STUDIES OF ENVIRONMENTAL FACTORS AFFECTING JACK PINE (PINUS BANKSIANA LAMB.) REGENERATION

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ABSTRACT

STUDIES OF ENVIRONMENTAL FACTORS AFFECTING JACK PINE (*PINUS BANKSIANA* LAMB.) REGENERATION

By

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The effects of several environmental factors on jack pine germination, survival, and growth were investigated under both laboratory and field conditions. Field comparisons were made between direct seeded and container-grown seedlings and between seedlings raised in two types of containers.

Potted jack pine seedlings were raised in controlled environment chambers for ten weeks under six combinations of three temperatures and soil moisture treatments. Day and night temperatures were controlled at 32°C and 21°C, 24°C and 13°C, and 16°C and 5°C, respectively. Soil-water suction was either maintained below 0.1 atm or allowed to fluctuate between 0.0 and 15.0 atms. All other factors were held constant at levels which simulated natural conditions.

Temperature and soil moisture treatments had a pronounced affect on seedling height, stem diameter, and dry weight. The soil moisture X temperature interaction was highly significant for every growth parameter measured. With adequate soil water, seedlings at the high and moderate temperatures had approximately two times more dry matter than those at the low temperature. By the tenth week, seedlings at the moderate temperature appeared to be larger and more vigorous than those at the high temperature. Trees under conditions of soil-water stress showed little response to temperature differences.

The presence of ample soil water increased total dry weight by more than two times at the high and moderate temperature, but only about 30 percent at the low temperature. Root mortality and a resultant decline in root dry weight seemed to be closely associated with fluctuations in soil-water suction. At the low temperature, terminal bud set appeared to be influenced by the amount of available soil water.

The first-year response of direct seeded and container-grown jack pine seedlings to site modifications influencing wind, light, soil moisture, and competition was examined under field conditions in northern Lower Michigan. Seedlings were raised in either split-plastic tubes or

Jiffy-7 pellets for comparison with each other and with seedlings from direct seeding. Experimental plots were arranged in a split-plot design, and treatments included: (1) reduction of the prevailing wind an average of 45 percent on one-half of the plots; (2) reduction of the light intensity an average of 55 percent on one-half of the plots; (3) maintenance of soil water near field capacity on one-half of the plots and allowing it to fluctuate between field capacity and wilting point on the remaining plots; (4) elimination of competition on one-half of the plots with direct seeded or plastic tube seedlings, and re-establishment of competition permitted on the remaining half.

Growth and development prior to planting was generally good in both types of containers; however, evaporative cooling in the Jiffy-7 pellets seemed to decrease the rate of germination.

During the first growing season, the presence of partial shade increased germination 19 percent and increased survival 21, 25, and 8 percent for direct seeded, Jiffy-7, and plastic tube seedlings, respectively. Seedling growth was improved by partial shade, ample soil moisture, and the removal of competition. The presence of partial shade benefited terminal growth for all seedlings, while the soil moisture treatment had its greatest affect on the growth of direct seeded and Jiffy-7 seedlings. The presence of competing vegetation reduced the total dry weight of direct seeded and plastic tube seedlings by an average of 20 and 35 percent, respectively. In general, there was no significant difference in growth parameters measured during the first growing season between trees growing with wind protection and those without.

By the end of the first growing season, seedlings in Jiffy-7 pellets were almost twice as tall and had produced 160 percent more total biomass than seedlings in split plastic tubes. Cool spring temperatures delayed germination in the field and gave container-grown seedlings a seven-week advantage over seedlings from direct seed. By the end of the growing season, this advanced start resulted in container-grown seedlings which averaged eight times more total biomass than trees from direct seeding.

STUDIES OF ENVIRONMENTAL FACTORS AFFECTING JACK PINE (<u>PINUS BANKSIANA</u> LAMB.) REGENERATION

By

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CHAPTER I

INTRODUCTION

Prior to 1910, jack pine (Pinus banksiana)[1] was largely considered a "weed tree" and was commercially utilized to only a limited extent (Pinchot, 1909). However, between 1910 and 1945, jack pine gained in economic importance. The often pure and even-age stands, rapid early development, and long useable fiber make this species easy to harvest and highly desirable for use as pulpwood (Beaufait, 1960).

Today there are almost 900,000 acres of jack pine in the state of Michigan, with over 50 percent of the total acreage located in the northern half of the Lower Peninsula (Chase et al, 1970). Use of this species for pulpwood has grown from 300,000 cords in 1937 to over 720,000 cords in 1966. Approximately one-fifth of the total pulpwood volume cut in the Lake States during 1966 was produced by the northern one-half of Michigan's Lower Peninsula (Blyth, 1967). The economic importance of this species is further

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[1]Common and scientific names of all species are according to Gray's Manual of Botany, 8th Ed. (Fernald, 1950). 1963 pp.

emphasized by the fact that it often grows and produces useable wood fiber on otherwise unproductive sites.

Because of the importance of this species to Michigan's forest economy, forest managers are interested in the requirements necessary to obtain successful regeneration. The serotinous cone, which releases the seed only under the influence of high temperature, coupled with the necessity for exposure of mineral soil have generally resulted in unsatisfactory attempts to regenerate this species naturally.

The planting of nursery-grown stock has been used extensively. However, the high cost of this technique has stimulated interest in finding alternative methods for regenerating this species.

Direct seeding and the planting of container-grown seedlings are two such alternatives. To a large extent, these methods overcome the disadvantages of using nursery-grown seedlings and still retain the potential of producing well stocked stands. A major problem associated with these methods is the exposure of the germinating seed or young seedling to unfavorable climatic conditions when they are in their most vulnerable state. Few studies have attempted to evaluate key environmental factor interactions that may influence jack pine establishment.

The objectives of this study were:

1. To establish a long term field study investigating the response of both direct seeded and container-grown seedlings to modifications in wind, light, soil moisture, and competition.
2. To examine the response of jack pine seedlings to controlled levels of soil moisture and temperature under laboratory conditions.

CHAPTER II

REVIEW OF LITERATURE

Jack pine is the smallest and shortest-lived of the pines native to the Lake States (Eyre and Lebarron, 1944). Its range extends from northern New England and the Lake States, across Canada to the foothills of the Rocky Mountains (Fowells, 1965). Within Michigan, the botanical range extends down the east side of Lake Michigan and terminates at the southern tip of the lake. Commercial production of the species, however, is confined primarily to the upper one-half of the Lower Peninsula and most of the Upper Peninsula. Seven counties in the northeast corner of Michigan's Lower Peninsula have in excess of 100,000 cords per county of commercial jack pine (Rudolph and Schoenike, 1963).

Jack pine is one of the most widely distributed pines in North America and, therefore, exists under a wide variation in habitat conditions. In general, the areas are characterized by warm-to-cool summers, cold winters and low-to-moderate rainfall. Daily mean temperatures in the middle of the growing season range from 55°F to 72°F, with annual precipitation averaging between 15 to 35 inches.

Drought periods of up to thirty days in duration are common during the growing season from Michigan west to the Rocky Mountains (Cayford *et al*, 1967; Fowells, 1965).

In Michigan, jack pine grows most commonly on level to gently rolling sand plains, usually of a glacial outwash or lacustrine origin. Maximum development is reached on well drained loamy sands (Cayford *et al*, 1967; Fowells, 1965). The principle edaphic requirements are good drainage and aeration coupled with a pH of 4.5 to 6.5.

Throughout its range, jack pine grows in extensive pure even-age stands. In the Lake States it is frequently found in association with red pine (*Pinus resinosa*), eastern white pine (*Pinus strobus*), quaking aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), red oak (*Quercus rubra*), Northern pin oak (*Quercus ellipsoidalis*), and black spruce (*Picea mariana*) (Fowells, 1965).

Regeneration Characteristics

Seed Production

Jack pine is a prolific seed producer, with good seed crops produced in three to four year cycles (Fowells, 1965). The viability of seed stored in the serotinous cones remains virtually unchanged for the first five years after maturity (Eyre and LeBarron, 1944). The amount of seed stored in the cones can be considerable, with amounts varying from 1.7 to 13 pounds per acre (Roe, 1963b; Eyre, 1938). The serotinous cones which occur over most of the species range, are held closed by a bonding material that breaks at temperatures of from 116° to 122°F (Cayford *et al*, 1967). Along the southern edge of its range, a variety of jack pine produces nonserotinous cones which open promptly upon maturity (Fowells, 1965). Jack pine has one of the smallest seeds of all North American pines, averaging approximately 131,000 seeds per pound (U.S.F.S., 1948).

Germination

Perhaps the most important requirements for satisfactory germination of jack pine seed is a suitable seedbed. Exposed mineral soil has repeatedly favored germination over all other types of seedbeds tested (LeBarron, 1944; Cayford, 1958, 1959, 1963; Beaufait, 1959; Eyre, 1938). Eyre and LeBarron (1944) reported almost three times more germination on bare mineral soil as compared to undisturbed duff. They summarized the beneficial effects of mineral soil as: (1) its lower wilting coefficient; and (2) the closer contact permitted between small soil particles and the seed.

Germination may be inhibited by soluble materials leached from the litter and foliage of associated ground cover plants. Water extracts from the foliage of *Prunus pumila*, *Gaultheria procumbens*, and *Solidago juncea* have been shown to consistently reduce germination of jack pine seed (Brown, 1967).

Germination of jack pine seed is subject to light control; however, once the moisture content of the seed reaches 10 to 20 percent, only a brief exposure to light is required for the seeds to germinate (Ackerman and Farrar, 1965).

Environmental conditions which favor germination include: fine-textured seedbed, ample soil moisture, the presence of partial shade, and placement of the seed beneath the soil surface (Fraser and Farrar, 1953). Beaufait, (1959) found that germination almost doubled when partial shade was provided, while LeBarron (1944) concluded that shade was only beneficial in dry years. Fraser (1959) found that germination was significantly decreased when the seedbed was exposed to more than four hours of direct sunlight.

Jack pine seeds will germinate rapidly whenever a 10-day mean maximum air temperature reaches 65°F (Eyre and LeBarron, 1944). Even though germination has been shown to occur in every month from May to September, seedling establishment is enhanced if germation occurs from April to June (Eyre and LeBarron, 1944; Rudolph, 1958; Cayford, 1961).

Jack pine seed can be stored under dry conditions at 32° to 41°F for five years with no apparent decline in vigor (U.S.F.S., 1948). Cayford and Waldron (1966) did detect a decline in normal germination after seed treated with Arasan-75, Endrin-75W, and aluminum flakes had been in storage for one year.

Seedling Establishment and Early Development

Survival

Survival and establishment of jack pine seedlings is also enhanced by good soil conditions. In the Lake States, the chances of a seedling surviving the first two years is 9 to 12 times greater on exposed mineral soil than on undisturbed duff (Fowells, 1965; LeBarron, 1944). In Canada, first-year survival of jack pine seedlings averages two to four times higher on mineral soil seedbeds than on unprepared sites (Cayford, 1961; Cayford *et al*, 1967).

High temperatures and drought are important factors causing seedling mortality (Beaufait, 1959; U.S.F.S., 1937; Cayford, 1963; Stoeckeler and Limstrom, 1950). The presence of partial shade may or may not improve survival, depending on the shade density and interactions between soil moisture and competition (Beaufait, 1959; LeBarron, 1944; Fowells, 1965; Cayford *et al*, 1967).

Survival and establishment is greatly improved where the permanent water table is within three to six feet of the soil surface (Stoekeler and Limstrom, 1942). A laboratory study determined that an optimum depth to water for one-year-old seedlings growing in sand is approximately 30 inches (Mueller-Dombois, 1964).

The detrimental effect of competition on seedling survival is well documented (Rudolph, 1958; Shirley, 1945; Cayford, 1961; Jameson, 1961). Dense grass has resulted in a reduction in stand stocking levels of more than two-thirds (Cayford, 1959).

Exposure to wind has also been found to contribute to seedling mortality. Jameson (1961) reported that protection against wind and sun assisted the establishment of reproduction. In Newfoundland, Lewis (1954) cites exposure to wind as the most frequent cause of plantation failure. While wind appears to be an important factor in the establishment of regeneration, little work has been done to investigate the response of jack pine to wind protection.

Growth

Growth of jack pine seedlings also varies with type of seedbed. Seedlings on exposed mineral soil tend to grow more rapidly than those on undisturbed sites (Jameson, 1961). However, seedlings grown on soil from just the B horizon were only two-thirds as large in terms of total dry weight as those grown on a normal profile (Beaufait, 1959).

Maximum seedling growth occurs on sites with adequate soil moisture and an absence of competing vegetation. Cayford (1963) reported that the total height of dominant five-year-old seedlings averaged 3.8 feet on moist sites and only 1.5 feet on dry sites. In another study, the total height of jack pine seedlings was reduced by 60 percent in the presence of grass competition (Sims and Mueller-Dombois, 1968).

A direct relationship exists between growth and exposure to sunlight. After two growing seasons, seedlings with 0 hours of daily exposure to direct sunlight averaged two inches in height, while those with twelve hours daily exposure averaged eleven inches (Fraser, 1959). Shirley (1945) found that optimum height growth was reached at 43 percent of full sunlight over a four-year period. Logan (1966) found very similar results for the first four years, after which seedlings in direct sunlight surpassed those under partial shade. LeBarron (1944) found that one-year-old seedlings grown on a clearcut area were about 40 percent taller than those under a partial cut.

Regeneration Methods

Site Preparation

The foremost prerequisite for the successful establishment of jack pine regeneration is the presence of exposed mineral soil. Measures to prepare the site must be taken prior to the initiation of any attempt at regeneration. This is often accomplished by mechanical scarification or prescribed burning. Mechanical scarification has consistently improved stocking, while the results of prescribed burning have been very unpredictable and failures not uncommon (Scott, 1966; Eyre, 1938; Benzie, 1968; Jarvis, 1966; Cooley, 1970; Chrosciewicz, 1959).

Natural Regeneration

In general, attempts to regenerate jack pine by clearcutting, seed tree cutting, or clearcutting in strips without further treatment have failed (Cayford *et al*, 1967). Shelterwood cutting has been tried with some success in Southern Michigan, but is limited to those sites where the open-coned variety of jack pine is prevalent (Caveney and Rudolph, 1970).

The scattering of cone-bearing slash on prepared sites has often been prescribed as a satisfactory method of regeneration (Eyre and LeBarron, 1944; Eyre, 1938; Cayford, 1958, 1966). The use of this method, however, requires intensive administrative supervision. In addition, the cones normally open and release the seed during the hottest portion of the growing season, jeopardizing successful germination and survival (Beaufait, 1959; Eyre, 1938; Eyre and LeBarron, 1944).

Artificial Regeneration

Planting of nursery stock is the most predominant method of artificially regenerating jack pine. Although jack pine plantations are generally successful, the high cost of this method limits its use to the most productive sites.

Early reports dealing with the prospects of direct seeding jack pine presented a rather pessimistic view (Eyre and LeBarron, 1944; Stoeckeler and Limstrom, 1950). The economic advantage of this method, however, has continued to stimulate interest in its potential usefulness. Roe (1963a) has concluded that much of the pessimism regarding the successful direct seeding of jack pine is unwarranted. Eighty percent of all successful direct seeding trials in the Lake States used jack pine seed. Almost 70 percent of the area seeded in Southwestern Manitoba had at least 500 stems per acre (Cayford, 1959). Day (1964) found an average of 1400 seedlings per acre three years after broadcast seeding over disced soil.

As a compromise between the planting of nursery stock and direct seeding, the use of balled, potted or containerized seedlings is receiving widespread attention. The modern concept envisions the use of a plantable container rather than one which must be discarded prior to planting (Schneider, White and Heiligmann, 1970). Coniferous seedlings have been successfully raised in several kinds of containers, including paper tubes, split-plastic tubes, wood fiber blocks, peat pots, peat pellets, and polyurethane "buns" (McLean, 1958; Carman, 1967; Huuri, 1966; Laitinen, 1965; Schneider _et al_, 1970; Walters, 1969).

The use of containerized seedlings offers several advantages, including: extension of the planting season, adaptability to mechanization, flexibility in meeting changing operational needs, efficient use of seed, minimum root disturbance when outplanted, and more efficient use of time and labor (Carman, 1967; Alm and Shantz-Hansen, 1970).

In the United States and Canada, emphasis over the last decade has been directed toward the production of conifers in small, split-plastic tubes. First-year survival in these containers has been high (Carman, 1967; McLean, 1958; Alm and Shantz-Hansen, 1970). The split-plastic tube is convenient to handle, easy to plant, and more easily adapted to mechanization. This container does have several disadvantages, however, which detract from its initial appeal. The principle drawbacks are: (1) the impermeable plastic wall inhibits lateral extension of the roots into the surrounding soil; (2) the confined roots have only a small soil interface into which they can extend vertically; (3) the combination of the above makes the seedlings susceptible to frost heaving; and (4) the container is non-bio-degradable (Schneider *et al*, 1970).

CHAPTER III

STUDIES IN CONTROLLED ENVIRONMENT CHAMBERS

The literature abounds with statements describing the detrimental effects of high temperature and drought on successful jack pine regeneration. However, there is a lack of definitive studies which investigate the response of jack pine seedlings to carefully controlled levels of temperature and soil moisture. Before specific management prescriptions can be made with predictable results, there must be a basic understanding of what changes in seedling growth result from alterations in these environmental factors.

The specific objectives of this portion of the study were: (1) to investigate the first year growth and survival of jack pine seedlings under conditions of controlled temperature and soil moisture; and (2) to examine the interactions of temperature and soil moisture on jack pine growth and survival.

Methods

Jack pine seedlings were raised in soil-filled plastic pots for approximately four weeks under uniform conditions. Observations indicate that terminal growth is completed and winter buds are set within six to ten weeks after growth initiation (Kaufman, 1945). Thus, the duration of this study was limited to ten weeks. Once established, seedlings were grown under six different temperature and soil moisture treatment combinations.

The tapered plastic pots in which the trees were grown measured approximately 14.5 cm in height, with a top and bottom diameter of 11.0 cm and 8 cm, respectively. Holes were drilled in the bottom of each container to permit adequate drainage. Each container was filled with 1050 g of soil on an oven-dry basis. The soil used was collected at the site of the field study described in Chapter IV. This soil, a Grayling sand, is typical of those soils supporting jack pine stands throughout Michigan. Samples were collected in the field by carefully removing layers approximately 2.5 cm in thickness to a depth of 10 cm. The top layer consisted entirely of the A_1 horizon, while the remaining samples were taken from the B_1 horizon. Each layer was kept separate from the others. The soil was passed through a 3 mm sieve to remove litter and coarse debris and then air dried. The soil profile was then reconstructed in each pot by carefully maintaining the sampling sequence and depth for each layer.

The seed used was collected in 1963 from several mature jack pine trees near the field study site on the Mio Ranger District, Huron-Manistee National Forest. For this study, germination tests conducted after cold soaking the seed for two days at 5°C indicated a 74 percent germination capacity. Ten jack pine seeds were uniformly sown in each pot after the soil had been saturated by subirrigation. Following sowing, all containers were placed in a controlled environment chamber set at 30°C day temperature and 20°C night temperature, 60 to 100 percent relative humidity and a 14-hour photoperiod.

Under the above conditions, germination was completed within twelve days, after which both day and night temperatures were lowered to 24°C and 13°C, respectively. The seedlings were held under these conditions for about twenty-five days following germination. By this time, the seed coat had fallen from most of the cotyledons and the epycotyl was beginning to develop. Soil moisture was maintained near field capacity by surface watering throughout this period.

Treatments

Following the initial establishment period, the trees were thinned so that five uniform seedlings remained in each container. The containers were then randomly assigned to one of six combinations of temperature and soil moisture level.

Three growth chambers (Sherer-Gillett model Cel-25) were utilized to create day and night temperature conditions of 32°C and 21°C, 24°C and 13°C, and 16°C and 5°C, respectively. These temperatures were controlled to within ± 1°C and shall be referred to as the high, moderate, and low temperature treatment in the remaining discussion. Examination of climatic data taken at the site of the field study indicated that these temperature conditions were well within the range normally encountered during the growing season.

Within each growth chamber, the containers were randomly assigned to two soil moisture treatments. The soil moisture in one-half of the containers was allowed to fluctuate between 20 percent and 10 percent moisture content, while in the remaining containers it fluctuated between 20 percent and 3.5 percent. All moisture contents are reported on a weight basis. When the soil in all containers was saturated and then allowed to drain for 48 hours, the moisture content averaged 32 percent, as compared to an estimated field capacity of 10 percent. The upper control limit of 20 percent moisture content was chosen as a reasonable compromise to avoid possible aeration problems occurring at 32 percent, and to help insure an even moisture distribution which might have been a problem at 10 percent moisture content. The soil-water suction under the high moisture regime never exceeded 0.1 atmospheres while that at the low moisture regime never exceeded

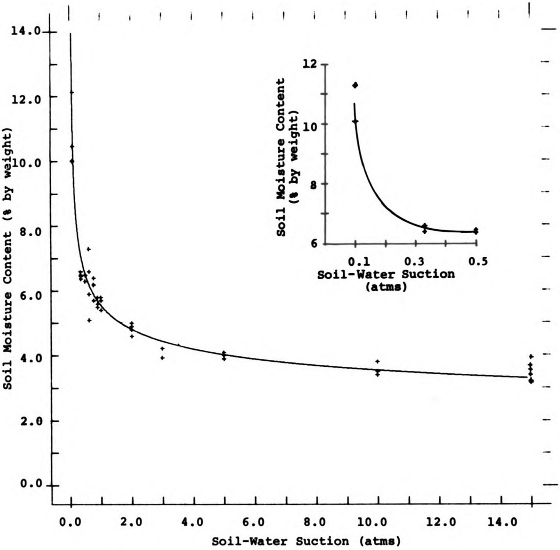

Figure 1. Soil moisture characteristic curve for composite samples of the A and B horizons, Grayling sand soil.

15 atmospheres (Figure 1). To insure that the soil moisture was evenly distributed upon re-watering, the necessary amount of water was injected into the soil at many depths and locations with a hypodermic syringe (Figure 2). Control of soil moisture levels was obtained by comparing total current pot weight with the weight at the desired soil moisture level. Pots were regularly weighed every three days, and as often as twice per day as the lower soil moisture limit was approached. Following growth initiation, corrections were made in total container weight to compensate for the wet weight of the seedlings.

Throughout the ten-week period, the photoperiod was maintained at 14 hours of light and 10 hours of darkness. A light intensity of 2600 footcandles, at foliage level, was maintained by using ten sylvania cool white flourescent bulbs and eight 25-watt incandescent bulbs. The relative humidity was maintained between 45 and 55 percent during the light hours, and between 60 and 70 percent during the dark hours for all treatments. To avoid nutrient deficiencies, a complete nutrient solution[1] was applied periodically to the pots. The concentrations and rates of application were varied so each pot received the same amount of nutrients.

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[1]RX-30, manufactured by Garden Research Laboratories, Ltd., Toronto, Ontario, Canada.

Figure 2. Replenishment of soil moisture with a hypodermic syringe to insure uniform moisture distribution.

Sampling Procedure and Statistical Design

Twenty containers were randomly assigned to each combination of temperature and soil moisture treatment. At seven-day intervals, two containers were randomly selected from each treatment combination. The tops of the seedlings were separated from the roots at the root collar, and the needles were removed from the stem. Measurements were taken on total length of stem, stem diameter, and needle green weight. The soil was then carefully removed from the roots and the root, needle, and stem tissue was dried to a constant weight at 65°C.

Factors of time and soil moisture level were replicated twice in this study, but the temperature treatment was unreplicated. Therefore, in the analysis of variance, the interaction of temperature and time was used as an estimate of the error mean square to test the main effect of temperature. As this interaction may be an underestimate of the true error, no probability statements have been reported on differences shown to be significant by this test. Standard analysis of variance procedures were used to test for significances of soil moisture level and time.

Results

Effect of Treatment on Total Height and Stem Diameter

Total Height

The maintenance of readily available soil water significantly increased total height by 14 percent and 21 percent at the high and moderate temperatures, respectively (Table 1). However, when soil water was limiting, temperature had no apparent effect on the total height of the seedlings. There was no apparent difference in total height between seedlings growing under the high and moderate temperature treatments at either soil moisture level.

Table 1. Temperature and soil moisture effect on total height (cm) of 10-week old jack pine.

Soil-Water Suction	Day/Night Temperature (°C) 32/21	24/13	16/5
0 to 0.1 atm	2.85[a]	2.90[a]	2.45[b]
0 to 15.0 atms	2.50[b]	2.40[b]	2.40[b]

[a]Values with the same letter in the superscript are not significantly different.

During the eighth week, terminal bud formation occurred on five seedlings subjected to low temperatures and soil-water stress. Bud set took place as soil moisture approached the wilting point. Buds resumed growth shortly after the pots were watered. Bud set again occurred during the tenth week, as soil water again approached the lower limit.

Stem Diameter

Stem diameter responded in a similar manner to tempearature when soil water was readily available (Table 2). Both the high and moderate temperature treatments increased stem diameter by 22 percent over the low temperature but were not apparently different from each other. However, when soil water was limiting, stem diameter was apparently different for every level of temperature. Seedlings grown at high temperatures had an average stem diameter of 11 percent larger than those at low temperatures. The average stem diameter of seedlings at the moderate temperature was 5 percent larger than that at the low temperature.

Stem diameter was significantly increased by the presence of readily available water at every temperature. An increase in stem diameter of 28 percent was found at the moderate temperature, while ample moisture at the high and low temperatures caused increases of 21 and 5 percent respectively. For both total height and stem diameter, the temperature x soil moisture interaction was highly significant.

Table 2. Temperature and soil moisture effect on stem diameter (mm) of 10-week old jack pine.

Soil-Water Suction	Day/Night Temperature (°C) 32/21	24/13	16/5
0 to 0.1 atm	0.86[a]	0.86[a]	0.67[b]
0 to 15.0 atms	0.71[c]	0.67[d]	0.64[e]

[a]Values with the same letter in the superscript are not significantly different.

Effect of Treatment on Dry Weight

There was an apparent increase in total dry weight as the temperature was increased from the low level to the moderate and high levels (Table 3). When soil water was readily available, seedlings growing under moderate temperatures produced 143 percent more dry matter and those at high temperatures 114 percent more dry matter than seedlings at the low temperature. There was no apparent difference in dry weights at high and moderate temperatures.

The presence of readily available soil moisture significantly increased total dry matter production irrespective of temperature level. At the moderate temperature level, maintenance of the soil moisture level above 10 percent increased dry matter by 142 percent, as compared to 98 and 31 percent increases at high and low temperatures, respectively (Table 3).

Table 3. Temperature and soil moisture effect on total dry weight (mg) of 10-week old jack pine.

Soil-Water Suction	Day/Night Temperature (°C) 32/21	24/13	16/5
0 to 0.1 atm	79^{a}	90^{a}	37^{b}
0 to 15.0 atms	40^{b}	38^{b}	28^{c}

[a]Values with the same letter in the superscript are not significantly different.

Differences in total dry matter production between temperatures and soil moisture treatments became evident very early in the ten week period (Figure 3). Differences between temperature levels were observed by the end of the third week, while soil moisture level began to have a significant influence by the end of the fourth week. Restriction in dry matter production with increasing soil-water suction was noted.

Shoot and Root Dry Weights

The individual responses of the shoot and root dry weights to the treatments paralleled that of total dry weight. When soil water was not limiting, shoot dry weight increased 145 percent and 113 percent, respectively, when moderate and high temperatures were compared to the low temperature (Table 4). The average increase declined to about 30 percent with increasing soil-water suction. The presence of ample soil moisture caused significant increases

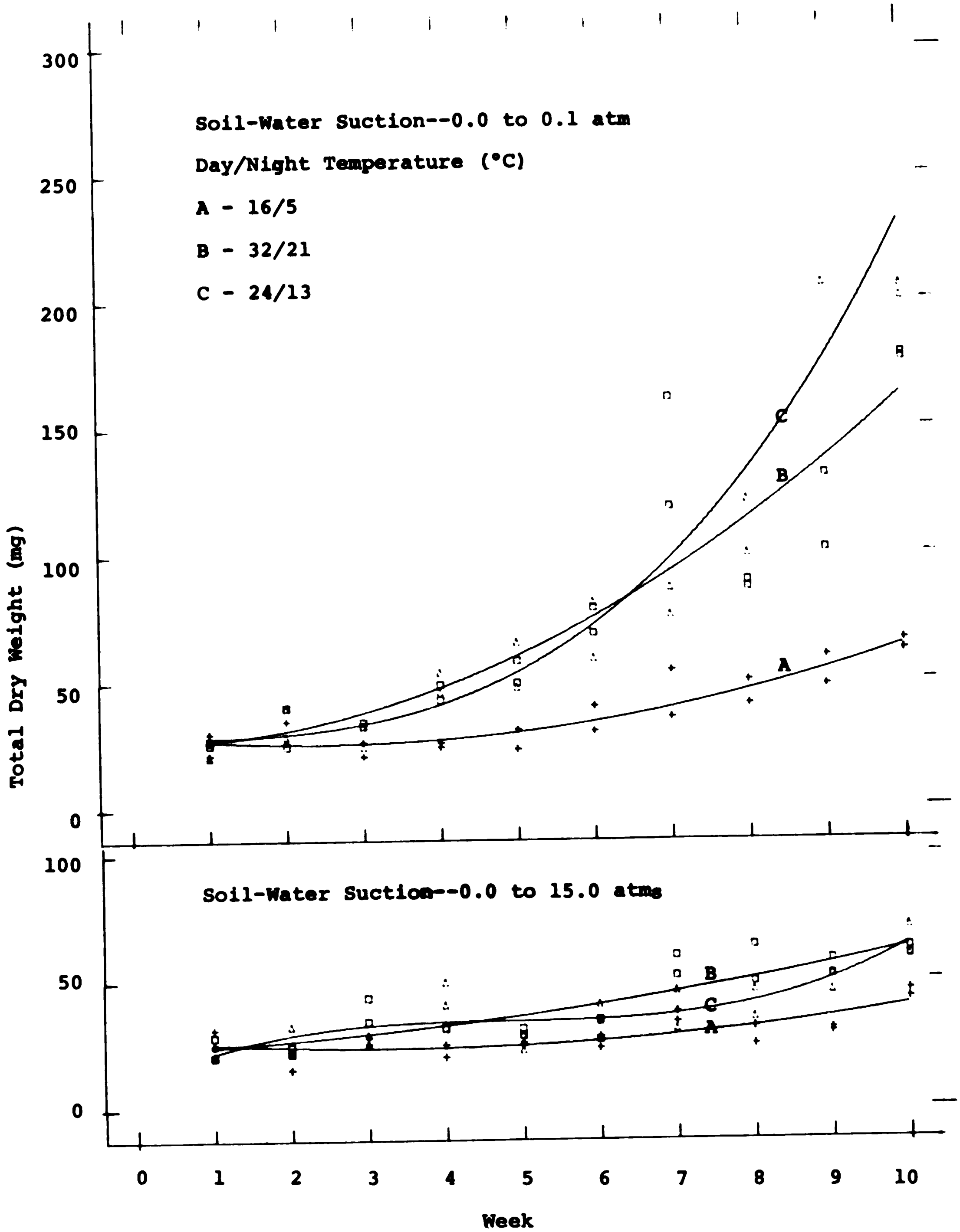

Figure 3. Temperature and soil moisture effect on total dry weight of jack pine seedlings over a 10-week period

in shoot dry weight of 114 and 157 percent at the high and moderate temperature levels, respectively. At the low temperature, this increase declined to 30 percent.

Table 4. Temperature and soil moisture effect on shoot dry weight (mg) of 10-week-old jack pine.

Soil Moisture Regime	Day/Night Temperature (°C) 32/21	24/13	16/5
0 to 0.1 atm.	47[a]	54[a]	22[b]
0 to 15.0 atms.	22[b]	21[b]	17[c]

[a]Values with the same letter in the superscript are not significantly different.

When soil moisture was not limiting, seedlings grown under high and moderate temperatures had increases in root dry weight of 107 and 133 percent, respectively, over that of seedlings grown at the low temperature (Table 5). When soil moisture was limiting, the increase declined to approximately 50 percent. There was no apparent difference between the results at the high and moderate temperature levels at either level of soil moisture. The presence of ample soil moisture significantly increased root dry weight by 72, 106, and 25 percent at the high, moderate, and low temperatures, respectively.

The response of root dry weight over time to increasing soil-water suction was extremely variable. Regression analysis of root dry weight over time showed that only 27

Table 5. Temperature and soil moisture effect on root dry weight (mg) of 10-week-old jack pine.

Soil-Water Suction	Day/Night Temperature (°C) 32/21	24/13	16/5
0 to 0.1 atm	31[a]	35[a]	15[b]
0 to 15.0 atms	18[b]	17[b]	12[c]

[a]Values with the same letter in the superscript are not significantly different.

to 34 percent of the variability could be accounted for by the time factor. This indicated that root dry weight was fluctuating over time in response to some other factor. When root dry weight was compared to soil moisture depletion cycles, a definite relationship appeared to exist (Figure 4). This relationship is best seen under low temperatures (C) where the soil moisture depletion cycle extends over a considerable period of time. The initial decline is probably caused by the low temperature. By the end of the fourth week, available soil water had been depleted and the pots rewatered to the upper limit of 20 percent. Increase in root dry weight tends to follow the replenishment of moisture until the soil moisture is depleted to approximately 4.3 percent moisture content by weight. After reaching this point, the root dry weight decreases and continues to decrease for about one week after the soil water is restored to the upper limit. It appears that during the tenth week, the roots began to increase in

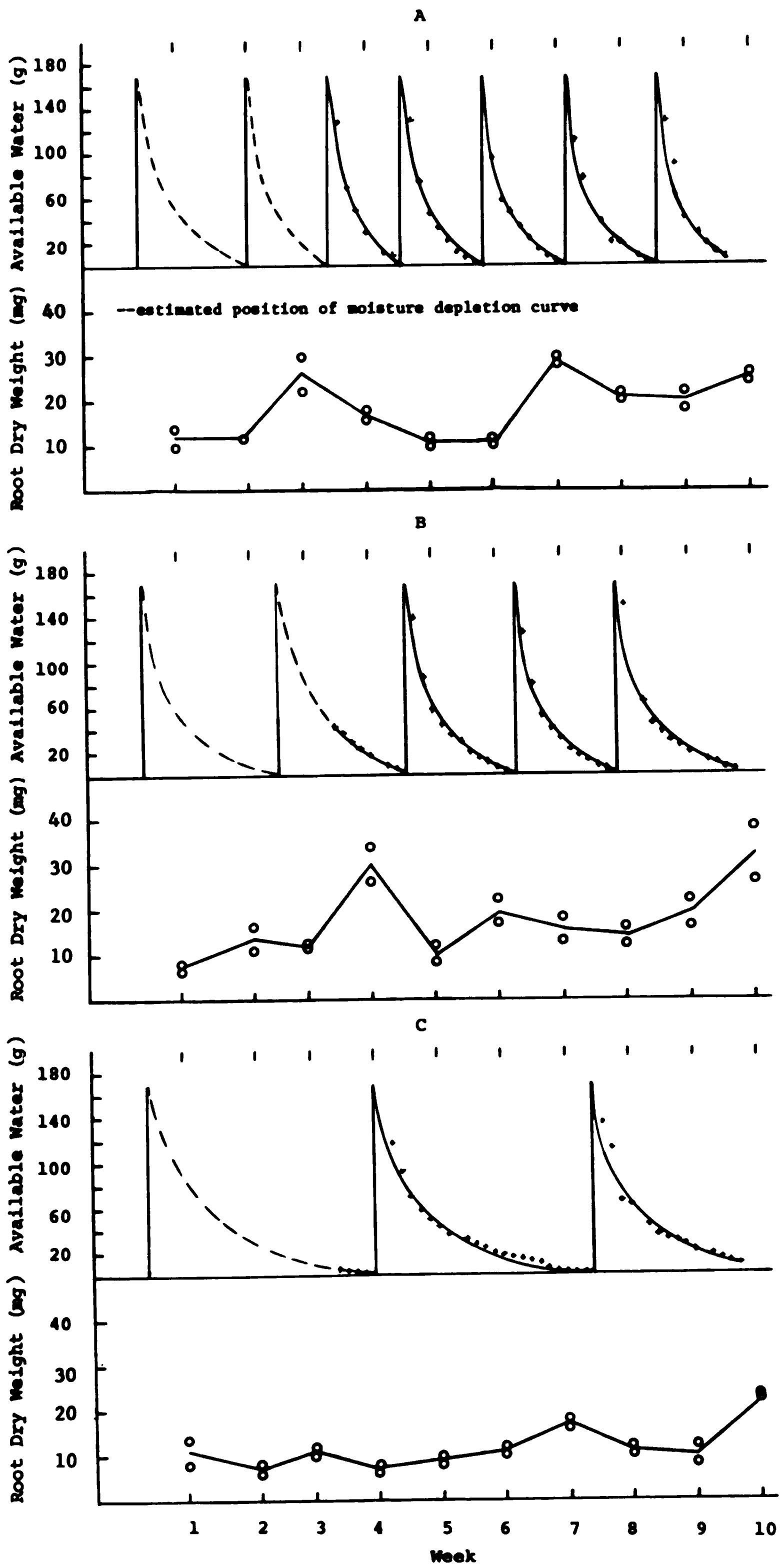

Figure 4. Relationship of root dry weight to soil moisture depletion cycles over ten weeks at temperatures of (A) 32°C day-21°C night, (B) 24°C day-13°C night, and (C) 16°C day-5°C night.

dry weight once again. This same cycling can be seen at the other temperatures, but the more rapid cycles of soil moisture plus the rigid sampling schedule may tend to mask some of the cycles in root dry weight. A decrease in root dry weight suggests the mortality and sloughing of root tissue. During at least two of the sampling periods, root mortality was noted in pots where soil water approached the lower limit. Furthermore, the decrease in root dry weight is initiated at approximately the same point on the soil moisture depletion curve for all temperatures. This point ranges from 4.3 to 5.0 percent moisture content by weight, which corresponds to soil-water suction values of approximately 3 to 3.5 atmospheres. This range of soil-water suction is very near the point on the soil moisture characteristic curve where very small changes in water content result in large differences in soil-water suction (Figure 1).

Shoot/Root Ratio and Dry Weight Distribution

The temperature and soil moisture treatments had little influence on the shoot/root ratio or the distribution of dry weight among needles, stem, and roots. However, the shoot/root ratio was significantly reduced by increasing soil-water suction at the high temperature. When soil water was limiting, the shoot/root ratio at the high temperature was also lower than that at the low temperature (Table 6).

Table 6. Average shoot/root ratio over a ten-week period as influenced by temperature and soil moisture.

Soil-Water Suction	Day/Night Temperature (°C) 32/21	24/13	16/5
0 to 0.1 atm	1.50[a]	1.40[a]	1.55[a]
0 to 15.0 atms	1.25[b]	1.39[ab]	1.58[ac]

[a]Values with the same letter in the superscript are not significantly different.

The distribution of biomass into needles, stems, and roots was influenced by soil moisture only at the high temperature (Table 7). The proportion of biomass in needles declined significantly from 50 percent to 45 percent as soil water became limiting. In contrast, 41 percent of the total dry weight was accounted for by roots where soil water was readily available as compared to 46 percent where it was limiting.

Table 7. Average percent of total dry weight in needles, stems, and roots over a ten-week period as influenced by soil moisture.

Temperature 32°C Day - 21°C Night			
Soil-Water Suction	Percent Dry Weight in Needles	Stems	Roots
0 to 0.1 atm	50.1[a]	8.1[a]	41.1[a]
0 to 15 atms	45.4[b]	8.2[a]	46.4[b]

[a]Values with the same letter in the superscript are not significantly different.

The distribution of biomass was influenced by temperature only where soil-water suction reached 15 atms. About 8 percent of the total dry weight was accounted for by stem tissue at the high and moderate temperatures as compared to 10 percent at the low temperature (Table 8). The amount of biomass distributed to the roots was also higher in seedlings under low temperatures as compared to those under high temperatures.

Table 8. Average percent of total biomass in needles, stems, and roots over a ten-week period as influenced by temperature at low levels of soil water.

Percent of Total Dry Weight in	Day/Night Temperature (°C) 32/21	24/13	16/5
Needles	45.4[a]	47.7[ab]	49.7[b]
Stems	8.2[a]	8.6[a]	10.4[b]
Roots	46.4[a]	43.7[ab]	39.9[b]

[a]Values with the same letter in the superscript are not significantly different.

Needle Moisture Content

An attempt to relate needle moisture content to soil-water suction showed no apparent relationship between these two factors.

Discussion

Temperature

An important response to temperature is the obvious decline in all growth parameters at the low temperature, when compared to the moderate and high temperatures (Figure 5). Only four days after the seedlings had been exposed to the low temperature treatment, the cotyledons began to exhibit a purple coloration. By the end of the fourth week, the purplish cast had intensified. It was also evident on all foliage of seedlings subjected to moisture stress, and on all tissue except primary needles of seedlings with ample moisture. The cool temperatures may have triggered the formation of anthocyanin, which then persisted throughout the ten week period. Also, the uptake or translocation of phosphorus may have been impeded by the low temperatures resulting in the purplish coloration. A similar response has been reported in ponderosa pine seedlings where air temperatures ranged from 13° to 7°C (Larson, 1967; Steinbrenner and Rediske, 1964). The influence of temperature on jack pine growth was most pronounced when soil water was not limiting. Differences in growth response to temperature were greatly diminished when seedlings were subjected to soil water stress.

Although no apparent difference in over-all seedling growth occurred between the moderate and high temperature treatments, a visible decline in seedling vigor was observed

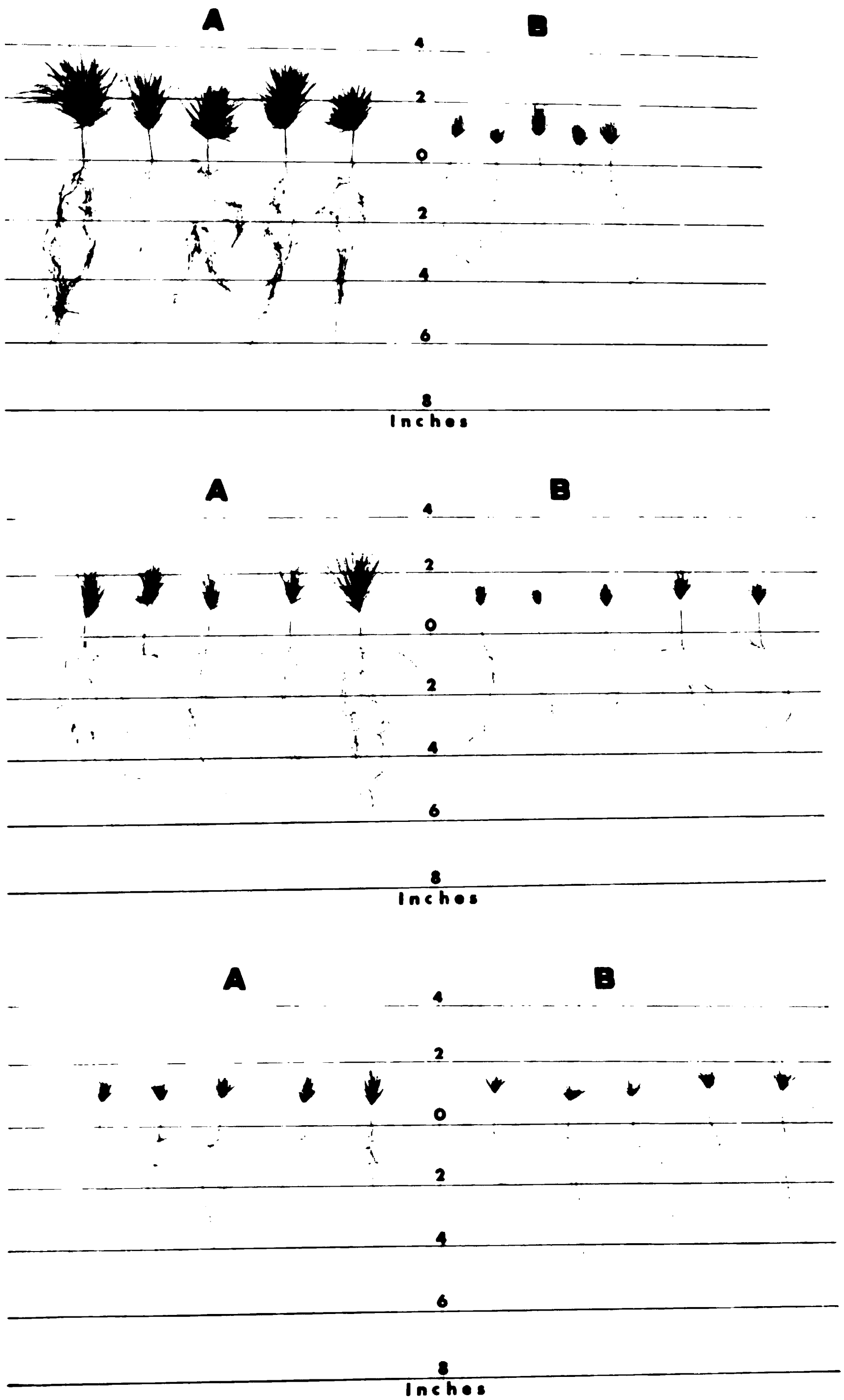

Figure 5. Ten-week-old jack pine seedlings grown under day/night temperatures of (from top to bottom) 24/13°C, 32/21°C, 16/5°C, and soil-water suctions of (A) 0.0 to 0.1 atm, and (B) 0.0 to 15.0 atms.

at the high temperature during the tenth week. The response to temperature on the basis of total dry weight indicates a lower rate of dry matter accumulation at the high temperature than at the moderate temperature (Figure 2). A similar decline in vigor of jack pine seedlings was also noted by Yeatman (1967) under conditions of 27°C day temperature and 19°C night temperature. High respiration rates stimulated by the high temperatures may have reduced the net production of photosynthate to a lower level.

Yeatman (1967) also concluded that temperature was the principal factor controlling the initiation of growth in the spring. In this study, the initiation of height growth at the high temperature occurred at least ten days prior to that at moderate temperatures.

Eyre and LeBarron (1944) have reported that terminal bud set in jack pine is under the control of environmental factors other than photoperiod. In this study bud set at the low temperature appeared to be controlled by soil water.

The low shoot/root ratio resulting from the high temperature and low soil moisture treatments results primarily from the influence of temperature and soil water on the distribution of root biomass (Tables 6, 7, and 8). Under soil water stress, the proportion of total weight in the roots increased as temperature increased. Correspondingly, shoot weight was reduced under these same conditions, thereby causing a low shoot/root ratio. Similar results were reported for ponderosa pine by Steinbrenner and Rediske (1964).

Soil Moisture

Regardless of temperature level, there was a significant increase in every observed growth parameter when soil-water suction was maintained at less than 0.1 atm. The importance of soil moisture definitely exceeded that of temperature at the moderate and high levels. At the low temperature level, the influence of soil water was diminished considerably. These results differ from those found by Steinbrenner and Rediske (1964) in ponderosa pine seedlings where temperature was the most important factor influencing growth. However, their moisture limits were set rather arbitrarily, and the relationship to soil-water suction was not defined.

The extent to which soil water must be depleted before plant growth is influenced has long been a subject of controversy (White, 1958). Veihmeyer and Hendrickson (1950) have supported the view that water is equally available for plant growth until very near the wilting point. On the other hand, Kramer and Kozlowski (1960) postulate that soil-water suctions above 1 or 2 atms would inhibit plant growth. Stanhill (1957) showed that in 66 studies out of 80, plant growth was apparently affected before soil moisture reached the permanent wilting point. Recent work supports the idea that growth is already reduced, with soil-water suctions well below the permanent wilting point (Sands and Rutter, 1959; Stransky and Wilson, 1964; Boersma, Babalola and Youngberg, 1969; Kaufmann, 1968; and Glerum and Pierpoint, 1968). In this study, the soil-water suction was allowed to remain at 15 atms for only short periods of time, normally no more than a few hours. The magnitude of the difference between seedlings at the two soil moisture treatments indicates that growth was affected at some value of soil-water suction above the 15 atm level.

CHAPTER IV

STUDIES UNDER FIELD CONDITIONS

The planting of bare-rooted nursery stock has been the commonly used method in artificially regenerating jack pine in Michigan. This method does have several disadvantages, however, such as: (1) the high cost of producing and planting the seedlings; (2) the often excessive time lag between nursery production and operational needs; (3) the planting "shock" often exhibited by newly planted seedlings; and (4) the frequent failures of plantations on adverse sites.

Direct seeding is an alternative method that can be conducted at a considerable reduction in cost while still retaining the potential of producing well-stocked stands. The success of direct seeding is diminished, however, by rodents, birds, and unfavorable climatic conditions. The young succulent seedlings are especially susceptible to heat and drought injury.

The use of container-grown seedlings is now receiving widespread attention as an alternate planting method. In the modern application of this technique, conifer seedlings are raised in plantable containers under ideal conditions for four to twelve weeks and then outplanted. In North America a small split-plastic tube has gained popular acceptance as a useable container for raising coniferous seedlings. Shortcomings of this tube, however, have stimulated interest in seeking a container that is more suitable.

Specific Objectives of the Study

The specific objectives of this portion of the study were:

1. To evaluate the response of direct seeded and container grown jack pine seedlings to site modifications influencing wind, light, soil moisture, and competition.
2. To compare the performance under field conditions of seedlings raised in split-plastic tubes, Jiffy-7 pellets, and those from direct seeding.

Methods

Study Area

The study is located on the Mio Ranger District, Huron-Manistee National Forest, approximately ten miles southeast of Mio, Michigan. This area is typical of jack pine sites in northern Lower Michigan (Figure 6). A commercial pulpwood harvest was conducted in the winter of 1965-

Figure 6. General view of study area near Mio, Michigan.

1966 and the area was broadcast burned with a fast moving headfire in October, 1966.

The soil, Grayling sand, is a uniform glacial outwash sand (Table 9). Field capacity was 10.3 percent by weight as established in the field, while wilting point was estimated to be 3.5 percent by weight using the 15-bar pressure membrane apparatus.

Ground cover was determined by randomly locating three transects over the study area (Table 10). The predominant ground cover species and the prime competitors of jack pine on this site are Pennsylvania sedge (*Carex pennsylvanica*) and blueberry (*Vaccinium angustifolium*). These two species occupy 32 percent and 8 percent of the ground surface, respectively. Occasional hardwood species found on the site are northern red oak (*Quercus rubra*) and black oak (*Quercus velutina*).

The general climate in this area is characterized by warm summers and cold winters, with approximately ten days out of every growing season exceeding 32°C. Average total precipitation equals 65.5 cm, with about 63 percent of this occurring during the growing season. Information concerning the climate at the study site was obtained from a standard evaporation pan, a 3-cup anemometer, a standard precipitation gauge, and a hygrothermograph (Table 11). During this first growing season, May and June precipitation was higher than the long-term average, but average

Table 9. A representative profile and soil properties of Grayling sand on the study area.

Horizon	Depth (cm)	Texture	pH	Percent Organic Matter	Available Nutrients (Kg./Ha.)			
					P	K	Ca	Mg
A_1	0-3	Sand	4.9	2.7	15	58	113	24
B_{21ir}	3-15	Sand	5.2	0.8	10	27	113	14
B_{22ir}	15-27	Sand	5.3	0.6	13	20	113	14
B_3	27-39	Sand	5.2	0.4	23	22	113	14
C	39+	Sand	5.7	0.2	31	13	113	14

Table 10. Classification of percent ground cover on a representative jack pine site in northern Lower Michigan.

Ground Cover	Percent of Ground Surface Occupied
Carex pennsylvanica	32
Vaccinium angustifolium	29
Organic Matter	19
Mineral Soil	8
Logging Slash	2
Comptonia peregrina	2
Andropogon scoparius	2
Oryzopsis pungens	2
Andropogon gerardi	1
Panicum depauperatum	1
Prunus pumila	< 1
Epigaea repens	< 1
Actostaphylos uva-ursi	< 1
Danthonia spicata	< 1
Viola subvestita	< 1
Pinus banksiana	< 1

Table 11. Comparison of climatic observations during the 1969 growing season with 15- and 30-year averages.[1]

Month	Total Precipitation		Total Evaporation		Total Wind	Air Temperature				Relative Humidity
						Daily Maximum		Daily Minimum		Average Daily Minimum
	1969	1931-1960	1969	1951-1966	1969	1969	1931-1960	1969	1931-1960	1969
	cm				km./da.	°C				%
May (15-31)	8.80	3.28	7.70	11.40	34.9	18(1)[2]	19	4(4)[3]	4	40
June	13.50	6.98	12.95	13.26	82.0	19(0)	25	8(5)	9	47
July	7.85	7.37	13.70	13.81	78.2	26(1)	28	12(0)	11	46
August	5.60	7.54	16.15	10.59	54.8	27(1)	26	10(2)	10	43
September (1-15)	2.85	3.82	5.35	3.40	72.4	23(0)	21	9(4)	7	46

[1]U.S. Weather Bureau, East Lansing, Michigan, Climatography of the United States, No. 20, Mio, Michigan.

[2]Values in ( ) indicate number of days maximum temperature exceeded 32°C.

[3]Values in ( ) indicate number of days minimum temperature was below 0°C.

daily maximum temperature was lower. The month of August, however, received a lower than average amount of rainfall, and evaporation exceeded the norm by 5.6 cm. Throughout the 1969 growing season, prevailing southwesterly winds were comparable to those normally occurring in the area.

Experimental Design

The response of jack pine seedlings to modifications in wind, shade, soil moisture, and competition was studied utilizing a split-plot factorial design with six replications (Figure 7). Prior to any treatment, all snags and logging slash were removed from each replication, and all competing vegetation was hand-scalped from each 1.2-meter-square experimental plot. A cut 30 cm deep was made around the edge of each plot to eliminate the influence of lateral roots from the surrounding vegetation.

Treatments

Wind. One-half of each replication was protected from the prevailing southwesterly wind by erecting a 1.2 meter high reinforced burlap wind barrier 2.1 meters away from the south and west sides of the plots. To allow some natural wind movement, approximately 25 percent of the total surface area of the wind barrier was removed by cutting 15.2 cm square holes in the burlap material (Figure 8).

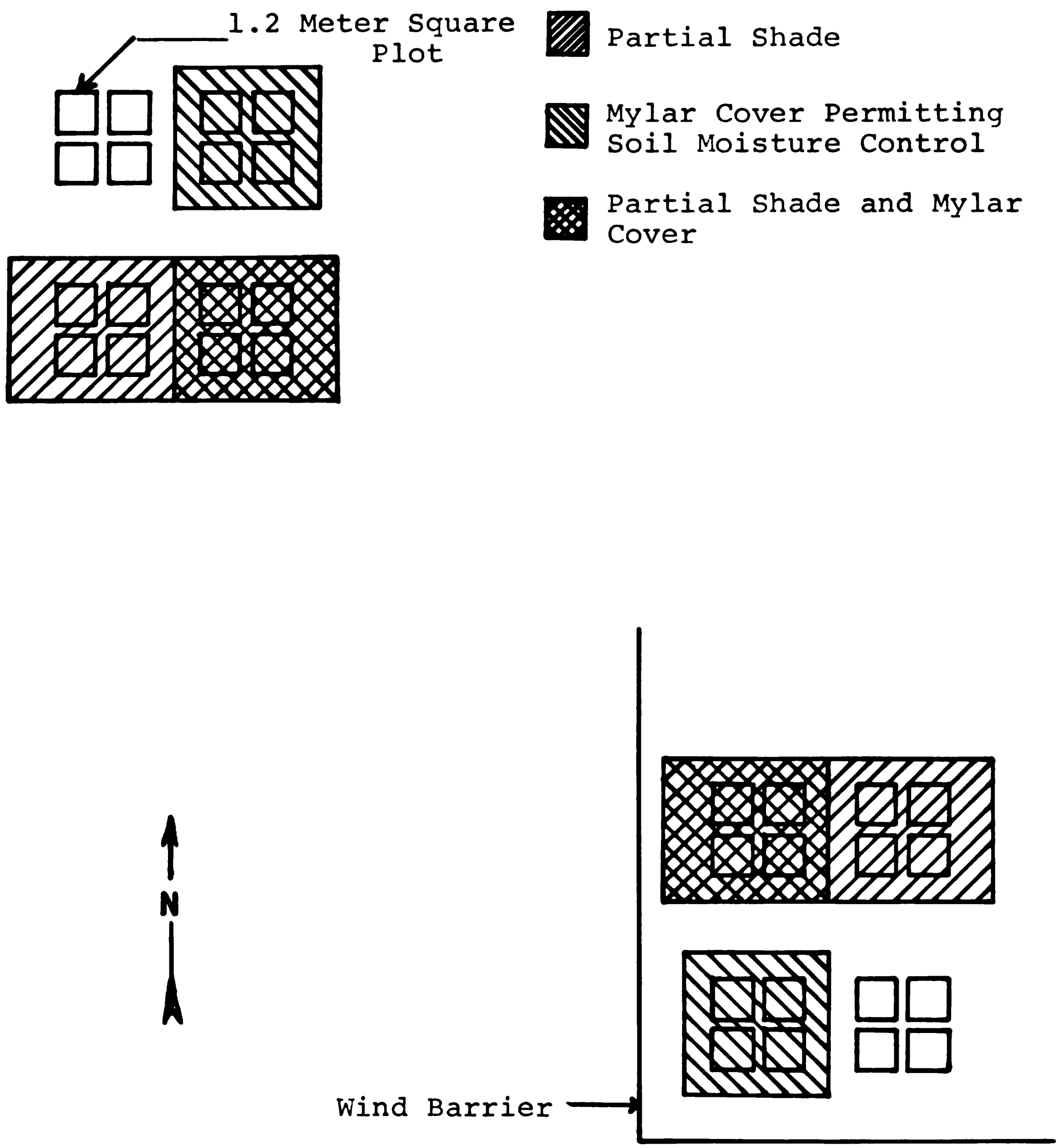

Figure 7. One complete replication of the design used to determine treatment effects of partial shade, wind, and soil moisture on jack pine regeneration.

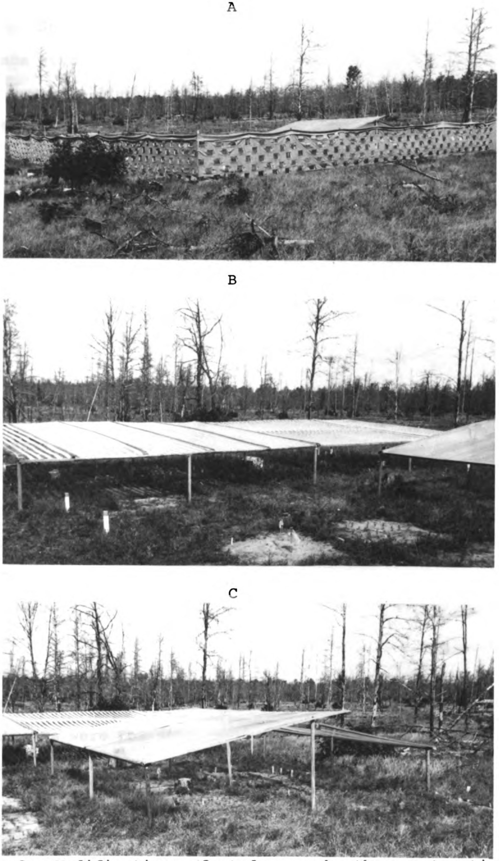

Figure 8. Modifications of study area by the construction of (A) wind, (B) shade, and (C) soil moisture control structures

Shade. Randomly selected plots were covered with a shade structure consisting of camouflage netting stretched over a wooden frame (Figure 8). The covering was effective in reducing light intensity to approximately 45 percent of that in the open. The structure sloped in one direction from 1.1 meters on the high side to 0.75 meters on the low side. The shade covering extended beyond the plot edge a distance sufficient to prevent direct sunlight from reaching the plot at any time during the day.

Soil Moisture. Randomly selected plots were assigned either a "wet" treatment, where soil-water suction at a depth of 10 to 20 cm was maintained below 0.5 atmospheres, or a "dry" treatment, where soil-water suction, at this same depth, was allowed to fluctuate between 0.0 and 15.0 atmospheres. Precipitation was excluded from the dry plots by constructing a transparent mylar-covered wooden frame over them (Stransky and Duke, 1964). This frame was 1.2 meters high in the center and sloped in two directions to 0.75 meters beyond the edge of the plot (Figure 8). The transparent mylar was also placed over the shade material on one-half of the shade structure to study the interactions between soil moisture level and shade. The moisture control treatments were not initiated until after germination was complete.

Direct Seed, Container Raised Seedlings, and Competition. Four plots were established within each combination of wind, shade, and soil moisture treatments (Figure 7). Three of these plots were randomly selected to be planted with either jack pine seed or jack pine seedlings raised in two kinds of containers. These plots were maintained weed-free by hand weeding throughout the growing season. One-half of the remaining plot was selected to be direct seeded, while the other half was planted with seedlings raised in split-plastic tubes. After the initial scalping, the competing vegetation was allowed to become re-established on this plot. Five replications were used to study the effects of competition as described above.

Micro-Climatic Measurements

Wind

Measurements taken with 3 cup totalizing anemometers showed that the wind barrier was effective in reducing prevailing winds by an average of 45 percent, varying from 64 percent to 26 percent at locations closest and farthest from the barrier, respectively. Wind movement from all directions throughout the growing season was reduced by 30 percent.

Temperature

Air temperatures were measured 10 cm above the soil surface with mercury-in-glass maximum-minimum thermometers. Shade structures significantly lowered maximum air temperatures by an average of 2°C from that in the open, but the mylar covering had no such effect. The mylar covering did significantly raise the minimum temperatures by an average of 0.5°C, but there was no affect by the shade structure. Air temperatures were not affected by the wind barrier.

Mercury-in-glass soil thermometers were used to measure temperature in the upper 5 mm of the soil surface. The presence of partial shade lowered soil temperatures an average of 3.5°C during the hottest portion of clear days. No other treatment appeared to influence soil temperature.

Soil Moisture

Gravimetric samples were collected at a depth of 10 to 20 cm throughout the growing season to determine the rate of moisture depletion on plots assigned the dry treatment. Tensiometers were randomly located on plots assigned the wet treatment to insure they did not exceed the soil-water suction limit of 0.5 atm. The presence of shade lengthened the time to reach wilting point at this sampling depth from four to nine days beyond that required for the exposed plots. Both competing vegetation and wind barrier appeared to have little influence on soil moisture depletion.

Seeding and Planting

Seeding

The jack pine seed used for both the direct seeding and the container trials came from the same seed lot as that used in the controlled environment studies described in

Chapter III. The seed was collected in 1963 from several mature trees near the study area. The use of a North Dakota Seed Blower to sort the seed improved the germination from the 74 percent reported earlier to 92 percent. Seeds were treated with a mixture of Endrin and aluminum flakes to prevent rodent and bird damage. On May 30 each scarified plot to be direct seeded was sown with 100 jack pine seeds. Seeds were evenly distributed over the mineral soil seedbed and lightly covered with soil to prevent movement from the action of wind and water.

Container-Raised Seedlings

The first type of container used in this study was a small split-plastic tube[1] measuring 1.6 cm in diameter by 7.6 cm in length. Each tube was filled to within 1.5 cm of the top with a mixture of 50 percent sifted peat and seeded with one jack pine seed. The seed was then covered with a shallow layer of perlite. The tubes were then arranged in shallow trays with holes in the bottom to permit subirrigation.

The second type of container was a small peat pot known commercially as the Jiffy-7 pellet (Hermann, 1969).[2] This container is shipped as a small compressed disk wrapped

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[1]Manufactured by Canada Building Products, Ltd., Micro-Plastics Div., Actin, Ontario, Canada.

[2]Manufactured by Jiffy Pot Ltd., Grorud, Norway.

in a fine plastic net. Upon wetting, the disk swells until it is approximately 4.5 cm in diameter and 4 cm high. The netting expands with the pellet and gives the saturated peat dimensional stability. Each Jiffy-7 was seeded with two jack pine seeds. The seeded containers were then placed on copper screen which covered the bottom of shallow plastic trays. The screen was used to inhibit root growth below the bottom of the pellets.

Following germination, the seedlings were grown in their respective containers for about four weeks. During the first three weeks, the seedlings were raised under greenhouse conditions. During the last week, both containers were placed outside to give the seedlings an adjustment period prior to outplanting. Both containers were fertilized twice by substituting a complete nutrient solution for a routine watering during the second week and again just prior to outplanting.

When the container-grown seedlings were about four weeks old, they were planted in the field. Trees in Jiffy-7 pellets were thinned so that only one seedling remained for each container. The randomly selected weed-free plots received either 50 seedlings in split-plastic tubes or 36 seedlings in Jiffy-7 pellets. The remaining half of the plot used to study the effects of competition was planted with 20 seedlings in split-plastic tubes. All field planting was done on May 27 and 28.

Sampling Procedure

Germination and survival counts were taken on June 12, June 30, July 12, and September 12. Frequent checks between these dates insured that no germination or mortality was overlooked between sampling periods. Percent survival was determined by counting living seedlings at each sampling period and dividing by total germination or number of seedlings planted.

On August 15 and September 15, representative seedlings were removed intact from each plot. Stem diameter, terminal growth, and rooting depth were measured after the soil had been carefully washed from the roots. Shoot and root dry weights were determined after drying the tissue at 70°C.

Analysis of Data

Both survival and growth data were analyzed using a split-plot analysis of variance. Wide ranges in values required the use of arcsin transformations in analyzing the percent germination and survival (Steel and Torrie, 1960).

Results

Germination and Seedling Development in Containers

Germination in both types of containers began approximately seven days after seeding. Total germination over the four-week period averaged about 80 percent in plastic tubes, but only 66 percent in the Jiffy-7 pellets. The reduced rate of germination in peat pellets may have been caused by the rather large exposed surface area which resulted in rapid evaporative cooling. Temperatures in the area of seed deposition were 3° to 7°C lower than the ambient daytime temperature of approximately 29°C.

Growth and development of the young seedlings were good in both types of containers (Figure 9). At outplanting, however, the Jiffy-7 seedlings were less well developed than those grown in the plastic tubes. The slower rate of germination in the peat pellets resulted in seedlings that were somewhat younger than those grown in split-plastic tubes. The copper screen placed beneath the Jiffy-7 pellets was effective in confining the root system to the container. While the presence of the copper screen normally resulted in the death of the primary root, a good secondary root system developed.

Germination, Survival and Growth of Seedlings From Direct Seeding

Germination

The first signs of germination occurred on June 22, twenty-four days after seeding. By June 30, 98 percent of the total germination was complete. No germination was observed after July 12.

A

B

Figure 9. The planting of four-week old container-grown seedlings in (A) split plastic tubes and (B) Jiffy-7 pellets.

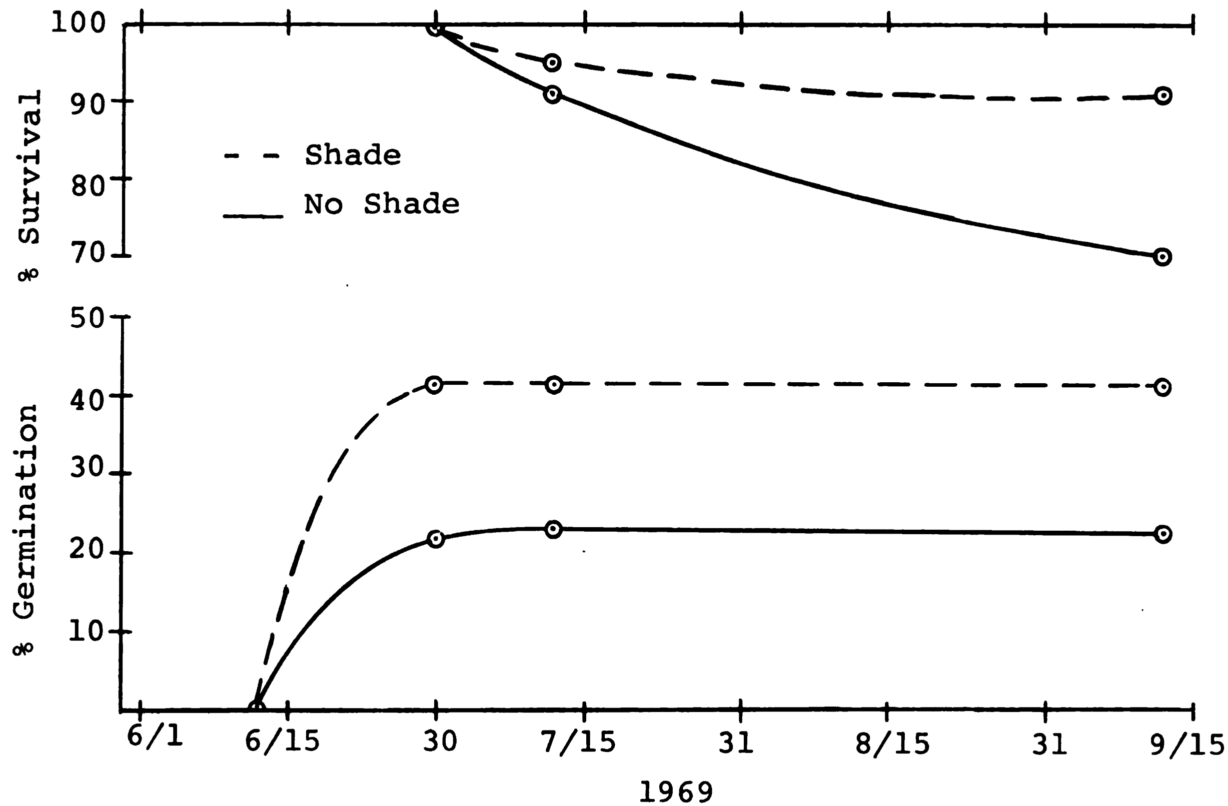


Figure 10. Main effect of shade on first year germination and survival.

The main effect of shade was a beneficial one. Average total germination was 42 percent under partial shade, but only 23 percent on plots without shade (Figure 10). The wind barrier alone had no significant effect on germination. However, the interaction between wind protection and shade was significant (Table 12). The reduction of air movement behind the wind barrier, combined with the lower air and soil temperatures caused by the presence of shade, probably reduced soil surface evaporation and provided improved moisture conditions for germination. No explanation can be offered for the observed reduction in germination with the presence of the wind barrier and in the absence of shade.

The design of the study did not include testing the effects of soil moisture level and vegetative competition on germination. Soil moisture was maintained near field capacity throughout the period of germination. Also, the re-invasion of competing vegetation had not progressed to the extent that it had any influence on germination.

Survival

Soil moisture and weed competition alone had no influence on survival. The presence of partial shade, however, did lower both soil and air temperatures and reduce the rate of soil moisture depletion so that by the

Table 12. Percent germination as influenced by partial shade and wind protection.

Wind Protection	Partial Shade	
	Yes	No
Yes	45	18
No	39	28

Interaction significant at the 5 percent level.

end of the growing season, survival was significantly increased by 21 percent (Figure 10). Seedlings exposed to competition and low soil moisture levels were, however, more chlorotic and of lower vigor. Survival was not increased by protection from wind.

Growth

Most of the stem and terminal growth had occurred by August 15. Total dry weight production, however, increased considerably between August and September, with approximately 40 percent of the total dry weight accumulated during this latter period (Table 13).

The most predominant treatment influencing growth was control of soil water level (Table 14). When soil water was maintained near field capacity, stem diameter and rooting depth were both significantly increased by about 15 percent. Terminal growth, however, was apparently not affected. Dry weight showed the largest response, with increases of 52 and 36 percent for the roots and shoots,

Table 13. Growth of jack pine seedlings grown from broadcast seed, by sampling period for all treatments.

Characteristic Measured	Sampling Date Aug. 15		Sept. 15
Terminal Growth (cm)	0.60	**	0.85
Stem Diameter (mm)	0.69	**	0.79
Rooting Depth (cm)	14.45	**	17.32
Shoot Dry Weight (mg)	22	*	39
Root Dry Weight (mg)	15	**	26
Total Dry Weight (mg)	37	**	65
Shoot/Root Ratio (length)	0.19	**	0.16
Shoot/Root Ratio (weight)	1.72	*	1.51

**Significant at the 1 percent level
*Significant at the 5 percent level

respectively. The lack of response in terms of shoot length, with a corresponding increase in rooting depth, produced a shoot/root ratio (length) which was significantly lower where adequate moisture was provided (Figure 11).

Shade significantly increased terminal growth but tended to decrease rooting depth. These two relationships combined to produce a shoot/root ratio significantly higher if shade was provided (Table 14).

The absence of competing vegetation apparently affected only dry weight increment. Stem dry weight was influenced the most, increasing approximately 38 percent, while root dry weight increased only 18 percent. The competition X shade interaction, as measured by rooting depth, and the competition X wind interaction, as measured by stem diameter,

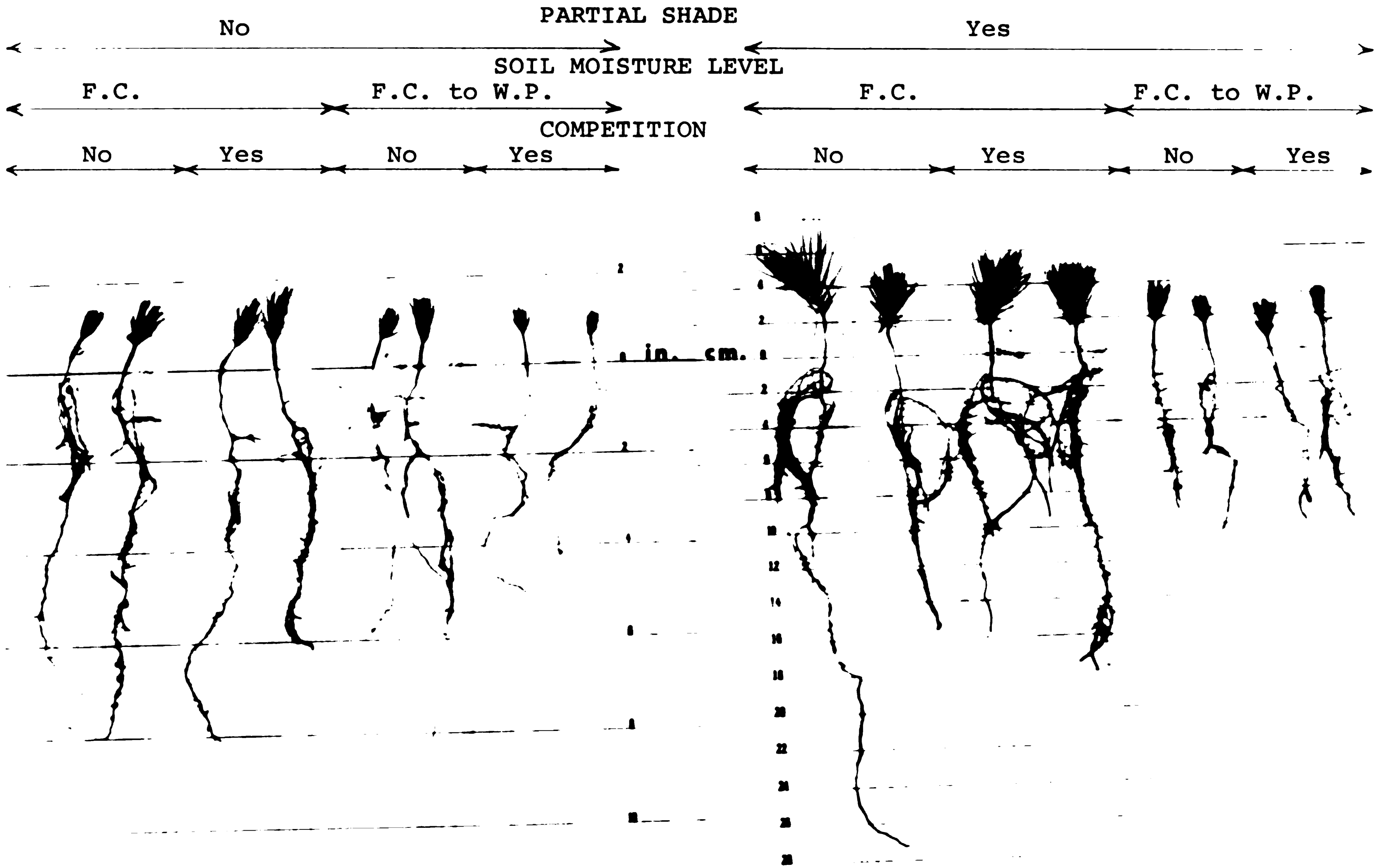


Figure 11. Response of fourteen-week-old, direct-seeded jack pine seedlings to shade, soil moisture, and competition when protected from prevailing winds.

Table 14. First year response of direct seeded jack pine by treatments.

Growth Parameter	Wind Protection		Shade		Soil-Water Suction (atms)		Competition	
	Yes	No	Yes	No	0.0 to 0.5	0.0 to 15.0	No	Yes
Terminal Growth (cm)	0.90	0.80	0.90	* 0.80	0.90	0.80	0.95	0.75
Stem Diameter (mm)	0.80	0.77	0.78	0.80	0.84	** 0.74	0.80	0.77
Rooting Depth (cm)	17.55	17.05	17.00	17.65	18.55	* 16.10	17.65	17.00
Shoot Dry Weight (mg)	43	35	44	34	45	* 33	44	** 34
Root Dry Weight (mg)	28	25	28	25	32	** 21	28	* 24
Total Dry Weight (mg)	71	60	72	59	77	* 54	72	** 58
Shoot/Root Ratio (length)	0.16	0.15	0.17	* 0.14	0.14	* 0.17	0.16	0.15
Shoot/Root Ratio (weight)	1.52	1.50	1.62	* 1.40	1.47	1.55	1.55	1.47

**Difference significant at the 1 percent level.
*Difference significant at the 5 percent level.

were both significant at the 5 percent level (Tables 15 and 16). In both cases, site amelioration in the presence of competition retarded jack pine growth. It thus appears that the improved conditions favored development of competing vegetation at the expense of the jack pine seedlings.

Table 15. Rooting depth (cm) of fourteen-week-old jack pine seedlings as influenced by partial shade and competition.

Competition	Partial Shade Yes	Partial Shade No
No	18.10	17.15
Yes	15.90	18.14

Interaction significant at the 5 percent level.

Table 16. Stem diameter (mm) of fourteen-week-old jack pine seedlings as influenced by wind protection and competition.

Competition	Wind Protection Yes	Wind Protection No
No	0.846	0.746
Yes	0.765	0.782

Interaction significant at the 5 percent level.

Survival and Growth of Container-Grown Seedlings

Survival

Seedlings growing in plastic tubes had a significantly higher rate of survival than those growing in Jiffy-7 pellets (Figure 12). By the end of the growing season, an average of 94 percent of all the trees growing in plastic

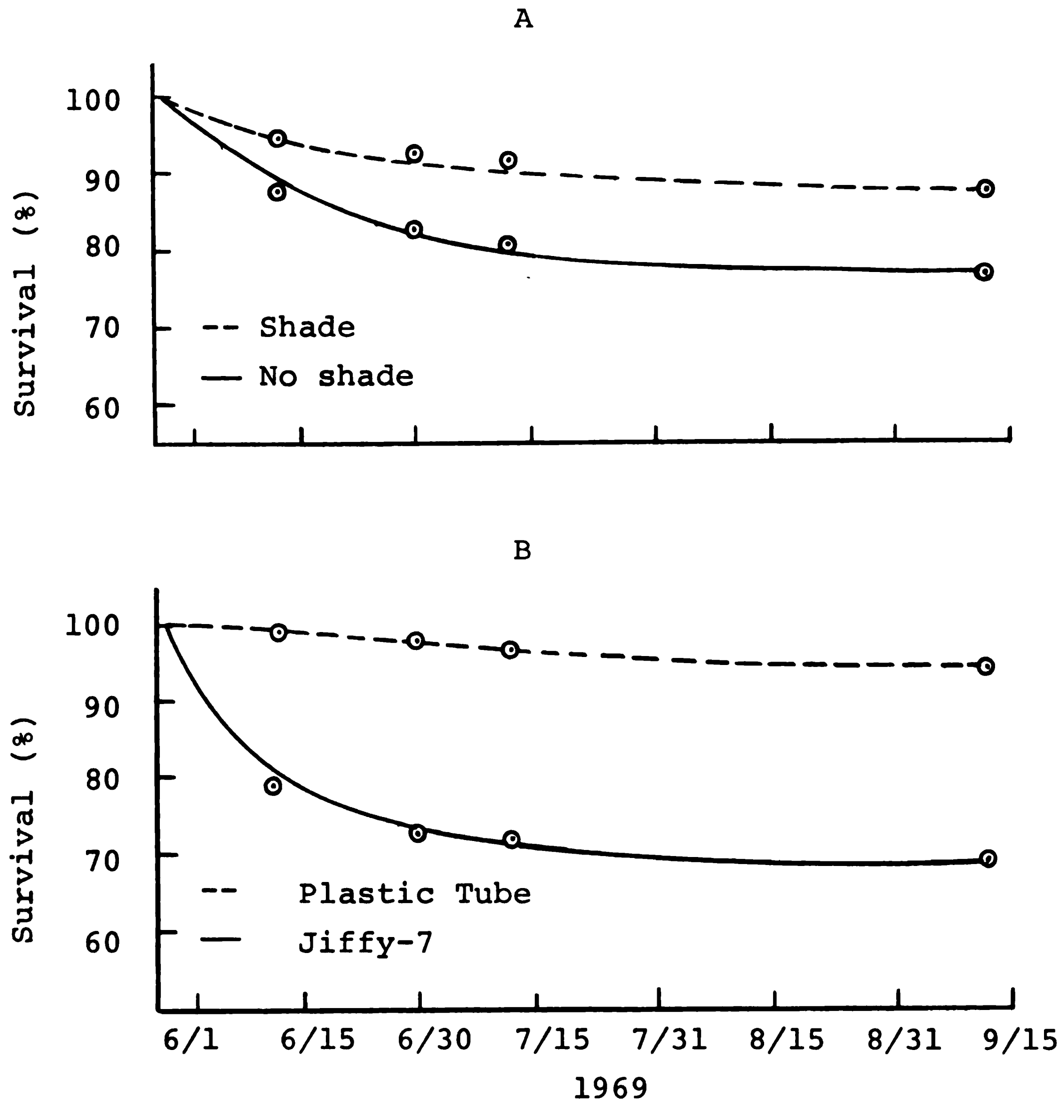


Figure 12. First year survival of container-grown jack pine seedlings, in the field, as influenced by (A) shade, and (B) type of container.

tubes were still alive, as compared to 69 percent of those in peat pellets. The rate of mortality in the plastic tubes was fairly uniform, averaging 1 to 2 percent per month from June 1 to September 15. The seedlings in Jiffy-7 pellets, however, suffered rather severe early season mortality; 27 percent of the trees died between June 1 and June 30.

The principal cause of mortality in all cases was physical rather than biotic. Whereas birds seemed attracted to the white plastic tube, their damage was confined to the tube itself, and the seedling was left undisturbed. The presence of partial shade significantly increased the survival of seedlings in both containers. When partial shade was provided, survival was increased 8 and 25 percent for seedlings grown in plastic tubes and Jiffy-7 pellets, respectively.

Growth

Seedlings in both containers had completed most of their diameter and height growth by August 15 (Table 17). Growth in terms of dry weight, however, increased considerably from August 15 to September 15. During this latter thirty-day period, shoot dry weight increased 54 and 89 percent, and root dry weight increased 85 and 146 percent, respectively for seedlings grown in plastic tubes and Jiffy-7 pellets. The proportionately greater increase

Table 17. Growth of jack pine seedlings raised in two types of containers by sampling period for all treatments.

Characteristic Measured	Plastic Tube Sampling Date Aug. 15	Plastic Tube Sampling Date Sept. 15	Jiffy-7 Sampling Date Aug. 15	Jiffy-7 Sampling Date Sept. 15
Terminal Growth (cm)	2.65[a]	2.90[b]	4.35[c]	5.30[d]
Stem Diameter (mm)	0.96[a]	1.21[b]	1.50[c]	1.98[d]
Rooting Depth (cm)	18.85[a]	22.05[b]	23.60[c]	26.90[d]
Shoot Dry Weight (mg)	110[a]	169[b]	261[c]	494[d]
Root Dry Weight (mg)	66[a]	122[b]	109[c]	268[d]
Total Dry Weight (mg)	177[a]	291[b]	370[c]	762[d]
Shoot/Root Ratio (length)	0.28[a]	0.26[a]	0.28[a]	0.29[a]
Shoot/Root Ratio (weight)	1.65[a]	1.41[b]	2.44[c]	1.89[d]

[a]Values with the same letter in the superscript are not significantly different.

in root dry weight between sampling periods reduced the shoot/root ratio (weight). On the other hand, the shoot/root ratio based on length was relatively unaffected during this time, because of the small increase in shoot and root extension. The relatively large increase in shoot dry weight by seedlings in peat pellets was primarily in the form of lateral branches.

After one growing season, the growth of seedlings raised in the Jiffy-7 pellets was significantly superior to that of seedlings in plastic tubes (Figures 13 and 14). The seedlings in peat pellets had an average of 83 percent more terminal growth, a stem diameter 65 percent larger, and roots approximately 5 cm longer than did seedlings in

Figure 13. Response of twenty-week-old jack pine seedlings, raised in Jiffy-7 pellets, to shade and soil moisture treatments when protected from prevailing winds.

PARTIAL SHADE

No | Yes

SOIL MOISTURE LEVEL

F.C. | F.C. to W.P. | F.C. | F.C. to W.P.

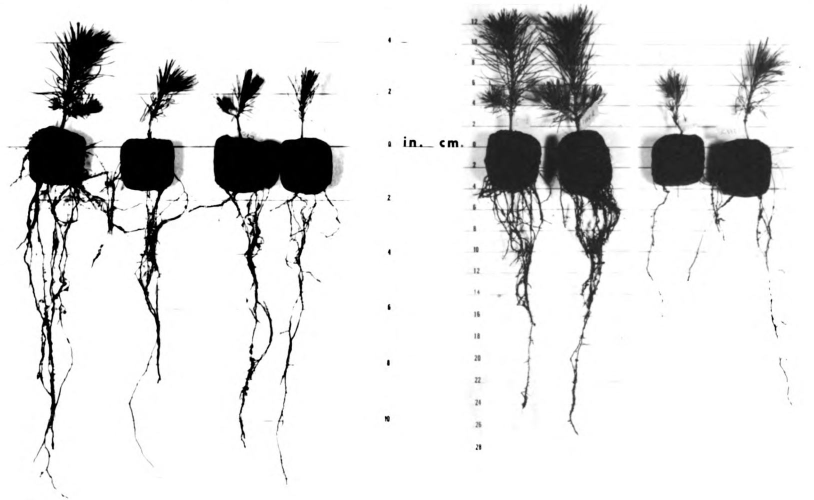
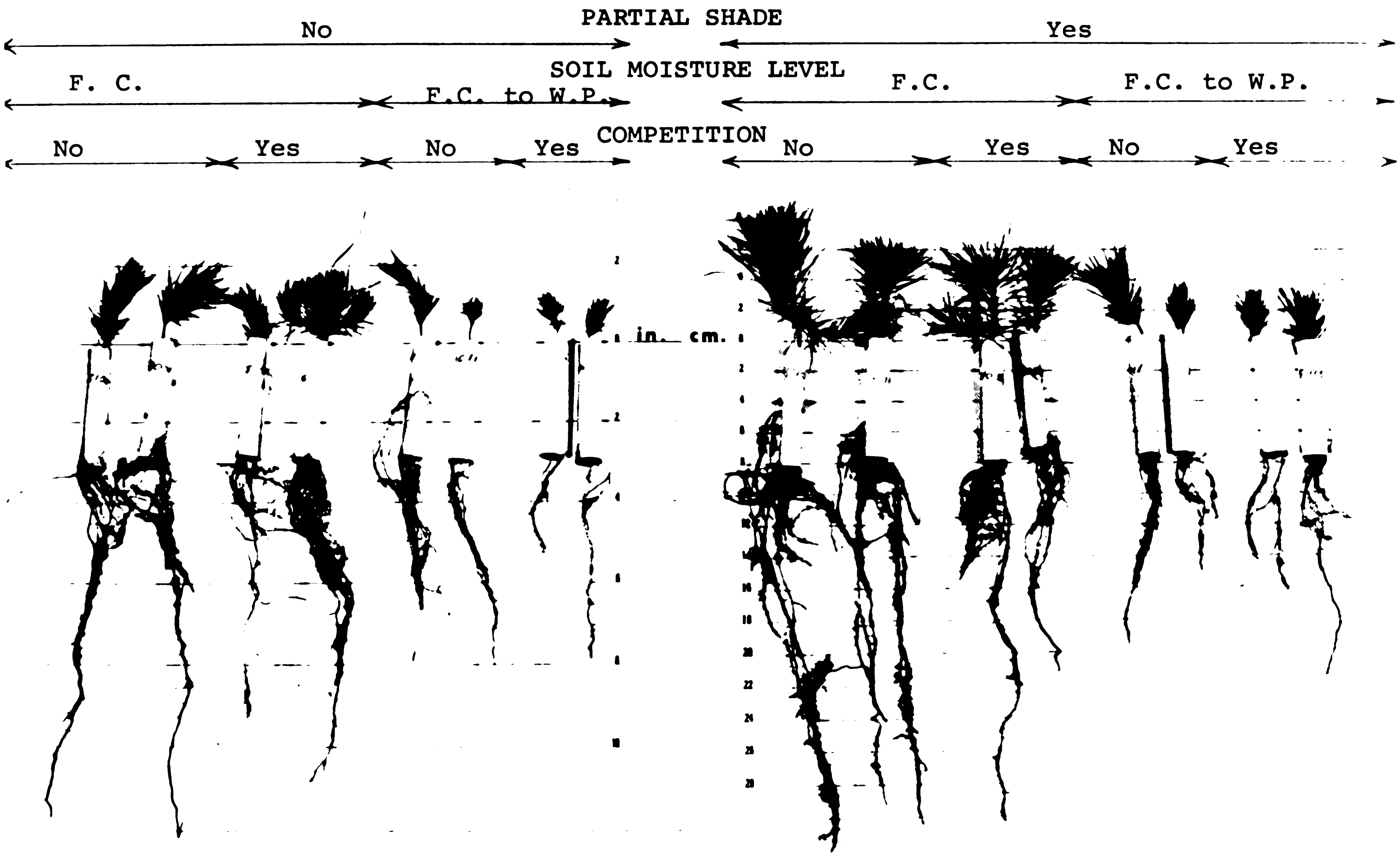


Figure 14. Response of twenty-week-old jack pine seedlings, raised in split plastic tubes, to shade, soil moisture, and competition when protected from the prevailing winds.



plastic tubes. Jiffy-7 seedlings had approximately four times more shoot biomass and two times more root biomass than plastic tube seedlings. The large difference in shoot dry weight resulted in a significantly increased shoot/root ratio for Jiffy-7 seedlings as compared to trees in plastic tubes (Table 17).

The presence of partial shade significantly increased the terminal growth of all seedlings, but increased the shoot and total dry weight for only those seedlings growing in plastic tubes (Table 19). However, the shade X container interaction was not significant at the 5 percent level. In contrast, only trees in Jiffy-7 pellets responded to an ample supply of soil water, with significant increases shown in terminal growth, shoot and total dry weight, and shoot/root ratio. The contrasting response of terminal growth to soil moisture treatment between trees in Jiffy-7 pellets and those in plastic tubes resulted in a significant interaction (Table 20; Figures 13 and 14).

The interaction between shade and soil moisture treatments as they affected terminal growth and shoot/root ratio (length) was also significant (Table 20). The presence of partial shade increased terminal growth by about 9 percent when the seedlings were under soil moisture stress, but increased it 34 percent when soil moisture was readily available. Maintaining soil water near field capacity in

Table 18. First year response of container-grown jack pine by treatment.

Characteristic Measured	Type of Container	Wind Protection Yes	Wind Protection No	Shade Yes	Shade No	Soil-Water Suction (atms) 0.0 to 0.5	Soil-Water Suction (atms) 0.0 to 15.0	Competition No	Competition Yes
		...Plot Means...							
Terminal Growth (cm)	Jiffy-7	5.60	4.95	5.75 *	4.85	5.90 **	4.65	--	--
	Plastic Tube	3.05	2.75	3.25 *	2.55	3.05	2.70	2.90 **	2.15
Stem Diameter (mm)	Jiffy-7	1.99	1.96	1.97	1.99	2.04	1.91	--	--
	Plastic Tube	1.23	1.18	1.26	1.16	1.28	1.13	1.22 **	1.03
Rooting Depth (cm)	Jiffy-7	26.60	27.20	27.25	26.55	26.85	26.95	--	--
	Plastic Tube	21.90	22.20	22.55	21.55	22.75	21.35	22.20 **	19.75
Shoot Dry Weight (g)	Jiffy-7	0.509	0.478	0.486	0.501	0.555 *	0.432	--	--
	Plastic Tube	0.184	0.153	0.194 *	0.143	0.180	0.157	0.169**	0.113
Root Dry Weight (g)	Jiffy-7	0.276	0.260	0.250	0.236	0.282	0.253	--	--
	Plastic Tube	0.122	0.122	0.135	0.109	0.135	0.109	0.124**	0.074
Total Dry Weight (g)	Jiffy-7	0.785	0.738	0.736	0.787	0.838 *	0.685	--	--
	Plastic Tube	0.306	0.275	0.329 *	0.252	0.316	0.266	0.293**	0.187
Shoot/Root Ratio (length)	Jiffy-7	0.31 **	0.27	0.30	0.28	0.31 **	0.27	--	--
	Plastic Tube	0.26	0.24	0.27	0.24	0.26	0.25	0.26	0.24
Shoot/Root Ratio (weight)	Jiffy-7	1.90	1.88	2.00	1.79	1.95	1.34	--	--
	Plastic Tube	1.55 *	1.27	1.46	1.36	1.34	1.47	1.40	1.53

**Significant at the 1 percent level.
*Significant at the 5 percent level.

Table 19. Influence of soil moisture and type of container on terminal growth (cm) of twenty-week-old jack pine seedlings averaged over all shade and wind treatments.

Soil-Water Suction	Container Plastic Tube	Container Jiffy-7
0.0 to 0.5 atm	3.05	5.90
0.0 to 15.0 atms	2.70	4.65

Interaction significant at the 5 percent level.

Table 20. Influence of shade and soil moisture on shoot/root ratio (length) and terminal growth (cm) of all container-raised jack pine seedlings twenty-weeks old.

Soil-Water Suction	Shade Yes	Shade No	Shade Yes	Shade No
	Shoot/Root Ratio (length)		Terminal Growth (cm)	
0.0 to 0.5 atm	.31	.27	5,15	3.85
0.0 to 15.0 atms	.26	.26	3.80	3.55

Interactions significant at the 5 percent level.

the absence of shade increased terminal growth only 8 percent. The greater increase in shoot extension under the favorable combination of partial shade and adequate soil moisture resulted in a corresponding increase in the shoot/root ratio.

The presence of competing vegetation caused a highly significant reduction in the growth of seedlings raised in plastic tubes (Table 18). The most pronounced effect was on shoot and root dry weights, which were reduced 33 and 40 percent respectively. There was no significant affect on the shoot/root ratios due to the relatively uniform reduction in both shoots and roots.

In general, there was no significant difference in the growth parameters measured between trees growing with wind protection and those without (Table 18). However, protected seedlings in Jiffy-7 pellets tended to have taller shoots and shorter roots. Likewise, the shoot dry weight of protected trees in plastic tubes tended to be greater than that in unprotected trees. These relationships resulted in shoot/root ratios significantly higher where the seedlings were protected from the prevailing wind.

Discussion

Germination and Survival

Improvements in germination in the presence of partial shade is in general agreement with the findings of other investigators (Fraser and Farrar, 1953; Beaufait, 1959; LeBarron, 1944; Fraser, 1959). The presence of shade reduces the rate of evaporation from the soil surface. Loss of surface moisture is especially severe in sandy soils, which are subject to very rapid drying when exposed to direct insolation.

The observed increased survival in the presence of partial shade for all seedlings differs with the results obtained by Beaufait, 1959, and LeBarron, 1944. They report a decrease in first-year jack pine survival under a level of shade very similar to that used in this study, indicating an early expression of the intolerance of this species. However, neither of the above investigators attempted to control soil moisture levels. The means by which they provided the shade may have intercepted or utilized the natural precipitation to such an extent that mortality due to soil moisture stress resulted.

Failure of the soil moisture treatment to influence mortality in the field agrees with the results found in the study conducted under controlled conditions (Chapter III). In the growth chamber, pots were not allowed to remain at a soil-water suction of 15 atms for more than a few hours, while in the field this period normally lasted no more than two days. The fluctuation of soil water between soil-water suctions of 0.0 and 15.0 atms apparently did not create a drought stress of sufficient intensity to influence mortality. This was true despite the exclusion of natural precipitation from the field plots for as long as 15 days during critical portions of the growing season.

The increased mortality of seedlings raised in Jiffy-7 pellets was probably caused by their slower initial germination and, therefore, younger age at the time of outplanting. A longer period of growth and conditioning prior to outplanting may be required to offset this delay, caused primarily by the lower temperatures resulting from the evaporative cooling of the wet peat surface.

Growth

Shade and Soil Moisture

Seedlings in both containers as well as those from direct seeding responded in about the same way to the environmental modifications imposed. The younger seedlings from direct seeding appeared to be affected by the soil moisture treatment to a greater extent than the container-grown seedlings. The large difference in root dry weight of those seedlings because of imposed soil moisture treatment indicates that the small immature root is especially susceptible to fluctuations in soil water. These field results agree with the laboratory study, indicating that soil water fluctuations indeed influence root system development (Chapter III).

For all seedlings, the presence of partial shade was beneficial, primarily to shoot growth. For container-grown seedlings, however, the benefit from shade in terms of terminal growth was much greater when ample soil water was available. This contrast in response resulted in a significant interaction (Table 20). Apparently the stress created by fluctuating soil water content was only partially alleviated by the presence of shade. When partial shade was removed but soil water remained at field capacity, resulting higher air and soil temperatures probably reduced growth. When ample soil water was combined with partial shade, terminal growth increased considerably. A comparable interaction was observed in the growth chambers, where the effect of temperature was greatly increased when soil water was not limiting (Chapter III).

Competing Vegetation

The growth of seedlings from both the direct seeding and those raised in plastic tubes was significantly reduced when competing vegetation was allowed to re-invade the plots. This was especially true for growth in terms of dry weight where reductions owing to competition averaged between 20 and 35 percent. In the case of direct seeding, the competition seemed to utilize the amelioration of the site to a greater extent than the smaller jack pine seedlings. This was demonstrated by the significant shade X competition and wind X competition interactions (Tables 15 and 16).

Wind

In general, there was no significant difference in the growth parameters measured during the first growing season between trees growing with wind protection and those without. The relative lack of response by the seedlings to wind protection may have resulted from the low stature of the young seedlings in comparison to the surrounding vegetation. Thus, differences between protected and unprotected seedlings may become more important as the trees grow older. The fact that there was a tendency for the shoots of protected seedlings to be larger, which resulted in significantly higher shoot/root ratios, is evidence that there was some response to protection.

Bud Set

An attempt was made to evaluate the treatment influence on terminal bud set. By September 15, only 100 trees had set bud. Sixty four of these were found on plots subjected to soil water stress. This effect of soil moisture was significant at the 5 percent level using a Chi-square test. There was only a small difference in bud set between the other treatments. These results tend to support observations in the growth chamber where terminal bud set appeared to be controlled by soil water level under the low temperature treatment.

Comparison of Containers

Seedlings in both containers responded similarly to the treatments imposed. However, the maintenance of soil water near field capacity was only beneficial to those seedlings grown in Jiffy-7 pellets (Table 19). While rooting depth averaged about 27 cm, most of the lateral root system extening from the Jiffy-7 pellet was concentrated in the upper 5 to 10 cm of soil. Thus, the bulk of the roots were susceptible to severe fluctuations in soil moisture content. In contrast, the roots of seedlings in plastic tubes were primarily confined to their container, and did not come into contact with mineral soil until they were approximately 8 cm below the soil surface. Therefore, they were not exposed to the rapid moisture depletion which occurred in the surface 8 cm of soil. Nevertheless, seedlings in Jiffy-7 containers had an average shoot growth of 4.65 cm, as compared to 2.70 cm for seedlings in plastic containers when both were grown under conditions of fluctuating soil water levels.

A comparison of growth performance after one growing season indicates that seedlings grown in Jiffy-7 pellets are clearly superior to those in plastic tubes. This increased growth is probably related to an unrestricted and prompt development of lateral roots and a subsequent penetration of a larger volume of soil. During the first year of establishment, the root system of trees in plastic tubes is primarily vertically oriented, resulting in a smaller total root system.

Comparison of Containers and Direct Seeding

One major advantage of container-grown seedlings over direct seeding is that the germination and early growth of the seedling can be initiated under controlled conditions. In this study, both the planting of seedlings grown in containers and the direct seeding was completed the last week in May. Cool temperatures throughout June delayed germination for twenty-four days following seeding. During this period, seedlings in containers were growing and were already seven weeks older by the time the broadcast seed had germinated. By the end of the first growing season, this advanced start had produced trees considerably larger and more vigorous than trees resulting from direct seeding (Figures 11, 13 and 14).

CHAPTER V

SUMMARY AND CONCLUSIONS

Attempts to regenerate jack pine naturally have generally been disappointing. This is due primarily to the existence of serotinous cones and the necessity of a mineral soil seedbed for adequate germination and survival. Although the planting of nursery-grown seedlings has been used with considerable success, the high cost of this method has stimulated interest in alternative methods.

Direct seeding and the planting of container-grown seedlings are two such alternatives. However, both of these methods expose a vulnerable seedling to unfavorable climatic conditions. Before either of these methods can be successfully employed, we must have a more complete understanding of the environmental factors affecting germination, survival, and growth of young jack pine seedlings.

In this study, the affects of several environmental factors on jack pine germination, survival, and growth were investigated under both laboratory and field conditions. Field comparisons were made between direct seeded and container-grown seedlings and between seedlings raised in two types of containers.

Growth Chamber Experiment

Jack pine seedlings were grown in plastic pots for ten weeks under six combinations of three temperature and two soil moisture treatments. Day and night temperatures were controlled at 32°C and 21°C, 24°C and 13°C, and 16°C and 5°C, respectively. Soil-water suction was either maintained below 0.1 atm or allowed to fluctuate between 0.0 and 15.0 atms. All other factors were held constant at levels which simulated natural conditions. The response to treatment was determined by destructively sampling one-tenth of the trees each week over the ten-week period.

No mortality was recorded for any trees under any of the above treatments. Temperature and soil moisture treatments had a pronounced affect on seedling growth. The soil moisture X temperature interaction was highly significant for every growth parameter measured. With adequate soil moisture, seedlings at the high and moderate temperatures had over two times more dry matter than those at the low temperature. By the tenth week, seedlings at the moderate temperature appeared to be larger and more vigorous than those at the high temperature. At the high and moderate temperatures, the presence of ample soil water increased total dry weight by more than two times. At the low temperature, however, the increase was only 32 percent. Trees under conditions of moisture stress showed little response to temperature differences.

The dry root weight appeared to be greatly influenced by fluctuations in soil water. Root tissue mortality occurred when moisture levels were low and a resumption of root growth took place following rewatering. Root mortality and a resultant decline in dry weight seemed to occur consistently between soil-water suctions of 2 to 3.5 atms.

At the low temperature, terminal bud set and the resumption of growth appeared to be influenced by soil moisture content.

Field Experiment

Germination, survival, and growth of direct seeded and container-grown jack pine seedlings were investigated on modified sites in northern Lower Michigan. The study area is located on the Mio Ranger District, Huron-Manistee National Forest, approximately ten miles southeast of Mio, Michigan. The site is typical of the sand plains that support stands of jack pine throughout Michigan.

The first-year response of jack pine seedlings to site modifications influencing wind, light, soil water, and competition was examined using a split-plot design with six replications. The basic experimental unit for this design was a 1.2 meter square plot which was cleared and scalped to mineral soil prior to planting.

Seedlings were raised in either split-plastic tubes or Jiffy-7 pellets for comparison with each other and with seedlings from direct seeding. All the seed used in the study was collected from mature trees near the study area.

The following treatments were arranged factorially in order to determine the significance of factor interactions.

1. Wind barriers, which reduced the prevailing south-westerly wind by an average of 45 percent, were randomly assigned to one-half of each replication.
2. Shade structures which reduced average light intensity to 45 percent of that in the open were randomly assigned and constructed over one-half of the plots. These structures also reduced maximum air temperatures by 2°C, soil temperatures by 3°C, and lengthened the time for the soil to reach wilting point by four to nine days beyond the time required for exposed plots.
3. Soil-water suction on one-half of the plots was continuously maintained below 0.5 atm, while on the remaining it was allowed to fluctuate between 0.0 and 15.0 atms.
4. Four experimental plots were included within each combination of the above treatments. Three of the plots were randomly assigned to be planted with either 50 seedlings in plastic tubes, 36 seedlings in Jiffy-7 pellets or 100 jack pine seeds. These

plots were maintained weed-free throughout the growing season. One-half of the fourth plot was planted with 20 seedlings in plastic tubes; the other half was seeded with 100 jack pine seeds. The competing vegetation was allowed to reinvade this plot after the initial scalping.

Germination and survival counts were taken four times and growth measurements were made twice during the first growing season.

Growth and development prior to planting was generally good in both types of containers. However, germination was slowed to some extent by evaporative cooling of the exposed wet peat in Jiffy-7 pellets. A somewhat longer growth period under controlled conditions is therefore recommended when using this container.

Germination and Survival

First-year results indicate beneficial effects of partial shade on germination and survival. Germination was increased by an average of 19 percent where shade was present. Shade increased survival by 21, 25, and 8 percent for direct seeded, Jiffy 7, and plastic tube seedlings, respectively. Natural shade provided by logging slash, microtopography, and standing trees should therefore be utilized to increase germination and initial survival of young seedlings.

Growth

The presence of shade also benefited terminal growth for all seedlings. However, for container-grown seedlings, the benefit from shade was much greater when ample soil water was available.

The soil moisture treatment had its greatest affect on the growth of direct seeded and Jiffy-7 seedlings. The lack of response to moisture treatment by the seedlings in plastic tubes resulted in a significant container X soil moisture interaction.

The presence of competing vegetation reduced the dry weight of direct seeded and plastic tube seedlings an average of 20 and 35 percent, respectively. Competing vegetation appeared to benefit more than jack pine from the amelioration of the site by shade and wind protection. This resulted in a significant treatment X competition interaction.

The results of this study indicate that first-year jack pine growth was improved by partial shade, ample soil water and the removal of competition. Although soil moisture is not subject to direct control under natural conditions, the presence of shade and the absence of competition would indirectly improve soil water conditions. In the past, emphasis has been placed on mechanical scarification as a means of controlling competition and exposing mineral soil. In this study, competing vegetation was allowed to re-establish itself to the extent that growth was impaired, even though plots were initially scalped to a depth of 5 to 8 cm before planting.

In general, there was no significant difference in growth parameters measured during the first growing season between trees growing with wind protection and those without. Differences may become more apparent as the height of the trees exceeds that of the surrounding vegetation.

During the first year, seedlings in Jiffy-7 pellets produced 160 percent more total biomass than plastic tubes. This increased growth is probably related to the unrestricted and prompt development of lateral roots extending into the soil from the peat pellet, and a subsequent penetration of a larger volume of soil.

One major advantage of container-grown seedlings over direct seeding is that germination and early growth can be initiated under controlled conditions. In this study, delayed germination of direct seeded plots due to cool temperatures gave the container-grown seedlings a seven-week advantage. By the end of the growing season, this advanced start resulted in container-grown seedlings which averaged eight times more total biomass than direct seeded trees. Although direct seeding should not be discounted as a regeneration method, the advantages offered by container-grown seedlings certainly merit attention.

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APPENDIX

Table 21. Significance of main effects and interactions on the growth of ten-week-old jack pine seedlings in controlled environment chambers.

Source of Variation	Total Height	Stem Diameter	Dry Weight			Shoot/ Root Ratio (weight)	Degrees of Freedom
			Needles	Stems	Roots		
A (temperature)	**	**	**	**	**	*	2
B (time)	**	**	**	**	**	**	9
AB	**	**	**	**	**	**	18
Error							30
C (soil moisture)	**	**	**	**	**		1
AC	**	**	**	**	**		2
BC	**	**	**	**	**		9
Remaining error							48

**Significant at the 1 percent level

Table 22. Total height (cm) of jack pine seedlings as influenced by soil moisture and temperature over a ten-week period in controlled environment chambers.

	Soil-Water Suction					
	0.0 to 0.1 atm.			0.0 to 15.0 atm.		
	Day/Night Temperature (°C)			Day/Night Temperature (°C)		
Week	32/21	24/13	16/5	32/21	24/13	16/5
1	2.60	2.72	2.55	2.80	2.40	2.35
2	2.55	2.70	2.65	2.20	2.40	2.15
3	2.50	2.30	2.45	2.25	2.40	2.60
4	2.45	2.50	2.25	2.30	2.35	2.55
5	2.40	2.55	2.40	2.55	2.25	2.55
6	2.85	2.85	2.70	2.20	2.35	2.40
7	3.80	2.95	2.25	2.55	2.55	2.35
8	2.85	3.20	2.40	2.55	2.55	2.10
9	2.90	3.80	2.25	2.75	2.30	2.50
10	3.60	3.60	2.80	2.90	2.45	2.65

Table 23. Stem diameter (mm) of jack pine seedlings as influenced by soil moisture and temperature over a ten-week period in controlled environment chambers.

	Soil-Water Suction					
	0.0 to 0.1 atm.			0.0 to 15.0 atm.		
	Day/Night Temperature (°C)			Day/Night Temperature (°C)		
Week	32/21	24/13	16/5	32/21	24/13	16/5
1	0.67	0.71	0.68	0.69	0.66	0.66
2	0.68	0.66	0.66	0.66	0.65	0.64
3	0.68	0.67	0.66	0.63	0.64	0.65
4	0.69	0.72	0.64	0.62	0.67	0.65
5	0.79	0.80	0.66	0.68	0.68	0.65
6	0.87	0.85	0.65	0.68	0.64	0.61
7	1.06	0.87	0.61	0.75	0.64	0.62
8	0.93	0.92	0.68	0.75	0.68	0.62
9	1.02	1.23	0.71	0.81	0.75	0.67
10	1.16	1.18	0.75	0.79	0.72	0.65

Table 24. Dry weight (mg) of jack pine seedlings as influenced by soil moisture and temperature over a ten-week period in controlled environment chambers.

	Soil-Water Suction 0.0 to 0.1 atm.								
	Day/Night Temperature (°C)								
	32/21			24/13			16/5		
Week	Needle	Stem	Root	Needle	Stem	Root	Needle	Stem	Root
1	12	4	11	12	3	9	12	4	9
2	14	3	16	13	2	19	13	3	14
3	12	3	19	12	2	14	12	3	8
4	25	3	18	20	3	27	13	2	10
5	33	3	18	30	4	23	14	2	11
6	40	5	29	36	5	29	17	3	15
7	75	11	54	42	6	34	26	3	15
8	48	6	34	61	8	42	24	4	18
9	64	12	41	140	15	88	29	3	22
10	91	13	73	118	14	71	29	4	30

Table 24. (cont.)

	Soil-Water Suction 0.0 to 15.0 atm.								
	Day/Night Temperature (°C)								
	32/21			24/13			16/5		
Week	Needle	Stem	Root	Needle	Stem	Root	Needle	Stem	Root
1	9	4	12	12	4	7	13	4	11
2	10	2	11	12	2	12	10	2	7
3	11	2	25	13	2	12	13	3	10
4	12	2	17	13	2	29	13	3	7
5	16	3	11	13	2	10	14	3	9
6	17	2	12	15	3	20	13	2	10
7	23	3	29	20	3	15	15	3	18
8	29	4	23	23	3	14	14	3	11
9	35	4	20	26	3	19	17	3	10
10	31	4	25	29	4	31	18	4	22

Table 25. Shoot/Root ratio of jack pine seedlings as influenced by soil moisture and temperature over a ten-week period in controlled environment chambers.

	Soil-Water Suction					
	0.0 to 0.1 atm.			0.0 to 15.0 atm.		
	Day/Night Temperature (°C)			Day/Night Temperature (°C)		
Week	32/21	24/13	16/5	32/21	24/13	16/5
1	1.46	1.68	1.96	1.19	2.36	1.62
2	1.14	0.83	1.17	1.06	1.23	1.67
3	0.82	1.08	1.83	0.54	1.30	1.56
4	1.50	0.87	1.61	0.83	0.54	2.17
5	2.05	1.47	1.49	1.74	1.50	1.90
6	1.53	1.40	1.31	1.66	0.92	1.37
7	1.57	1.41	1.90	0.94	1.59	1.02
8	1.62	1.62	1.59	1.44	1.86	1.50
9	1.84	1.75	1.53	1.69	1.56	2.00
10	1.46	1.85	1.11	1.44	1.11	0.96

Table 26. Significance of main effects and interactions on the growth of container-grown jack pine seedlings, twenty-weeks old.

Source of Variation	Degrees of Freedom	Terminal Growth	Stem Diameter	Rooting Depth	Dry Weight			Shoot/Root Ratio	
					Shoot	Root	Total	Length	Weight
Replication	5								
A (wind)	1								
Error (a)	5								
B (shade)	1	*							
AB	1								
Error (b)	10								
C (soil moisture)	1	**			*		*	*	
AC	1								
BC	1	*						**	
ABC	1								
Error (c)	20								
D (container type)	1	**	**	**	**	**	**	**	**
AD	1								
BD	1								
ABD	1								
CD	1	*							
ACD	1								
BCD	1								
Remaining error	41								

**Significant at the 1 percent level
*Significant at the 5 percent level

Table 27. Average response of twenty-week-old jack pine seedlings raised in Jiffy-7 pellets, by treatment combination.

Characteristic Measured	W[1/] S M	W S m	W s M	W s m	w S M	w S m	w s M	w s m
Terminal Growth (cm)	7.65	4.95	5.25	4.60	5.80	4.55	5.00	4.50
Stem Diameter (mm)	2.25	1.86	1.14	1.02	1.95	1.80	1.37	1.09
Rooting Depth (cm)	26.65	27.85	27.65	24.35	26.15	28.30	26.95	27.30
Shoot Dry Weight (g)	0.650	0.390	0.494	0.503	0.507	0.397	0.569	0.438
Root Dry Weight (g)	0.294	0.243	0.280	0.287	0.265	0.196	0.290	0.287
Total Dry Weight (g)	0.945	0.633	0.774	0.790	0.772	0.594	0.860	0.725
Shoot/Root Ratio (length)	0.37	0.27	0.28	0.32	0.32	0.25	0.27	0.25
Shoot/Root Ratio (weight)	2.26	1.80	1.77	1.79	1.84	2.09	1.94	1.66

[1/] W - Wind protection present
w - Wind protection absent

S - Partial shade present
s - Partial shade absent

M - Soil moisture maintained near field capacity
m - Soil moisture fluctuating between field capacity and wilting point

Table 28. Average response of twenty-week-old jack pine seedlings grown in split-plastic tubes, by treatment combination.

Characteristic Measured	W[1/] S M	W S m	W s M	W s m	w S M	w S m	w s M	w s m
Terminal Growth (cm)	4.15	3.20	2.55	2.25	3.00	2.60	2.55	2.75
Stem Diameter (mm)	1.47	1.29	1.14	1.02	1.17	1.11	1.37	1.09
Rooting Depth (cm)	24.85	21.30	22.05	19.30	21.45	22.60	22.65	22.15
Shoot Dry Weight (g)	0.270	0.199	0.146	0.120	0.152	0.156	0.152	0.153
Root Dry Weight (g)	0.174	0.125	0.110	0.081	0.128	0.113	0.129	0.116
Total Dry Weight (g)	0.444	0.324	0.257	0.200	0.772	0.269	0.281	0.269
Shoot/Root Ratio (length)	0.30	0.27	0.24	0.26	0.26	0.24	0.26	0.25
Shoot/Root Ratio (Weight)	1.57	1.69	1.40	1.53	1.21	1.36	1.18	1.31

[1/] W - Wind protection present; w - Wind protection absent
S - Partial shade present; s - Partial shade absent
M - Soil moisture maintained near field capacity; m - Soil moisture fluctuated between field capacity and wilting point

Table 29. Significance of main effects and interactions on the growth of direct-seeded jack pine seedlings, fourteen-weeks old.

Source of Variation	Degrees of Freedom	Terminal Growth	Stem Diameter	Rooting Depth	Dry Weight Shoot	Dry Weight Root	Dry Weight Total	Shoot/Root Ratio Length	Shoot/Root Ratio Weight
Replication	4								
A (wind)	1								
Error (a)	4								
B (shade)	1	*						*	*
AB	1								
Error (b)	8								
C (soil moisture)	1		**	*	*	**	*		*
AC	1								
BC	1								
ABC	1								
Error (c)	16								
D (competition)	1				**	*	**		
AD	1		*						
BD	1			*					
ABD	1								
CD	1								
ACD	1								
BCD	1								
Remaining Error	33								

**Significant at the 1 percent level
*Significant at the 5 percent level

Table 30. Average response of direct-seeded jack pine seedlings fourteen-weeks old, by treatment combination.

Characteristic Measured	W[1/] S M C	W S M c	W S m C	W S m c	W s M C	W s M c	W s m C	W s m c
Terminal Growth (cm)	1.25	0.90	1.20	0.95	0.90	0.80	0.55	0.50
Stem Diameter (mm)	0.88	0.85	0.81	0.72	0.92	0.80	0.77	0.68
Rooting Depth (cm)	21.40	17.40	15.80	15.40	18.00	19.85	16.20	16.50
Shoot Dry Weight (g)	0.068	0.048	0.054	0.035	0.047	0.036	0.034	0.022
Root Dry Weight (g)	0.042	0.035	0.027	0.019	0.032	0.025	0.024	0.020
Total Dry Weight (g)	0.111	0.082	0.081	0.054	0.080	0.062	0.058	0.042
Shoot/Root Ratio (length)	0.14	0.16	0.22	0.19	0.15	0.14	0.17	0.14
Shoot/Root Ratio (weight)	1.63	1.39	1.74	1.78	1.52	1.51	1.52	1.11

[1/] W - Wind protection present
w - Wind protection absent
M - Soil moisture maintained near field capacity
m - Soil moisture fluctuated between field capacity and wilting point

S - Partial shade present
s - Partial shade absent
C - Competition absent
c - Competition present

Table 30. (cont.)

Characteristic Measured	w S M C	w S M c	w S m C	w S m c	w s M C	w s M c	w s m C	w s m c
Terminal Growth (cm)	0.90	0.95	0.60	0.45	0.75	0.80	1.50	0.45
Stem Diameter (mm)	0.81	0.82	0.71	0.66	0.78	0.87	0.75	0.78
Rooting Depth (cm)	18.85	15.30	16.45	15.45	18.65	19.00	15.75	17.15
Shoot Dry Weight (g)	0.048	0.042	0.031	0.025	0.037	0.036	0.032	0.029
Root Dry Weight (g)	0.034	0.029	0.019	0.016	0.024	0.032	0.025	0.020
Total Dry Weight (g)	0.082	0.071	0.050	0.041	0.061	0.068	0.057	0.048
Shoot/Root Ratio (length)	0.14	0.18	0.16	0.15	0.13	0.13	0.16	0.14
Shoot/Root Ratio (weight)	1.40	1.56	1.74	1.70	1.57	1.15	1.24	1.58