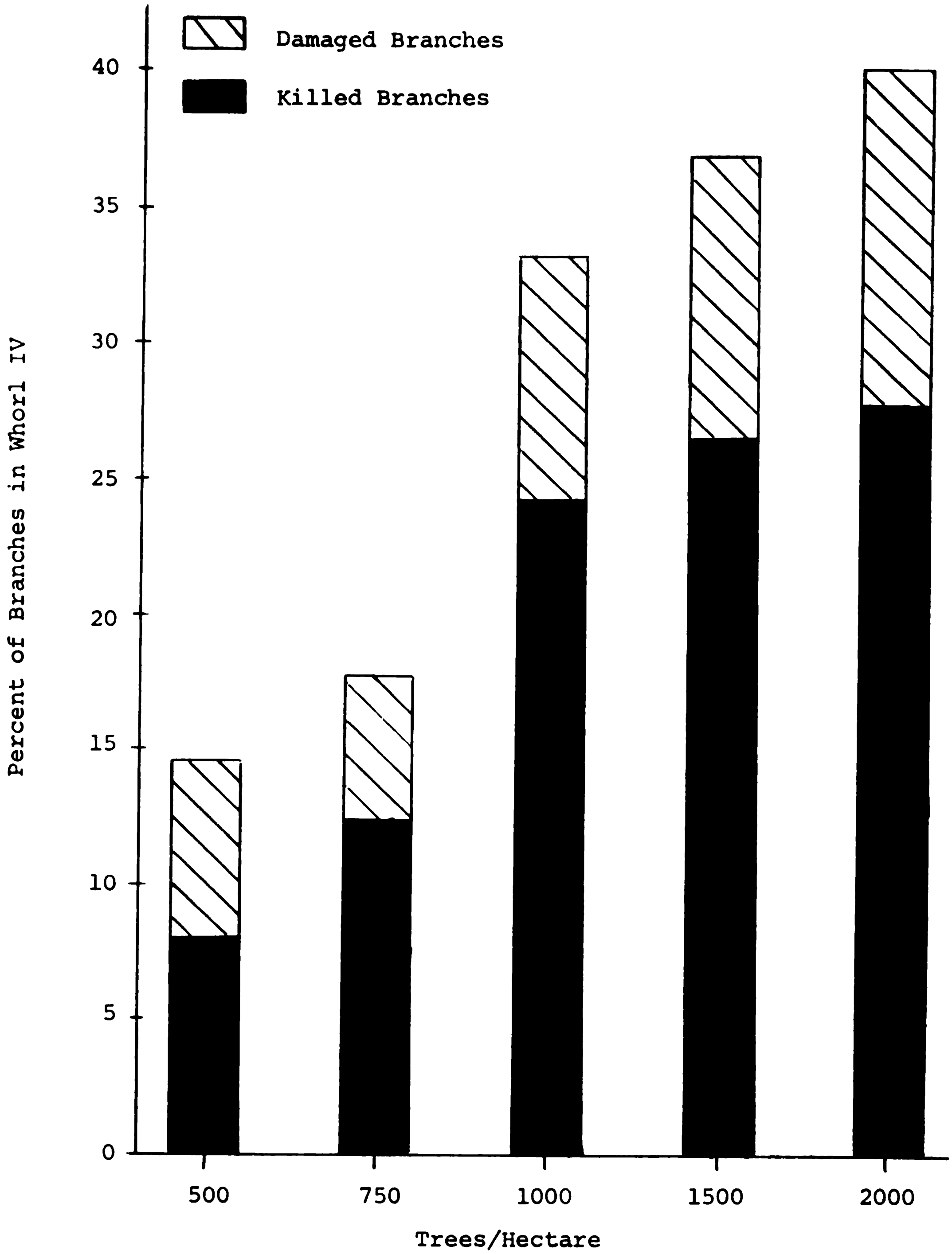


Figure 18. Percentage of all branches in Whorl IV damaged and killed.

the tree is a function of: initial snow depth, height of the tree, surface area of the branches in each whorl, and the depth of the snow when it reaches a critical density.

Biomass

Nutrients

Plant nutrient analyses were performed in both 1968 and 1971 to determine if any variations in nutrient content had arisen as a consequence of the differences in stand density. Only the nitrogen and potassium results were available from the 1971 analysis. No significant differences attributable to the spacing of red pine could be found. The mean values of nitrogen and potassium for the various portions of the tree are presented in Table 13.

Table 13. Comparisons of changes in the nitrogen and potassium distribution in young red pine from 1968 to 1971.

Tree Portion	Year	Mean Grams of Biomass	Nitrogen		Potassium	
			%	Grams	%	Grams
Needle	1968	1229	1.33	16.3	0.38	4.7
	1971	3675	1.23	45.2	0.28	10.3
Branches	1968	675	0.40	2.7	0.20	1.4
	1971	2584	0.36	9.3	0.14	3.6
Stem	1968	411	0.35	1.4	0.20	0.8
	1971	2096	0.35	7.3	0.14	2.9
Roots	1968	-	-	-	-	-
	1971	1314	0.44	5.8	0.16	2.1

Biomass Distribution

No relationship of biomass to spacing was evident in the trees collected during 1968. The mean dry weight of the above ground portion of each tree was found to be 2.315 kg. This weight was composed of 53.3 percent needles, 29.0 percent branches, and 17.1 percent stem.

The trees used for the biomass analysis in 1971 showed no evident trends that could be associated with the level of spacing. The root biomass averaged 1.314 kg while the above ground portion averaged 8.356 kg, of which the needles made up 44.4 percent, the branches 30.5 percent, and the stem 25.1 percent. These percentages reflect the changes that have occurred over the three-year growth period from 1968 to 1971. The foliage portion of the biomass decreased 9.9 percent while the stem and branch components increased 7.4 and 1.5 percent respectively. The three years of growth produced three times as much needle biomass, four times as much branch biomass, and five times as much stem biomass as the trees possessed in 1968.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Historically, most artificial stands of red pine in northern Michigan have been planted at relatively close spacings of 2.4 x 2.4 meters (2000 trees/hectare). Close spacings have been considered to be desirable since it was believed that: (1) maximum plant productivity resulted only when the site was fully utilized, (2) sufficient numbers of seedlings were necessary to provide for adequate growing stock, and (3) inter-tree competition did not occur until after crown closure. However, Lemmien and Rudolph (1959), Stiell (1964), Byrnes and Bramble (1965), and Berry (1970) have cast doubt on the silvicultural and economical desirability of close spacing in young red pine plantations.

The tree growth of both stem and crown during 1969 through 1971 indicates that better growth is occurring in the plots with 500 trees/hectare (4.8 x 4.8 meters). Terminal shoot growth appears to be best in this density, and is least affected by dry conditions. While no significant differences in the height growth have occurred, the 500 trees/hectare plots are gradually gaining in height, and the DBH of these trees has already become significantly greater than that of the 2000 trees/hectare plots (2.4 x 2.4 meters). The percentage of trees with a DBH greater than 5.1 cm (2 in) grades from about 28 percent for that of the 2000 trees/hectare plots to about 77 percent for that of the 500 trees/hectare plots. This trend of increasing tree diameter with increasing distance between individual trees strongly points to greater volumes per tree, and hence greater value per tree, in the low density plots by the end of the rotation.

At this point in the rotation period, maximum productivity, in terms of tree biomass, is occurring in the high-density plots. This is due solely to the numbers of trees involved (2000 vs. 500 trees/hectare). As Lemmien and Rudolph (1959), Stiell (1964), and Byrnes and Bramble (1965) have shown, the same phenomenon does not hold true over the entire rotation. After 30 or 40 years of growth, the volume of wood produced per hectare in high- and low-density stands tends to be equalized. However, in the low-density stands that volume is concentrated in fewer, larger diameter trees.

The analysis of root patterns and growth has revealed that competition between red pine in a plantation definitely occurs before crown closure. Roots showed a definite tendency to become oriented along the furrow line. In several instances roots were observed to extend from one tree and traverse under two or more adjacent trees in the same row and direction. The unequal distribution patterns arising as a consequence of furrow planting led to early competition in the red pine plantation and a subsequent loss of potential growth. Thus more growing space has to be allowed than is apparent from above ground stem and crown features.

Heavy snowfalls, common in the upper peninsula of Michigan, cause considerable damage in conifer plantations. The snow damage observed for the past three years in the study plantation has resulted in significant damage that bears a direct relationship to the density of the plantation. Plots with 2000 trees/hectare suffered three times as much injury in the 1968-1969 and 1969-1970 winters, and four times as much injury in the 1970-1971 winter than the 500 trees/hectare plots. Much of the snow damage was concentrated at about 75 cm above ground level in the fourth whorl from the tops of the trees. In that whorl, the 2000, 1500, and 1000 trees/hectare plots lost over 33 percent of all the branches in the whorl (twice that of the 500 and 750 trees/hectare plots). This heavy loss of branches was severe enough in several instances to completely girdle and kill the tree. Many trees remained alive, but were supported only by narrow strips of cambium around the whorl. Severe injury of this sort often reduces the tree's vigor and predisposes it to subsequent insect or disease attack.

Spacings ranging from 4.8 x 4.8 to 3.9 x 3.9 meters, which result in densities between 500 and 750 trees/hectare respectively, appear to be the most desirable for the growth of young red pine. This indicates that a change toward lower initial plantation densities from those commonly used at the present is necessary. However, evaluation of studies such as this must be carried out over an entire rotation before any firm decision on altering planting density can be made. The low densities possess several distinct advantages that make their use worth consideration:

(1) establishment costs are lowered by as much as one-half;
(2) precommercial thinnings are not required;
(3) greater DBH and volume increments per tree result;
(4) the rotation is shortened.

The use of lower densities in plantations should result in larger, higher quality trees. This coupled with reduction in planting costs, elimination of cultural operations, and a decrease in the rotation period would improve the economic feasibility of red pine plantations in northern Michigan.

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APPENDIX

Table 14. Metric--English equivalent measurements.

1 Hectare = 2.47 Acres						
1 Acre = 0.405 Hectares						
1 Foot = 0.305 Meter						
1 Meter = 3.3 Feet						
1 Inch = 2.5 Centimeters						
1 Centimeter = .4 Inch						

500	Trees/Hectare	=	200	Trees/Acre
750	"	=	300	"
1000	"	=	400	"
1500	"	=	600	"
2000	"	=	800	"

500	Trees/Hectare	= 4.82 x 4.82	Meters	=	14.7 x 14.7	Feet
750	"	= 3.94 x 3.94	"	=	12.0 x 12.0	"
1000	"	= 3.41 x 3.41	"	=	10.4 x 10.4	"
1500	"	= 2.85 x 2.85	"	=	8.7 x 8.7	"
2000	"	= 2.43 x 2.43	"	=	7.4 x 7.4	"

Table 15. Minimum, maximum, and mean air temperatures within the plantation during the growing seasons of 1969, 1970, and 1971.

Date	Distance Above Ground			
	30.5 cm		152.4 cm	
	Average Min/Max	Mean	Average Min/Max	Mean
	(Degrees Centigrade)			
1969				
6/25	-3.9/25.0	10.6	-	-
7/02	3.3/28.3	15.6	-	-
7/09	0.6/29.4	15.0	-	-
7/16	8.3/36.7	22.2	-	-
7/23	6.7/36.7	21.7	-	-
7/30	6.7/33.3	20.0	-	-
8/06	8.3/36.1	22.2	-	-
8/13	7.2/34.4	21.1	-	-
8/20	-0.6/35.6	17.8	-	-
8/28	1.7/38.9	20.0	-	-
9/10	3.3/33.9	18.9	-	-
1970				
6/03	1.1/24.4	12.8	-	-
6/10	-2.2/35.0	16.7	-	-
6/24	-1.7/36.1	17.2	-	-
6/30	1.7/35.0	18.3	-	-
7/09	3.9/36.1	20.0	-	-
7/22	5.6/36.7	21.1	-	-
8/05	0.6/35.6	17.8	-	-
8/19	3.3/37.8	20.6	-	-
9/02	-0.6/31.1	15.6	-	-
9/11	5.6/30.6	17.8	-	-
9/14	-1.1/26.7	12.8	-	-
1971				
6/22	6.7/33.3	20.0	8.3/28.9	18.9
6/29	10.6/32.2	21.7	11.1/27.8	19.4
7/06	8.3/32.8	20.6	8.9/28.3	18.9
7/13	10.6/32.2	21.7	10.6/28.3	19.4
7/20	9.4/28.9	18.9	10.0/25.0	17.8
7/27	7.8/28.9	18.3	7.8/25.6	16.7
8/03	7.2/24.4	16.1	6.7/22.2	14.4
8/10	10.0/30.0	20.0	10.0/26.7	18.3
8/17	6.1/27.2	16.7	5.0/25.0	15.0
8/24	5.0/29.4	17.2	4.4/26.7	15.6
8/31	9.4/21.1	15.6	9.4/20.0	14.4

Table 16. Precipitation in the plantation during the growing seasons of 1969, 1970, and 1971.

Date	Amount (cm)	
	1969	
6/04	4.85	
6/12	1.98	
6/18	1.52	
6/25	1.35	
7/02	6.20	
7/09	0.00	
7/16	0.28	
7/23	1.24	
7/30	3.84	
8/06	0.30	
8/13	1.04	
8/20	0.00	
8/28	0.00	
9/10	2.51	25.11 Total
	1970	
6/03	6.73	
6/10	0.00	
6/24	2.03	
6/30	0.10	
7/09	1.73	
7/22	8.46	
8/05	2.34	
8/19	0.10	
9/02	5.56	
9/14	1.27	28.32 Total
	1971	
6/09	7.80	
6/22	0.30	
6/29	1.37	
7/06	0.25	
7/13	0.97	
7/20	1.12	
7/27	1.61	
8/03	1.98	
8/10	0.10	
8/17	3.15	
8/24	3.43	
8/31	1.93	
9/08	0.76	24.77 Total

Table 17. Weekly minimum, maximum, and mean relative humidities within the plantation during the 1971 growing season.

Date	Percent Relative Humidity		
	Minimum	Maximum	Mean
6/22	33.3	99.7	66.5
6/29	33.9	100.0	66.9
7/06	30.7	99.7	65.2
7/13	26.0	99.4	62.7
7/20	32.6	99.6	66.1
7/27	47.1	99.1	73.1
8/03	39.3	97.3	68.3
8/10	36.3	99.3	58.2
8/17	43.9	100.0	71.9
8/24	41.6	99.3	70.4
8/31	49.9	96.7	73.3

Table 18. Mean daily solar radiation values over weekly periods during the summer of 1971.

Week Ending:	Langleys/Day (gm-cal/cm^2/day)
6/22	499.32
6/29	506.92
7/06	491.73
7/13	467.05
7/20	487.93
7/27	370.22
8/03	454.08
8/10	388.73
8/17	341.11
8/24	311.37
8/31	281.31
9/07	296.81

Table 19. Percent soil moisture (by weight) for varying spacings during 1969 in the 0 to 15 centimeter depth range.

Date	Trees/Hectare[1]					Average
	500	750	1000	1500	2000	
5/28	8.9	8.1	8.6	5.2	9.4	8.0
6/04	12.6	13.7	12.4	17.1	14.7	14.1
6/12	11.0	13.6	10.1	11.4	15.4	12.3
6/18	11.8	12.9	13.3	8.1	13.1	11.8
6/25	7.8	11.9	10.9	12.4	10.7	10.7
7/02	8.2	11.9	9.8	11.1	10.0	10.2
7/09	8.1	--	9.7	--	9.3	9.0
7/16	6.3	5.8	9.1	7.8	6.0	7.0
7/23	5.8	3.5	6.9	6.5	8.0	6.1
7/30	10.3	7.1	11.6	10.4	9.2	9.7
8/06	7.5	5.9	6.6	6.4	8.2	6.9
8/13	7.7	4.0	6.1	7.0	8.1	6.6
8/20	6.7	2.2	4.0	4.4	4.8	4.4
8/28	4.1	2.7	2.4	3.1	1.4	2.8
9/10	8.2	3.4	5.4	4.8	4.5	5.3

[1]The soil moisture determinations were made in one plot for each spacing.

Table 20. Percent soil moisture (by weight) for varying spacings during 1971 in the 0 to 15 and 15 to 30 centimeter depth range.

Date		Trees/Hectare[1]					Average
		500	750	1000	1500	2000	
6/18	A[2]	6.9	4.9	5.0	4.9	4.3	5.2
	B	-	-	-	-	-	-
6/25	A	10.0	12.2	10.4	8.5	8.0	9.8
	B	9.8	5.3	4.5	8.8	6.4	7.0
7/03	A	4.1	4.2	4.8	3.0	2.5	3.7
	B	4.3	8.5	5.9	4.1	4.2	5.4
7/09	A	2.0	2.2	2.6	1.6	1.7	2.0
	B	3.3	8.3	5.6	4.3	4.4	5.2
7/19	A	6.2	7.2	5.7	5.7	5.3	6.0
	B	5.4	6.2	6.6	5.6	4.6	5.7
7/24	A	10.3	13.7	12.4	13.1	12.6	12.5
	B	12.3	14.8	9.3	12.6	10.2	11.8
8/02	A	11.7	11.6	9.6	11.1	9.6	10.7
	B	5.9	5.6	4.9	8.9	5.5	6.2
8/09	A	4.9	4.2	5.1	2.9	3.2	4.0
	B	8.5	6.5	3.9	4.6	4.9	5.7
8/16	A	9.8	8.5	9.1	8.3	7.2	8.6
	B	8.3	7.3	6.8	9.5	7.8	8.0
8/23	A	11.8	14.2	13.2	9.4	9.0	11.5
	B	11.3	8.0	7.3	11.4	6.5	8.9

[1]The soil moisture determinations for the 0 to 15 cm depth were made at a selected point in each plot. Those for the 15 to 30 cm depth were made at the same points in each plot of Blocks I and IV only.

[2]A = 0 to 15 centimeters
B = 15 to 30 centimeters

Table 21. Block and spacing comparisons of percentage of ground area covered by herbaceous vegetation, 1971.

Vegetation	Percent Area Cover								
	Block				Trees/Hectare				
	I	II	III	IV	500	750	1000	1500	2000
Moss	45.1	37.3	36.8	15.8	34.7	31.3	43.7	29.9	29.5
Dock	13.6	10.5	11.1	13.7	16.8	13.0	11.2	11.9	9.6
Kingdevil	9.3	8.9	7.1	11.8	8.5	9.8	10.1	11.1	8.1
Orange Hawkweed	4.2	8.2	9.0	19.6	9.7	10.8	7.0	6.5	17.3
Leafy Spurge	4.1	2.3	3.0	10.6	3.2	3.9	1.6	12.4	4.0
Strawberry	1.2	1.5	1.2	0.9	0.9	1.6	0.7	2.4	0.5
Raspberry	0.4	2.9	1.7	2.2	2.7	1.1	0.7	1.5	3.1
Grasses	5.4	7.8	8.6	12.3	7.8	7.6	9.0	6.2	12.1
Quack Grass	0.0	1.4	0.7	2.9	0.0	2.6	0.0	2.1	1.5
Lichen	10.9	13.1	11.2	7.2	9.6	10.8	11.0	11.6	10.2
Milkweed	0.2	0.0	0.5	0.5	0.2	0.5	0.5	0.0	0.2
Fern	0.2	0.0	0.7	0.0	0.0	0.2	0.0	0.0	0.9
Bare Soil	4.4	5.8	7.4	2.5	5.8	6.7	4.8	4.7	3.2

Table 22. Average tree height on each .04 hectare plot before and after thinning, 1968.

Plot	Block	Stems/Ha. Spacing	Before Cutting		After Cutting	
			Trees	Ave. Ht.	Trees	Ave. Ht.
				- (m) -		- (m) -
1	1	1000	95	1.52	42	1.60
2	1	500	85	1.52	22	1.66
3	1	2000	106	1.53	82	1.61
4	1	1500	102	1.46	62	1.39
5	1	750	101	1.54	32	1.70
6	2	500	110	1.51	22	1.68
7	2	750	107	1.33	32	1.50
8	2	2000	96	1.44	82	1.49
9	2	1000	101	1.52	42	1.62
10	2	1500	105	1.51	62	1.56
11	3	1000	98	1.49	42	1.52
12	3	500	114	1.54	22	1.66
13	3	1500	92	1.54	62	1.54
14	3	750	108	1.51	32	1.60
15	3	2000	95	1.36	82	1.41
16	4	1000	96	1.36	42	1.43
17	4	2000	99	1.31	83	1.35
18	4	750	89	1.27	32	1.35
19	4	500	94	1.38	22	1.53
20		1500	92	1.39	62	1.42
		Block and Treatment Summary				
Block 1			97	1.51	48	1.59
Block 2			103	1.52	48	1.57
Block 3			101	1.49	48	1.55
Block 4			94	1.34	48	1.42
500 Trees/Hectare			100	1.49	22	1.63
750 Trees/Hectare			101	1.41	32	1.54
1000 Trees/Hectare			97	1.47	42	1.54
1500 Trees/Hectare			97	1.47	62	1.48
2000 Trees/Hectare			99	1.41	82	1.46

Table 23. Average leader growth by spacing during the 1969 through 1971 growing seasons.

Date	Trees/Hectare				
	500	750	1000	1500	2000
	(cm)				
1969					
5/28	5.67	5.67	6.00	5.67	5.33
6/04	3.33	3.33	3.67	3.67	3.33
6/12	5.67	6.00	7.33	6.33	6.33
6/18	3.67	5.00	3.67	3.67	3.33
6/25	5.00	5.00	5.67	5.00	5.00
7/02	6.33	7.67	8.33	6.00	7.00
7/09	5.67	7.67	7.00	6.67	7.00
7/16	9.33	4.33	9.67	15.00	9.67
7/23	2.33	3.00	2.67	5.33	2.67
7/30	1.33	1.00	0.33	2.00	1.00
8/06	0.00	0.00	1.33	1.00	0.33
Total[1]	48.33 b	48.67 ab	55.67 ab	60.34 b	50.99 ab
1970					
5/20	5.58	5.24	5.13	5.10	5.32
5/28	1.45	1.33	1.34	1.31	1.28
6/03	3.10	2.90	2.92	3.04	2.82
6/10	7.68	7.51	6.97	6.98	6.84
6/24	20.28	18.91	19.66	19.74	18.49
7/09	14.07	13.42	13.47	12.63	11.15
7/22	2.80	1.94	1.51	2.28	1.27
8/05	1.12	0.46	0.33	0.63	0.66
8/19	0.00	0.29	0.34	0.00	0.25
9/02	0.00	0.04	0.00	0.00	0.09
Total[1]	56.08 a	52.04 a	51.67 a	51.71 a	48.17 a
1971					
5/28	6.67	5.92	6.17	5.95	5.87
6/09	7.15	7.54	7.51	7.04	7.05
6/16	9.60	10.09	10.15	9.50	9.56
6/23	12.90	12.82	13.04	12.37	12.51
6/30	11.04	12.48	11.55	12.02	10.89
7/07	9.49	7.47	7.66	7.00	6.37
7/14	4.00	3.09	3.25	3.74	2.96
7/21	1.05	1.04	0.71	1.21	1.08
7/28	0.35	0.37	0.29	0.42	0.21
8/04	0.05	0.13	0.09	0.04	0.04
8/18	0.05	0.08	0.16	0.09	0.00
Total[1]	62.85 a	61.04 a	60.58 a	59.38 a	56.62 a

[1]Means not followed by the same letter are significantly different at the 5 percent level (Tukey's test).

Table 24. Average height and DBH of three sample trees per plot at the end of the growing season, 1968 to 1971.

Plot	Total Height				DBH	
	1968	1969	1970	1971	1970	1971
	(Meters)				(cm)	
1	1.646	2.134	2.661	3.252	3.74	5.08
2	1.411	1.899	2.478	3.170	3.81	5.41
3	1.615	2.155	2.652	3.271	3.63	5.00
4	1.472	1.929	2.429	2.987	2.97	4.39
5	1.676	2.195	2.713	3.322	3.68	5.21
6	1.753	2.225	2.774	3.368	3.68	5.21
7	1.503	1.972	2.569	3.191	3.56	4.90
8	1.494	1.996	2.469	3.033	3.05	4.44
9	1.637	2.173	2.734	3.362	3.73	5.33
10	1.594	2.185	2.752	3.392	3.63	5.08
11	1.563	2.073	2.621	3.322	3.73	5.33
12	1.646	2.225	2.835	3.536	4.44	6.10
13	1.554	2.051	2.569	3.170	3.48	5.08
14	1.524	2.033	2.652	3.240	3.30	4.75
15	1.484	1.960	2.417	2.947	3.05	4.39
16	1.454	1.929	2.338	2.917	3.12	4.57
17	1.433	1.920	2.417	3.027	2.97	4.32
18	1.423	1.920	2.478	3.139	3.38	5.16
19	1.564	2.042	2.501	3.210	3.63	5.26
20	1.655	2.155	2.673	3.261	3.23	5.16

Table 25. Diameter distribution for all trees by plot, below and above a DBH of 5.1 centimeters.

Plot	Trees	DBH = < 5.1 cm		DBH = > 5.1 cm	
		Number	Percentage	Number	Percentage
1	42	16	38.1	26	61.9
2	22	4	18.2	18	81.8
3	82	48	58.5	34	41.5
4	62	35	56.5	27	43.5
5	32	7	21.9	25	78.1
6	21	4	19.0	17	81.0
7	32	18	56.2	14	43.8
8	82	54	65.9	28	34.1
9	42	17	40.5	25	59.5
10	62	27	43.5	35	56.5
11	43	19	44.2	24	55.8
12	22	2	9.1	20	90.9
13	62	24	38.7	38	61.3
14	32	9	28.1	23	71.9
15	81	62	76.5	19	23.5
16	42	28	66.7	14	33.3
17	81	71	87.7	10	12.3
18	32	21	65.6	11	34.4
19	22	10	45.5	12	54.5
20	62	42	67.7	20	32.3

Table 26. Weekly tree circumference growth measurements by band dendrometer for observed spacings, 1971.

Date[1]	Trees/Hectare				
	500	750	1000	1500	2000
	(mm)				
6/23	4.2	3.5	3.6	4.2	4.0
6/30	4.4	4.3	5.2	3.0	4.2
7/07	3.4	1.4	3.0	3.8	2.3
7/14	1.8	2.6	2.0	1.8	2.3
7/21	0.7	0.7	0.4	0.4	1.2
7/28	4.3	3.7	3.8	4.3	3.5
8/04	2.2	3.3	1.5	2.0	2.5
8/11	4.0	2.3	3.5	3.0	2.5
8/18	2.2	2.2	3.8	2.7	2.0
8/25	2.8	3.5	3.7	3.0	3.7
9/08	2.5	2.5	2.5	2.0	2.0
Total[2]	32.5 a	30.0 a	32.0 a	30.2 a	30.2 a

[1]Dendrometer bands were placed on one tree in each plot on 6/16.

[2]Means not followed by the same letter are significantly different at the 5 percent level (Tukey's test).

Table 27. Average needle growth by spacing during the 1969 through 1971 growing seasons.

Date	Trees/Hectare				
	500	750	1000	1500	2000
	(cm)				
1969					
7/09	3.00	3.67	3.00	3.33	3.00
7/16	2.67	2.00	3.00	3.33	2.33
7/23	2.00	1.67	1.67	1.00	1.33
7/30	0.67	1.00	1.00	1.33	1.67
8/06	1.67	1.00	1.00	1.33	0.67
8/13	1.33	1.67	1.67	1.00	1.33
8/20	1.00	1.67	1.67	1.33	1.00
8/28	0.33	0.00	0.00	0.35	0.67
Total[1]	12.67 ab	12.67 ab	13.00 a	13.00 a	12.00 b
1970					
7/09	5.95	5.92	5.33	5.93	5.85
7/22	2.66	2.16	2.69	1.99	2.15
8/05	1.39	1.54	1.44	1.50	1.78
8/19	1.21	1.38	1.12	1.62	1.14
9/11	0.62	0.50	0.92	0.38	0.54
Total[1]	11.83 a	11.50 a	11.50 a	11.42 a	11.46 a
1971					
6/30	4.72	4.64	4.52	4.42	4.62
7/07	1.48	1.34	1.26	1.36	1.06
7/14	1.33	1.08	1.08	1.10	0.74
7/21	1.03	0.99	0.75	0.66	0.90
7/28	0.61	0.74	1.09	0.91	0.78
8/04	0.55	1.07	0.58	0.69	0.72
8/18	1.30	1.15	1.36	1.24	1.53
9/08	1.34	0.95	0.63	0.71	0.69
Total[1]	12.36 a	11.96 ab	11.27 ab	11.09 b	11.04 b

[1]Means not followed by the same letter are significantly different at the 5 percent level (Tukey's test).

Table 28. Red pine root orientation with the furrow according to diameter class.

Tree	Root Angle	1.	2.	3.	4.	No. of Roots	Weighted Total	% of Root System[1]
1.	0°	2	3	2	0	7	14	56.0
	45°	2	1	1	0	4	7	28.0
	90°	2	1	0	0	3	4	16.0
	Total	6	5	3	0	14	25	100.0
2.	0°	2	4	1	0	7	13	41.8
	45°	2	2	1	0	5	9	29.1
	90°	1	4	0	0	5	9	29.1
	Total	5	10	2	0	17	31	100.0
3.	0°	1	4	0	0	5	9	45.0
	45°	2	1	0	1	4	8	40.0
	90°	3	0	0	0	3	3	15.0
	Total	6	5	0	1	12	20	100.0
4.	0°	6	3	0	1	10	16	50.0
	45°	3	6	0	0	9	15	46.9
	90°	1	0	0	0	1	1	4.1
	Total	10	9	0	1	20	32	100.0
5.	0°	4	1	0	1	6	10	31.2
	45°	2	4	3	0	9	19	59.4
	90°	1	1	0	0	2	3	9.4
	Total	7	6	3	1	17	32	100.0
6.	0°	6	5	0	0	11	16	44.4
	45°	4	1	1	1	7	13	36.1
	90°	2	1	1	0	4	7	19.5
	Total	12	7	2	1	22	36	100.0
7.	0°	3	4	2	0	9	17	48.6
	45°	5	2	1	0	8	12	34.3
	90°	2	2	0	0	4	6	17.1
	Total	10	8	3	0	21	35	100.0

[1]Percent of horizontal root system that was identified and mapped.

Table 29. Three-year summary of snow damage to branches, 1968-1971.

Plot	Trees	Damaged Branches	Damage Category 90-100%	Damage Category 50-90%	Damage Category 0-50%	Bran./Tree 90-100%	Bran./Tree 50-90%	Bran./Tree 0-50%
1	42	50	26	24	0	0.62	0.57	0.00
2	22	13	7	6	0	0.32	0.27	0.00
3	82	135	95	38	2	1.16	0.46	0.02
4	61	64	48	16	0	0.79	0.26	0.00
5	32	22	15	7	0	0.47	0.22	0.00
6	21	3	1	2	0	0.05	0.10	0.00
7	32	23	12	8	3	0.38	0.25	0.09
8	82	177	137	30	10	1.67	0.37	0.12
9	42	28	19	8	1	0.45	0.19	0.02
10	62	57	43	14	0	0.69	0.23	0.00
11	43	48	36	11	1	0.84	0.26	0.02
12	22	7	1	5	1	0.05	0.23	0.05
13	62	77	58	15	4	0.94	0.24	0.06
14	32	15	11	4	0	0.34	0.12	0.00
15	82	105	74	23	8	0.90	0.28	0.10
16	42	48	34	11	3	0.81	0.26	0.07
17	81	111	76	32	3	0.94	0.40	0.04
18	32	27	15	10	2	0.47	0.31	0.06
19	22	11	7	4	0	0.32	0.18	0.00
20	62	68	37	29	2	0.60	0.47	0.03

Table 30. Intensity of snow damage by percent disruption of the vascular cambium during the winter of 1970-1971.

Plot	Trees	Whorls Damaged	Whorls/ Tree	New Damage[1]			Old Damage[2]	
				Branches	Bran./Tree	Ave. Diameter	Branches	Bran./Tree
1	42	70	1.67	50	1.19	2.59	80	1.90
2	22	17	0.77	13	0.59	2.49	13	0.59
3	82	145	1.77	135	1.65	1.88	197	2.40
4	61	90	1.48	64	1.05	1.98	88	1.42
5	32	37	1.16	22	0.69	1.83	34	1.06
6	21	11	0.52	3	0.14	1.91	6	0.29
7	32	30	0.94	23	0.72	1.80	19	0.59
8	82	166	2.02	178	2.17	1.78	189	2.30
9	42	38	0.90	28	0.67	2.01	29	0.69
10	62	84	1.35	57	0.92	2.01	100	1.61
11	43	66	1.53	48	1.12	2.13	85	1.98
12	22	12	0.55	7	0.32	2.26	7	0.32
13	62	113	1.82	77	1.24	1.70	144	2.32
14	32	27	0.84	15	0.47	1.96	22	0.69
15	82	147	1.79	105	1.28	1.70	161	1.96
16	42	68	1.62	48	1.14	1.70	67	1.60
17	81	137	1.69	111	1.37	1.63	116	1.43
18	32	46	1.44	27	0.84	1.63	51	1.59
19	22	28	1.27	11	0.50	1.78	34	1.55
20	62	102	1.65	68	1.10	1.50	114	1.84

[1]Damage from the winter of 1970-1971.

[2]Damage from the winters of 1968-1969 and 1969-1970.

Table 31. Snow damaged branches remaining on or missing from trees during the winters of 1968-1969 and 1969-1970.

Plot	Trees	Branches Damaged	Damage Category		Remaining Branches/Tree	Missing Branches/Tree
			Remaining	Missing		
1	42	80	33	47	0.79	1.12
2	22	13	4	9	0.18	0.41
3	82	197	81	116	0.99	1.41
4	61	88	47	41	0.77	0.67
5	32	34	21	13	0.66	0.41
6	21	6	5	1	0.24	0.48
7	32	19	10	9	0.31	0.28
8	82	189	92	97	1.12	1.18
9	42	29	19	10	0.45	0.34
10	62	100	55	45	0.89	0.73
11	43	85	41	44	0.95	1.02
12	22	7	5	2	0.23	0.09
13	62	144	62	82	1.00	1.32
14	32	22	12	10	0.38	0.31
15	82	161	75	86	0.91	1.05
16	42	67	34	33	0.81	0.79
17	81	116	64	52	0.79	0.64
18	32	51	23	28	0.72	0.88
19	22	34	17	17	0.77	0.77
20	62	114	59	55	0.95	0.89

Table 32. Summary of the number of snow damaged branches by whorl classified in terms of recent damage/old damage, 1968-1971.

Plot	Whorl[1]					
	I	II	III	IV	V	VI
1	0/0	0/1	0/1	34/46	16/28	0/4
2	0/0	0/0	0/0	9/8	4/5	0/0
3	0/0	4/0	41/8	71/120	18/67	1/2
4	0/0	6/0	16/4	32/48	10/35	0/1
5	0/0	1/0	0/0	11/13	10/21	0/0
6	0/0	0/0	0/0	3/4	0/1	0/1
7	0/0	5/0	2/0	10/10	6/9	0/0
8	0/0	29/4	75/15	60/115	13/55	1/0
9	0/0	0/0	4/0	14/17	10/12	0/0
10	0/0	0/0	19/2	34/64	4/34	0/0
11	0/0	0/0	12/11	24/50	12/34	0/0
12	0/0	0/0	0/0	2/4	5/3	0/0
13	0/0	2/2	22/10	42/90	11/40	0/2
14	0/0	0/0	1/0	10/12	4/10	0/0
15	0/0	0/0	65/15	27/92	13/54	0/0
16	0/0	1/0	17/4	23/36	7/26	0/1
17	0/0	9/0	54/7	28/61	20/45	0/3
18	0/0	5/0	6/6	6/23	10/22	0/0
19	0/0	0/0	2/1	3/12	6/19	0/1
20	2/0	4/0	21/6	25/59	15/47	1/2
Sub Total	2/0	66/7	357/90	468/885	184/557	3/17
Total	2	73	447	1,353	741	20

[1]The whorls are numbered consecutively starting with the top whorl and proceeding down the stem for six whorls.

Table 33. Percentage of branches in whorl IV killed and damaged by snow.

Plot	Branches Damaged	Branches Killed	Original Branches	% Damaged	% Killed
1	80	55	194	41.2	28.4
2	17	13	98	17.3	13.3
3	191	145	393	48.6	36.9
4	80	59	266	30.1	22.2
5	24	19	152	15.8	12.5
6	7	2	101	6.9	2.0
7	20	12	131	15.3	9.2
8	175	114	363	48.2	31.4
9	31	20	189	16.4	10.6
10	98	65	268	36.6	24.3
11	74	55	183	40.4	30.1
12	6	3	110	5.5	2.7
13	132	101	289	45.7	34.9
14	22	18	144	15.3	12.5
15	119	82	331	36.0	24.8
16	59	47	169	34.9	27.8
17	89	58	316	28.2	18.4
18	29	18	118	24.6	15.3
19	26	13	91	28.6	14.3
20	84	58	234	35.9	24.8

Trees/Hectare	% Damaged[1]	% Killed
500	14.6 a	8.1 a
750	17.8 ab	12.4 ab
1000	33.2 bc	24.2 bc
1500	37.1 bc	26.6 bc
2000	40.2 c	27.9 c

[1]Means in each category not followed by the same letter are significantly different at the 5 percent level (Tukey's test).

Table 34. Biomass distribution of the needles, branches, stem, and roots of young red pine.

Tree	Trees/ Ha.	Needles	Branches	Stem	Total Above Ground	Roots	Total
		(grams)					
1968							
1	1000	1278	846	539	2663	-	-
2	500	1356	752	425	2533	-	-
3	2000	1312	676	382	2370	-	-
4	1500	1088	532	352	1972	-	-
5	750	1110	571	358	2039	-	-
Mean	-	1229	675	411	2315	-	-
1971							
1	2000	4596	2039	1869	8504	1117	9621
2	1000	3518	2004	2044	7566	1067	8633
3	500	4503	4392	2890	11785	1687	13472
4	2000	3476	2660	2009	8145	1141	9286
5	2000	3254	2854	2156	8364	1674	9938
6	500	3244	2044	2075	7363	1346	8709
7	500	3137	2096	1631	6864	1164	8028
Mean	-	3675	2584	2096	8356	1314	9670