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THE EFFECT OF PHOTOPERIOD AND DEFOLIATION ON ROOT GROWTH OF EUROPEAN BIRCH (Betula Pendula) SEEDLINGS

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THE EFFECT OF PHOTOPERIOD AND DEFOLIATION ON ROOT GROWTH OF EUROPEAN BIRCH (*BETULA PENDULA*) SEEDLINGS

by

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ABSTRACT

THE EFFECT OF PHOTOPERIOD AND DEFOLIATION ON ROOT GROWTH OF EUROPEAN BIRCH (*BETULA PENDULA*) SEEDLINGS

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Short photoperiods induce a reduction in growth of daylength sensitive plants by shortening of the internodes and decreasing the number of new nodes formed. Photoperiod and defoliation were studied with the use of a modified water culture system to observe the effect on shoot and root elongation.

Long days (8 hours of natural light plus 2 hours of supplemental light in the middle of the dark period) resulted in a continued elongation of the shoot. Short days (8 hours of natural light) resulted in a cessation of shoot elongation and promoted dormancy. Dormant terminal and lateral buds were present on the shoot by the end of the third week of treatment. Two weeks of short days was sufficient to promote dormancy.

Daylength did not affect the rate of root elongation on foliated plants. Root pruning suppressed the rate of root elongation until active meristems were initiated above the pruned area on foliated plants. Once active tips were

formed the rate of root elongation was similar to those plants not root pruned.

Various levels of defoliation reduced root elongation in proportion to the amount of foliage removed. Complete defoliation of long- and short-day plants resulted in a cessation of root elongation and promoted dormancy of the root system. Normally white active root meristems turned brown and stopped elongating. The entire root system became more pliable to the touch following defoliation.

Covering of various amount of foliage with aluminum foil resulted in a reduction of root elongation similar to that of defoliated plants. Complete covering of the foliage promoted the cessation of root elongation and the onset of dormancy of the root system.

The thesis is dedicated to my advisor, Dr. Roy Mecklenburg, who gave me the opportunity to do this research and whose friendship and guidance were an invaluable source of inspiration, and to my family whose love and support made this possible.

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Introduction

An increasing proportion of nursery stock marketed in the United States is sold with its root system intact in the soil, either balled and burlaped or boxed. Transplanting with intact soil is a common cultural practice for many landscape plants since it is believed that some plants do not regenerate their root system destroyed during bare root transplanting. Nurserymen have reported that birch (Betula sp.) have specific transplanting requirements. This plant may be successfully transplanted in the spring by various methods, including bare root or balled and burlaped. However, little success has been reported with fall transplanting of birch regardless of the method of transplanting, balled and burlaped or boxed. The need to understand this phenomenon and perhaps develop cultural practices that will minimize losses during fall transplanting is necessary.

Birches are generally rapidly growing plants native to the cooler regions of North America and Europe and range in size from small shrubs to large trees. European Birch (Betula pendula) is a medium sized pyramidal-shaped tree with branches somewhat pendulous in older trees (71). It grows to an ultimate height of 60 feet and is valued for its

white exfoliating bark and yellow fall foliage color. Numerous varieties exist for this relatively short-lived (approximately 25 years) but unique tree. It can be grown either single or multiple-stemmed, the latter being the most common. The infloresence is a long catkin and develops into catkin-like clusters of small dry fruits. Several insects are associated with European birch. Most can be controlled with a regular spray program. However, bronze birch borer is tranditionally controlled by removing the infested wood.

Root Growth

The root growth characteristics of landscape ornamental trees is greatly influenced by species, root environment and cultural practices. Investigations by Weaver and Himmel (65) have shown that plants exhibit species and varietal differences with respect to relative development of roots when grown under the same environmental conditions. The depth of the root system shows little relation to the size of the plant above ground. The soils' physical resistance and aeration were shown to be factors affecting primary root elongation rates of pea seedlings (Pisum sativum) (61). The major soil factors affecting root growth are mechanical resistance, water supply and aeration. However, it is difficult to attribute a change in the rate of root elongation to a specific soil factor. A change in water supply, for instance, will result in a change in aeration and mechanical resistance of the soil (1).

Luckwell (47) showed that the three major environmental factors influencing the root/shoot ratio are soil moisture, nitrogen supply and light intensity. Under high light intensities, soils which were dry or deficient in nitrogen favored a greater development of the root system. Root pruning and care during the first two nursery transplantings of four tree species (Eucalyptus sideroxylon, Pinus radiata, Pistachic chinensis and Quercus Ilex) significantly increased the percentage of plants with larger and more extensive root system (17).

Roots of trees often spread laterally as far as or well beyond the width of the crown. Soil moisture, fertilizing, plant age, weight and species effect the spread (14). The maintenance of a proper balance between root and shoot is very important. If either is limiting or too great in extent, the other will not thrive. The root system must be sufficiently wide-spread to absorb enough water and nutrients for the stem and leaves, which in turn, must manufacture sufficient photosynthate for the maintenance of the root system (65). Laboratory deformation of the taproot of loblolly pine (Pinus Taeda) seedlings into a knot or double-J caused a greater lateral root formation than plants of the same species not deformed (18). On loblolly pine the extensive, well-branched lateral root system developed in the upper layers of the soil and appeared to absorb water and nutrients more effectively than plants with the normal tap root structure.

A well-developed lateral root system could increase the survival and early growth rates of plants after transplanting. Kozlowski (35) indicates that many small absorbing roots in the upper layers constitute the primary water and nutrient absorbing surfaces. Translocation of photosynthate to the roots is substantially affected by the extent of root development (1). Radioactive carbon (^{14}C) was used to observe the nature of photosynthate transport in pine seedlings (Pinus strobus, P. resinosa). In plants with poorly developed root systems, the rate of translocation of photosynthate was shown to be low as compared to plants with well-developed root systems (54).

Root systems of trees consist of few relatively large perennial roots and many short-lived smaller roots. Kolesnikov (33) concluded that during each vegetative period a natural decay of roots occurs. This phenomenon is believed to effect the life of the root system and the general vigor of the plant.

The absorption of water and mineral nutrients for the plant is through the unsuberized portion of the root system. Generally, the intake of solutes from the soil and passage through the cortex to the stele is accomplished both by simple diffusion and by active physiological absorption against a concentration gradient (12). However, under some conditions, absorption must occur through the suberized portion of the root system. Furthermore, the suberized portion of the root system comprises the greatest portion of the

root system. It is believed that the suberized portion of the root system of trees and woody shrubs constitutes an important part of the absorbing system (4).

Suberization of roots, evident by the browning of elongating root areas behind the tip, occurs soon after their formation, within a few months (53). Acceleration of the suberization process may be caused by drying of the roots, high temperatures or other factors favoring oxidation. Kramer and Bulloch (39) found that a major part of the water absorption in loblolly pine (Pinus Taeda) and yellow poplar (Liriodendron tulipifera) occurs through suberized roots and mycorrhizal roots. Further studies indicated that absorption of water and mineral nutrients through suberized roots appears to be important in the water economy and mineral nutrition of woody plants (4). It is also believed that absorption through suberized roots is of some importance during the summer, particularly following summer drought which causes root elongation to cease. Kramer's (41) work with yellow poplar (Liriodendron tulipifera) and white pine (Pinus strobus) indicated that appreciable quantities of water can be absorbed through suberized roots, even through roots 1-2 centimeters in diameter and covered with a thick layer of bark.

Active root growth occurs throughout the year, however, the ratio of active to dormant roots vary with the season (1). Root elongation of most trees and shrubs almost entirely ceases during the cold or dry soil conditions (53, 29). There is a cyclic nature of root growth associated

with plants in the temperate zone. Generally, active root growth begins when soil temperatures become favorable for growth in the spring, and decrease or cease with the cooler soil temperatures in the fall (5, 16, 53). Root production is a function of the difference between the rate of growth and the rate of browning, both of which are affected by temperature in a similar manner. A reduction in root growth during the summer months is associated with a lack of water, a stress condition (5, 16, 36, 53). Head (19) notes this seasonal change on root growth by the measurement of white roots through visible panels near apple (Malus) and plum (Prunus) tree root systems. Maximum white root production occurred in May and again in August and September after shoot growth had ceased. White root production was reduced during periods of intense shoot growth on the apple (Malus) species. Branch pruning stimulated shoot growth and prolonged the reduction in new white root production in both species.

Kaufmann (29) studied the effects of water stress on the growth and water relations of loblolly pine (Pinus Taeda) and white pine (Pinus strobus) during a series of three drying cycles. As the soil water potential decreased, growth of roots, needles and buds decreased. The growth of roots during successive drying cycles was not uniform. The study showed that of the total root growth that occurred in three seven-day drying cycles, only six percent occurred in the third cycle. The difference was attributed to the

effect of water stress on the growing regions. When subject to a severe stress, roots matured toward the tip and became dormant.

A substantial portion of the unsuberized, rapidly elongating tissue is removed when a landscape plant is transplanted. Thus absorption of water through suberized root tissue is important during this time. The ability for a plant to initiate new roots or elongate existing roots at the time of transplanting is essential to insure survival of the plant. In a greenhouse forcing study with northern red oak (Quercus rubra), root regeneration was correlated with shoot growth, which began with increasing rapidity as the chilling requirements were met. Root regeneration, as reflected by the number of new root initials, of physiologically dormant northern red oak seedlings was limited (46). Lathrop and Mecklenburg (45) evaluated the annual cycle of root-regeneration potential of three-year old taxus (Taxus hunnewelliana) plants by recording the number of new root initials produced six weeks after bare root transplanting. During the summer (June-August), few root initials were produced, whereas increasing root regeneration potentials occurred in the fall (September) and reached a peak in January. This was followed by a decline in root regeneration potential through the spring and early summer. This annual cycle can be partially explained by root dormancy or root/shoot competition for photosynthate. The root system appears to be sensing the chilling necessary to break dormancy in taxus (Taxus cuspidata) roots (45).

Photoperiod and Shoot Growth

Variation in the length of day can control the duration of the growing season of certain tree species (15). The response to photoperiod (daylength) has been reported by Gardner and Allard as early as 1923 (60). Gustafson (16) described a situation where a street light caused an increased growing period in shrubs planted near it which prevented the wood from maturing and resulted in the stems being winter killed. The response to day length varies with species. Nitsch (50) suggests four different classifications of plants according to their photoperiodic response to long days and short days.

Group I: Plants grow continuously under days longer than 15 hours but stopped growing completely under day length of 12 hours or less:

a) Betula pubescens

b) Cercis canadensis

c) Platanus occidentalis

Group II: Plants stop growing under short days; under long days (20 hours or more) they make three to four flushes of growth interspersed with periods of dormancy in one year:

a) Picea abies

b) Quercus borealis

Group III: Plant growth continues under long and short days. However, long days cause a more rapid growth:

a) Juniperus horizontalis

b) Thuja occidentalis

Group IV: Plant growth is prolonged by long days but eventually dormancy sets in regardless of the daylength:

a) Buxus sempervirens

b) Syringe vulgaris

Vegetative processes in woody species which has been shown to be affected by day length include the duration of extension growth, internode extension, leaf growth and abscission (63). Exposure to short day conditions resulted in reduced elongation of the stem which may be attributed to earlier cessation of growth, reduced internode extension and the development of dormant buds.

Photoperiod and Root Growth

The rate of root growth appears to vary seasonally, with species, age of the tree and root environment. The period from spring to summer is one of elongating photoperiods followed by a period of decreasing photoperiods with a peak photoperiod in the summer. Root growth is regulated in part by the products produced by the shoots which varies in turn with the environment (1). Consequently, the photoperiodic affect on shoot growth may also be affecting root growth. The majority of plants used to study the affect of photoperiod on root growth are seedling material. There is a difference in the response of seedling and more mature plant material to photoperiod. Young and Hanover (72)

report that seedling spruce (Picea pungens) grown initially under natural conditions did not respond to extended photoperiodic treatment after reaching three or more years of age.

Under West Australian climatic conditions winter dormancy appeared to be the main seasonal influence on the root growth of young apple (Malus) trees. In older fruiting trees, root extension was most rapid in late spring and early summer, with a small peak in the fall. In both old and young trees, root growth was concurrent with shoot growth. This study suggests that the lack of root growth in the winter is due to the dormancy or absence of leaves and consequently the non-production of carbohydrates (5).

In a photoperiod study on the root growth with Spika spruce (Picea sitchensis) seedlings long days appeared to stimulate growth. Generally plants exposed to long days showed a constant rate of root elongation over an 81-day observation period. Root growth of seedlings transferred to short days decreased within two weeks. Short-day plants returned to long days paralleled long-day seedlings in respect to root growth even though top growth had ceased (55).

Hardiness of intact roots of Potentilla fruiticosa 'Katharine Dykes' and Picea glauca were determined during the autumn by Johnson and Havis (28). Both extended photoperiod and warm temperatures interferred with root acclimation to cold. Seasonally short days and near freezing temperatures were necessary for maximum rates of cold acclimation of roots in this study.

In a series of controlled environment studies with sugar maple (Acer saccharum) seedlings, the rate of root elongation appeared to be dependent, in part, on current photosynthate produced by the shoot. No shoot growth was observed under short day (eight hour) or long day (16 hour) conditions after previous exposure to short days. Under conditions of low light intensity, which altered the photosynthate production of the shoot, root elongation rates were reduced (66). Following defoliation or detopping of Eucalyptus regnans and E. verminalis root elongation stopped within four days (70). Complete defoliation of nine- and ten-year old apple trees four to six weeks before natural leaf fall, greatly reduced root growth for the remainder of the year (38). When photosynthetic activity is suppressed in the shoot, root growth is greatly restricted (1, 20, 38, 66, 70).

Under constant long days actively growing Acer saccharum seedlings continued to grow normally, whereas root growth was reduced. It appeared that shoot growth took place at the expense of root growth. A study of the seasonal pattern of apple (Malus) root growth suggests that the lack of growth in winter is due to the absence of leaves and the non-production of carbohydrates or dormancy. There appeared to be competition between roots and shoots for growth materials (66). A pruning study on northern red oak (Quercus rubra) indicated that shoot growth was significantly correlated with root weight when planted. Severely pruning the root system reduced the rate of shoot growth.

The best growth was achieved when there was a balance between the shoot and root systems. Severely pruning the root system also resulted in few new roots being produced as compared with moderately pruned root systems on red oak (Quercus rubra) (46).

Dormancy

The majority of temperate plants show a marked dormancy or rest phase during the annual growth cycle. This is usually accompanied by the development of resting buds. Protective scales may or may not be present during the quiescence period. Doorenbos (8) used the terms imposed dormancy, summer dormancy and winter dormancy to differentiate between the three basic types of physiological dormancy. These conditions may occur simultaneously in the course of a growing season.

Imposed dormancy or quiescence is caused by external factors, directly and reversibly imposed. It is imposed by the environment, i.e., cold or drought, and disappears as soon as conditions become favorable again.

Summer dormancy is caused by internal processes. These processes occur within the plant but outside of the bud. The environmental influence is indirect. Summer dormancy appears to be caused by a lack of stimulus from the roots or inhibiting influence from the leaves. Little is known about the nature of either the stimulus or inhibiting influence (8). Lateral bud summer dormancy is believed to be caused by inhibition influences from the terminal bud.

Auxins are known to be an important factor in the control of lateral bud dormancy, however, the specific mechanism is not known.

Winter dormancy, or rest, is caused by internal factors inside the bud. The environmental influence is indirect. A variety of methods to break winter dormancy exist, the two most common are photoperiod and cold treatment. It has been found by Gustafson (15) that if red pine (Pinus resinosa) seedlings are not exposed to freezing temperatures during the winter, they make little or no growth unless exposed to photoperiods of approximately 16 hours in spring and summer.

Where photoperiod affects dormancy, it appears that short days will hasten and long days will delay the onset of imposed dormancy at any season. The short day induced dormancy in the northern hemisphere species is often broken by a prolonged chilling (64). Under long days, the onset of dormancy (winter dormancy) can be delayed and if the day length is above the critical daylength growth may be maintained for extended periods of time. Wareing (63) reports that growth was maintained for 18 months under extended photoperiods and favorable temperatures with yellow poplar (Liriodendron tulipifera) and black locust (Robinia pseudoacacia). It was found that in order to break dormancy induced by short days, both the buds and the leaves must be exposed to long days.

Apparently, leaves maintained under short days of European beech (Fagus sylvatica) have an inhibiting effect on bud growth. In some cases, the chilling requirement may be overridden by long photoperiods. Exposure of buds of leafless seedlings of European beech to long days resulted in bud break (62). Long photoperiods created with supplemental lighting did not stimulate bud break in physiologically dormant red oak (Quercus rubra) (11). In a series of experiments, Wareing (62) concluded that when mature leaves are present, the buds themselves must be directly exposed to continuous illumination for the resumption of growth. The direct exposure of the buds cannot be substituted for by maintaining the leaves alone under continuous illumination. If the leaves are maintained under short days, however, normal expansion of the bud fails to occur even if the latter is exposed to continuous illumination. However, this inhibitory effect is not sufficient to suppress growth of an active apex maintained under long days (62). This series of experiments implicate that both the bud and the leaves play an active role in the perception of photoperiodic stimuli.

Where continuous growth is maintained with long days, a definite critical day length to control dormancy is recognized. Weigela florida and Acer rubrum have a critical day length between 12 and 14 hours. A day length below 12 hours causes the plants to cease growth while continuing to grow indefinitely with photoperiods of 14 hours or more (60). The critical day length varies with the species.

The duration of the daily dark period appears to be the major factor regulating photoperiodic response (60). In many species, the short day/long night cycle will not induce dormancy when the dark period is below the critical level or interrupted near the middle of the night by a break of relatively low light intensity. The length of the dark period and the light intensity during the night break is dependent on the species (49). Temperature may also effect the nature of the response to photoperiod (20, 36, 53). The greatest height, needle number and total green weight growth was with long photoperiods (12-20 hours) with 40 foot candles of artificial light beyond the natural day length and cooler temperatures (56°F) with Scotch pine (Pinus sylvestris). Longer photoperiods increased the rate of bud burst at temperatures of 14°C and 20°C on douglas fir (Pseudotsuga menziesii) (3).

Photoperiod, Root Growth and Birch Species

The photoperiodic conditions to which an active shoot apex is exposed to can have a direct effect upon the nature of growth of that apex. Species closely related to European birch (Betula pendula) are affected by photoperiod (50). In a series of photoperiodic experiments with B. pubescens seedlings, Wareing (62) found that the formation of resting buds was induced by short-day treatment and elongation continued with constant illumination. It appears that photoperiodic perception is in the shoot apex (60, 63). To bring about a resumption of growth in dormant, leafy seedlings of

B. pubescens, Wareing (62) found that both the buds and the leaves must be exposed to long days. With actively growing seedlings of the same species, he found the response of the apical bud was directly controlled by the photoperiod it is exposed to regardless of the day length that the leaves were exposed to.

Many birch species are sensitive to the amount of illumination given them (42, 51) in addition to extended photoperiods. The growth of paper birch (B. papyrifera) and European white birch (B. verrucosa) was greatly accelerated by extended photoperiods and high light intensities. A series of illumination experiments with high light intensities (2,500 ft. candles) and long days (16 hours) were conducted with B. papyrifera seedlings. Growth was extended and accelerated with these conditions. High light intensities produced plants which were six times as tall and lateral shoots containing seventeen times as much dry matter as plants grown under natural day length supplemented with 200 ft. candles of light under similar photoperiods (42).

The length of the daily photoperiod also has a quantitative affect on photoperiodically induced dormancy with birch species. Dormancy is capable of a full gradation in depth. Kawase (30) found the degree of dormancy depends on the number of successive photoperiods which are shorter than a critical threshold. It becomes increasingly more difficult to break short day induced dormancy with long days as the number of short days increases, once visible growth has

ceased (30). Evidence is available (7, 36, 53) that the regulation of bud dormancy is a balance and interaction among indogenous growth promoters and inhibitors. Inhibitors appear to play an important role in the development of dormancy. The breaking of dormancy appears to be associated with the activity of growth promoters. Domanski and Kozlowski (7) found that under short day conditions, the leaves of many woody species (Betula and Populus) inhibit the growth of the shoot apex. Greater amounts of inhibitors are found in the leaves and buds under short days than under long days. When inhibitors were extracted from the leaves of a dormant plant and reapplied to actively growing plants of the same species, shoot elongation ceased and development toward a dormant state was initiated.

There is a distinct pattern of seasonal variation in leaf nutrient levels as exhibited by major elements in a foliage composition study with yellow birch (Betula alleghaniensis) (25). Nutrient levels (Nitrogen, Potassium and Sulphur) increased during leaf expansion in June. The levels remained steady until late September, then began to fall off prior to leaf abscission. Further nutrient studies by Hoyle (25) with yellow birch found that the nature of the root system is highly dependent on the soil type. Nitrogen deficiencies inhibited root growth. A nutrient deficient sub-soil resulted in a shallow root system.

Little information is available on the nature of root growth of birch species. Birch root systems were found to

have a horizontal branching pattern and could be related to soil type on which they grew. On poor soil sites the roots grew radially and were sparcely branched. As the soil composition improved, the amount of branching increased (24).

Injury to a root tip modifies the process of lateral root formation and the subsequent lateral root growth (23). Tip injury was found to affect the nature of the branching which occurs in the root system of paper birch (B. papyrifera). Following the removal of at least 2.0 mm of the root apex, large diameter lateral replacement roots are formed behind the injured area. These replacement tips become a permanent part of the woody portion of the root system. Removal of the apex also permits primordia formed before the injury and normal lateral roots to grow out rapidly. In a second study, the analysis of paper birch root systems showed the fate of a root tip is related to its relative primary xylem diameter (PXD) (dimensions of the first annual ring and number of proto xylem poles) of the root (24). In seedling root systems, the primary root and first formed laterals are initially about the same size and their PXD all enlarge with increasing distance from the stem as the tips elongate to form the initial horizontal wood of the root system. Permanent lateral root branches with a large relative PXD develop after root tip injury. Abnormal development of primary xylem tissue proximal to injury surface aids in identifying injury caused branching (23). This evidence implicates the existence of some form of apical dominance in birch root systems.

Summary

In general, a short photoperiod induces a reduction in growth of birch (Betula) species through a shortening of internodes and a decreases in the number of new nodes formed. These same plants grow continuously under long photoperiods. Breaking dormancy induced by short photoperiods has been accomplished by both long photoperiods or chilling. When leaves remain on the plant and are subjected to short days after visible growth has stopped, dormancy becomes increasingly more difficult to break (9).

Objective

The objective of this research was to determine the effect of photoperiod and defoliation on the root growth of Betula pendula, a day length sensitive species. This information would then be used to improve commercial transplanting of this species.

MATERIALS AND METHODS

The treatments imposed upon the test plants were designed to observe the effect photoperiod and defoliation had on the root growth of a day length sensitive plant (B. pendula). Measurements were taken weekly on both the shoots and roots to observe the treatment effects. While the nature of the shoot growth is an indication of the physiological state of the plant, little is known about how the root system reacts during a particular physiological condition of the shoot.

The root chamber system utilized in this study was adopted from H. C. de Sitgter (6). This water culture system was modified for use with woody ornamental plant material. The chamber itself was made from black plexiglass (Rohn and Haas Co.), 18 inches long (45.7 cm), 12 inches wide (30.5 cm) and 2 inches high (5 cm). The bottom was made from material 1/8 inch thick (.33 cm), the sides from material 1/4 inch thick (.6 cm). A removable aluminum lid was made to fit securely over the box opening. The ends of the lid were bent over the sides for more complete light exclusion. Each root chamber was virtually light tight.

A plexiglass plant holder supported the stem of the plant while in the root chamber. This plant holder was made

from 1/4 inch (.6 cm) thick plexiglass and secured to the top of the box with a slot cut in it for plant insertion. The top of the holder was covered with reflective aluminum tape. Each stem was cushioned with a piece of pliable vinyl tubing for protection against injury by the holder. The slot for insertion was covered with a piece of black plastic tape after the plant was in place to prevent light penetration into the box.

The bottom of the box was lined with black acetate cloth. A dilute nutrient solution was supplied to the plants by trickle irrigation adopted from Kenworthy (32). The solution dripped continuously from the feeder tubes onto the acetate cloth. The solution was dispersed over the entire box area by capillary action in the cloth. Tubing .025 (.06 cm) P.V.C. (polyvinyl chloride) diameter was used for the feeder tubes into the boxes off of the main supply lines. A twelve gallon per hour (G.P.H.) flow valve provided approximately one liter per hour to each plant. The system required no other controls other than a constant water supply. The nutrient solution supplied to the plants was alternated weekly between two fertilizer solutions of 100 parts per million (p.p.m.) concentration of nitrogen (N). Peters fertilizer (Allentown, Pennsylvania) with an analysis of 20-20-20 and 25-0-25 plus soluble micro nutrients were used.

The water was filtered through an Aqua-pure A X P dirt/rust filter prior to entering the system. The water passed through a density graded body of cellulose fibers

during the filtering process. The fibers in the filter became more dense at the core. The root boxes were placed on the benches on a slight angle to allow the excess water and nutrients to drain to the lower front of the container. A drainage hole was provided for the removal of the excess material. The excess was discarded to the sewer system. The root chambers were situated in both a north/south and on an east/west orientation.

Seeds from European birch (Betula pendula) were obtained from the stock block of John Zelenka Nursery, Grand Haven, Michigan. The nursery is located in southwestern Michigan in Ottawa County. Once harvested, the seed was stored in a refrigerated cooler at 2°C (35°F) until sown for germination. The seeds were germinated in flats in an artificial soil mix (Metro-Mix, G. J. Ball Co., West Chicago, Illinois) and grown in the greenhouse until transferred to the root chambers.

Bare root plants in full leaf were placed in the root boxes approximately ten weeks after germination. The lower leaves were removed approximately two inches up the stem for insertion into the plant holder. The plants were allowed to become acclimated in the root chambers for approximately two weeks. Each plant was trained to a single stem. As the lateral buds began to elongate, they were removed. No modifications aside from the experimental treatments were made to the root systems.

The environmental conditions of temperature and day length were controlled throughout the experiments. The greenhouse temperatures were generally maintained at 68± 5°F (20°C). The greenhouse utilized had no temperature modification system other than a series of automatic vents controlled by thermostats. Consequently, during the hot summer months, the greenhouse temperatures were considerably warmer than the ideal. Generally the temperatures within the root boxes were that of the air or slightly cooler (approximately 5°F). During the hotter days, the temperatures were about 5°F cooler than the greenhouse temperatures in the early evening through the late morning. Temperatures were between 5 and 15°F cooler than greenhouse temperatures during the early and late afternoon.

Jet black sheen mum shade cloth (Jednak Floral, Columbus, Ohio) was used to control day length. All plants received eight hours of natural day light and were then covered with black cloth. Once covered, the long day treated plants received two hours (11 p.m.-1 a.m.) of low intensity light in the middle of the dark period. The interrupted photoperiod was accomplished by providing light from 40 watt incandescent light bulbs hung above the plants. This procedure resulted in approximately 20-25 foot candles of light.

Treatment observations were made on a weekly basis. Both shoot and root elongation was recorded. The shoot elongation was measured in total neight of the plant in centimeters. The root elongation was measured as centimeters

of new elongation of the elongating root tip. This was accomplished by placing a small plastic ruler near the elongating tip and noting the change in length. Since there was a thin layer of water held in the black cloth lining the box, the ruler was held securely in place. There was little chance of the ruler moving from its position between observations.

General maintenance to the experimental equipment was in two major areas; weekly and periodically. The weekly maintenance included a complete flushing of the water lines and cleaning or changing the water filter. This was done to remove any dirt and rust which may have accumulated in the lines after the water was filtered. The plant stems were trained to one stem and any elongating lateral buds were removed weekly. A fine film of iron rust would accumulate on the roots and the cloth lining. The root chamber would be washed with a fine mist of water from a Hudson (Batavia, New York) sprayer. Special attention was given to avoid any movement or damage to the root system. The root chambers were washed thoroughly between experiments.

A periodic insect control program was utilized in this study. The greenhouse was fumigated every 10 to 12 weeks with Tedeon for general insect control. A direct spray of Pentax was applied to all plants as needed to control insects on the plants not controlled by the fumigation.

The experimental design was a split plot with the whole plots either in completely randomized or a factorial

arrangement. Initially, the plants were graded into uniform size groups and randomly assigned to the treatments. However, in later studies, more seedlings were available of a uniform size for random assignment to the treatments. There were approximately 120 root boxes utilized in this study. Each experiment was evaluated to best utilize the boxes available and achieve statistical significance. Only those treatment means which are less than or equal to 5% probability will be discussed unless otherwise stated. All mean comparisons are based on either the L.S.D. and Tukey Q values.

Experiment 1

The effect of long day and short day conditions on shoot and root elongation was tested in experiment 1. The test was conducted from July 2 to August 20, 1975. Five groups of plants with 15 plants per group were grown under the following conditions: two under short days, two under long days and one control. A total of 75 experimental units were used and measured over an eight week period.

The experimental design was a split plot. Treatments were the whole plot with weeks as a repeated measure over time as the sub plot. The whole plots were arranged in a completely randomized design.

Experiment 2

A series of experimental treatments were applied to a group of plants to test the effect of day length, accumulated

day length and root pruning on shoot and root elongation. The study was conducted from August 21 through November 6, 1975. Plants were grown under both long and short day conditions. Within one day length regime, plants were grown under constant day length and transferred after two weeks to the opposite day length, i.e., constant long days, transferred to short days after two weeks. The transfer took place at the start of the experiment. Each of these groups were further divided on the basis of root pruning: pruned versus non-pruned. The root pruning was similar to that which would occur during transplanting. The plants were root pruned at the start of the experiment.

The experimental design was a split plot with treatment as the whole plot and the repeated measure (weeks) as the sub plot. The whole plots were a 2 x 2 x 2 factorial for a total of eight treatment combinations. There were three experimental units per treatment measured over twelve weeks.

Experiment 3A

The effect of accumulated short days necessary for the onset of dormancy was investigated in experiment 3A. The study was conducted from January 19 to April 19, 1976. Two, four, six and eight weeks of short days were given to four respective plant groups. After the designated period of short days, the plants were transferred back to long days, i.e., two weeks of short days transferred to long days.

The experimental design was a split plot with treatments (number of weeks of short days) as the whole plot and weeks as a repeated measure as the sub plot. The four treatments were arranged in a completely randomized design. There were eight experimental units per treatment over a fourteen week period.

Experiment 3B

The effect of complete, partial and no defoliation on shoot and root growth was tested in experiment 3B. The experiment was conducted between March 2 and April 19, 1976. Prior to the start of the experiment, all plants received two weeks of short days. The plants remained under short days throughout the entire experiment.

Various amounts of foliage were selectively removed from the plants. Defoliation of the plant was accomplished by removing the leaf blade. The petioles were left attached and allowed to abscise. Petiole abscission was complete two weeks after the leaf blade was removed. The defoliation levels were as follows: completely defoliated, every other leaf removed, one half of every leaf removed, one third of every leaf removed and non-defoliated.

The experimental design was a split plot with the treatments as the whole plot and weeks as a repeated measure as the sub plot. The whole plot was arranged in a completely randomized design. There were six treatments with eight experimental units per treatment over an eight week period.

Experiment 4

The effect of photoperiod, defoliation and root pruning on shoot and root elongation was investigated in experiment 4. The test was conducted between May 18 through August 7, 1976. The plants were divided into long and short day groups. Each day length group was subdivided into plants which were completely defoliated and those which were non-defoliated. These treatment groups were further subdivided into plants which were root pruned and plants which were unpruned. Defoliation was imposed at the end of the fifth week and root pruning at the end of the ninth week.

The experimental design was a split plot with the treatments as the whole plot and weeks as a repeated measure as the sub plot. The treatments were arranged in a 2 x 2 x 2 factorial. There were eight treatment combinations with eight experimental units per treatment measured over eighteen weeks.

Experiment 5

The effect of limiting photosynthetic activity to varying degrees as compared to partial and complete defoliation were tested in experiment 5. The experiment was conducted from October 5, 1976 through January 11, 1977. The plants were all grown under short day conditions throughout the experiment. The test plants either had their leaf blades selectively removed or selectively covered with aluminum foil. The treatments on each shoot included: two controls, the bottom half of the leaves removed or covered,

every other leaf removed or covered, the top half of the foliage on each shoot removed or covered, and completely defoliated or covered.

The experimental design was a split plot with treatments as the whole plot and weeks as a repeated measure as the sub plot. The whole plots were arranged in a completely randomized design with ten treatments and five experimental units per treatment measured over fifteen weeks.

Viability Testing

The viability of root tissue was evaluated by a refined Triphenyl Tetrazolium Chloride (TTC) test. Root tissue was evaluated for its viability according to the procedure described by Stephonbus and Lanphear (56, 57). The root tissue of dormant and actively growing roots was evaluated in this study.

RESULTS AND DISCUSSION

Experiment 1

Initially there was no difference between treatments and all shoots grew at approximately the same rate. As the time period progressed, the response to the short-day treatment became apparent; plants grown under short days had their shoot elongation suppressed by the end of the third week (Figure 2). Some shoot elongation occurred after the fourth week, however, this elongation was confined to the internode area. No new stem or leaf tissue was initiated. Terminal and lateral buds were formed by the end of the fourth week. Shoots under long days continued to elongate at a rather uniform rate (3.40 cm/week) until termination of the experiment.

There was no difference with respect to root elongation between long and short day treatments. Roots continued to elongate at approximately the same rate (6.70 cm/week) regardless of day length (Table 1).

Short days directly affected the vegetative processes by reducing the shoot and internode extension. The foliage remained on all plants throughout the experiment. However, the foliage on the short day plants assumed a firm leathery texture and a dark green color as compared to foliage on

actively growing long days shoots. There was no evidence of the leaf abscission process occurring. It appeared that the plants could remain in this condition for an indefinite period of time. The limiting factor causing the termination of the experiment was the size of the root system in relation to the size of the root chamber.

Experiment 2

The shoots of plants grown under constant long day continued to elongate (4.34 cm/week) throughout the experiment. Those plants grown under constant short days had their growth arrested after two weeks of short days. The onset of dormancy was evident by the cessation of growth and the formation of terminal and lateral buds.

Plants transferred from long days to short days had their growth arrested by the second week of the experiment (Figure 4). Two weeks of short days prior to transfer to long days appeared to be adequate to stop shoot elongation and promote the onset of dormancy.

The fact that shoots did not resume growth when plants were returned to long days can be explained partially by two theories. The low light intensities utilized in this study were not sufficient to override the dormancy induced by short days or two weeks of short days were sufficient to promote irreversible dormancy.

Root growth exhibited no significant difference due to day length. Difference between treatments was primarily due to the removal of active root tips during the root

pruning process (Figure 3). However, after new active root meristems were initiated, root elongation continued at a rate similar to those that were not root pruned (5.45 cm/ week pruned versus 6.26 cm/week unpruned). It took approximately two weeks for the establishment of new active root tips outside the pruned area.

Experiment 3A

There were no significant differences between treatments with respect to shoot elongation (Table 4). Two weeks of short days were sufficient to promote the onset of dormancy. After two weeks of short days shoot elongation had ceased and terminal and lateral buds were formed. Ten weeks of long days was not sufficient to break dormancy induced by two weeks of short days.

Root elongation was not significantly different with respect to treatment over time. Roots continued to elongate at a constant rate of 5.67 cm/week regardless of treatment.

Experiment 3B

Five levels of defoliation were found to effect the rate of root elongation on short day induced dormant shoots to varying degrees (Table 5). Removal of every other leaf blade and removal of one half of each leaf blade reduced the rate of root elongation by one third as compared to control. Complete defoliation almost completely stopped root elongation. All but a very few normally white active root tips ceased elongation and turned a brown color. In addition,

the root system took on a different appearance. The root system was much more pliable as compared to an actively growing root system.

Complete defoliation of a plant reduced the photosynthetic area. This reduction in photosynthetic activity causes a reduction in root elongation and promotes the onset of an apparent dormancy in the root system.

Experiment 4

Defoliation was found to significantly effect shoot elongation. Shoots grown under constant long days continued to elongate at a rate of 6 cm/week until defoliated at the sixth week. Following leaf blade removal, the rate of shoot growth was reduced to 1 cm/week (Figure 8). These plants continued this slower rate of shoot elongation until termination of the experiment. The slower rate of stem elongation was accompanied by the formation of lateral buds. At the termination of the experiment, terminal buds had formed and elongation was confined to the internode area. Shoots of control plants grown under constant long days continued to elongate throughout the experiment.

Plants grown under short days had ceased stem elongation at the end of the fourth week. Defoliation of these plants two weeks after stem elongation had ceased had no additional affect.

The interaction of root pruning and defoliation over time was found to be significant for root elongation. Defoliation of plant shoots effected the rate of root

elongation. One week after defoliation, the rate of root elongation was reduced to approximately 1 cm/week (Table 6). The cessation of root elongation following defoliation occurred on both long- and short-day plants. As in previous work, the white active root tips turned brown and ceased elongation. Following defoliation it was difficult to locate an active root apex and those which did remain active were of a thinner size as compared to those not defoliated.

Root pruning resulted in a further reduction in the rate of root elongation. Long-day and short-day plants not defoliated or root pruned had the greatest rate of root elongation. Long-day and short-day plants that were also defoliated and root pruned had their rate of root elongation curtailed for the remainder of the experiment (Figure 7).

Defoliation of actively elongating shoots caused a cessation of growth and promoted the onset of dormancy (Figure 8). Furthermore, defoliation of dormant shoots due to short-day induction or defoliation of actively elongating shoots caused a cessation in root elongation. Those plants which were not defoliated regardless of day length were least effected by root pruning. The rate of root elongation was reduced on all plants root pruned. Within one week after root pruning active root meristems were present on pruned tissue on non-defoliated plants. Root pruning of defoliated plants did not stimulate root elongation.

Experiment 5

Complete defoliation or covering of the foliage on short-day induced, dormant shoots resulted in the cessation of root elongation. Covering or removing the foliage on the bottom half of a plant or removing or covering every other leaf blade reduced the rate of root elongation 20% as compared to control. Covering or removing the foliage on the top half of a plant resulted in a rate of root elongation approximately 30% that of the control. Removing or covering the upper foliage resulted in a greater reduction in root elongation than removing or covering the lower foliage.

The treatment effect was apparent after the fourth week (Figure 10). The rate of root elongation was reduced in proportion to the amount of foliage removed and location of the foliage. Complete defoliation or covering of the foliage resulted in the normally white active root tips turning a dark brown color and the entire root system becoming more pliable as compared to the control.

This phenomenon can be partially explained by the fact that any amount of covering or defoliation reduces the photosynthetic activity. This reduced rate of activity is apparently effecting the root system, by modifying the rate of root elongation. It was only after the complete defoliation or coverage of the foliage did the root system cease elongation and become dormant. Partial coverage of the terminal portion of the shoot did reduce the rate of root elongation. Covering or removing the foliage on the top

half of the plant reduced the rate of root elongation more so than did covering or removing half of the foliage in the every other pattern. This tends to indicate that the leaves on the terminal portion of the shoot effects the rate of root elongation more than the foliage on the lower portions of the shoot.

Viability Testing

The TTC test on root tissue was not significantly different with respect to treatment. The procedure effectively indicated the viability of the root tissue but comparison of the percent of live tissue between treatments was difficult. The difficulty encountered was due to the inability to obtain uniform root tissue samples. The weight of root tissue of the same length could vary 100 percent.

However, it is interesting to note that viable root tissue was present in all treatments whether the roots appeared to be actively growing or not, indicating that live tissue was present on all root systems. Live tissue was present in varying degrees from the apical root tips back to secondary thickened root tissue.

Summary and Conclusions

The day length treatment resulted in a significant difference between long-day and short-day treatments in relation to shoot elongation. Short days (eight hours of natural light) caused a cessation in shoot elongation and promoted the onset of dormancy. Day length did not appreciably effect the rate of root elongation.

Transferring plants from short days to long days was not effective in stimulating shoot elongation. Two weeks of short days effectively arrested shoot elongation and promoted dormancy. Root elongation under all day length transferred conditions was not significantly different on foliated plants. Roots continued to elongate regardless of day length or the number of weeks of exposure.

Root pruning of foliated plants suppressed the rate of root elongation until active root apexes were again initiated regardless of the day length treatment. Once active root apexes were initiated, the rate of root elongation was similar to those plants not root pruned.

Complete defoliation of long-day shoots resulted in a cessation of shoot elongation. Root elongation rates were effected in proportion to the degree of defoliation. Partial removal of each leaf blade or removal of every other leaf blade resulted in a partial suppression of root elongation. Complete defoliation resulted in a total cessation of root elongation on both long- and short-day plants. The active root apexes stopped elongating and turned a brown color. The entire root system was softer to the touch and more pliable as compared to the root system of foliated plants.

Covering the foliage on short-day induced, dormant plants limited the rate of photosynthesis and produced results similar to those plants that had been defoliated. Partial covering of the foliage resulted in a suppression of

root elongation as compared to those not covered. Complete covering of all leaf blades resulted in a cessation of root elongation. The root system resembled that of the completely defoliated plants.

These results may explain, in part, why birch trees are not commercially transplanted in the fall to any great extent. The root system becomes dormant following defoliation in the fall and there is not time for the establishment of the root system on a transplanted tree, leading to the eventual death of the plant. The most effective time to transplant European birch is in the spring just prior to growth. Furthermore, when transplanting foliated material, removing the foliage during the transplanting process would be detrimental to the survival and establishment of the plant.

Future work in the area of root dormancy is essential. Little information is available on temperature requirements and temperature sensing by the root system. Investigation ofthe effect of day and night temperature differential on root elongation and dormancy is needed. The root system appears to be capable of dormancy following defoliation. An investigation including the removal of buds in addition to leaf removal could lead to new information related to root dormancy. There is a need to understand the annual root elongation cycle and how it relates to shoot elongation.

TABLES

Table 1. The Effect of Photoperiod on Root and Shoot Elongation. Root elongation was measured in centimeters of weekly, new elongation. Shoot elongation was a cumulative measure in centimeters. The treatments were Long (LD), Short (SD), and Natural daylengths (C). Any two means in the same column having the same letter are not significantly different from each other by Tukey's test at the 5% level. $Tukey_{(.05)(Roots)} = 3.97$; $Tukey_{(.05)(Shoots)} = 7.28$

Root Elongation

Treatment	Weeks 1	2	3	4	5	6	7	8
1) LD	3.81a	5.94a	7.75a	7.08a	8.01a	8.31a	8.69a	4.38a
2) SD	4.03a	6.68a	9.32a	7.05a	5.55a	8.02a	8.14a	4.87a
3) SD	6.50a	9.30a	9.72a	7.39a	5.94a	8.71a	8.30a	7.39a
4) LD	5.40a	7.62a	6.75a	6.52a	4.14a	6.84a	7.78a	7.42a
5) C	4.50a	7.88a	10.70a	5.88a	4.50a	6.58a	7.50a	8.81a

$Tukey_{(.05)} = 3.97$

Shoot Elongation

Treatment	1	2	3	4	5	6	7	8
1) LD	4.11a	6.56a	8.66a	12.38a	16.98a	19.30a	21.67a	29.69a
2) SD	4.48a	7.54a	9.04a	10.42a	11.78a	12.56a	12.31b	12.78b
3) SD	4.32a	6.79a	7.79a	8.26a	8.69b	9.36b	10.24b	10.70b
4) LD	4.32a	6.98a	8.90a	11.49a	14.20a	17.44a	21.60a	26.37a
5) C	4.26a	7.00a	8.69a	11.69a	13.58a	17.98a	21.66a	26.60a

$Tukey_{(.05)} = 7.28$

Table 2. The Effect of Root Pruning on Root Elongation. The measurements were taken in centimeters of weekly new root elongation. The values were averaged over daylength and day length transferral treatments. Any two means in the same column having the same letter are not significantly different from each other by LSD at the 5% level. $LSD_{(.05)} = 2.91$

	Weeks					
Treatment	1	2	3	4	5	6
Pruned	0.00b	2.92b	5.25a	3.88a	5.32a	5.53a
Unpruned	4.68a	5.85a	4.72a	5.27a	5.74a	6.42a
	7	8	9	10	11	12
Pruned	6.20a	4.62a	5.12a	5.20a	5.08a	8.32a
Unpruned	5.82a	6.98a	5.62a	4.65a	8.11a	9.22a

$LSD_{(.05)} = 2.91$

Table 3. The Effect of Daylength and Daylength Transferral on Shoot Elongation. The treatments were: constant long days, constant short days, two weeks of long days then trasnferred to short days and two weeks of short days then trasnferred to long days. Any two means in the same column having the same letter are not significantly different from each other by LSD at 5% level. $LSD_{(.05)} = 12.23$

Long Days

	Weeks					
Treatment	1	2	3	4	5	6
Transferred (1)	9.62b	9.82b	10.00b	10.96b	11.58b	12.60b
Not Trans. (2)	21.87a	27.20a	31.40a	34.23a	41.18a	46.98a

	7	8	9	10	11	12
(1)	13.30b	14.40b	15.91b	17.65b	19.51b	22.08b
(2)	52.10a	56.43a	61.08a	64.80a	69.13a	73.93a

Short Days

	Weeks					
Treatment	1	2	3	4	5	6
Transferred (1)	20.70a	24.80a	23.17a	26.30a	26.30a	26.15a
Not Trans. (2)	10.75a	11.00b	10.78b	10.75b	10.70b	10.77b

	7	8	9	10	11	12
(1)	26.13a	26.05a	26.10a	26.13a	26.12a	26.20a
(2)	10.72b	10.83b	10.80b	10.85b	10.82b	10.90b

$LSD_{(.05)} = 12.23$

Table 4. The Effect of Accumulated Short Days to Promote Dormancy. Treatments included: two weeks, four weeks, six weeks and eight weeks of short days and then transferred back to long days. Root measurements are in centimeters of new elongation. Any two means in the same column having the same letter are not significantly different from each other by Tukey's test at the 5% level.
$Tukey_{(.05)} = 4.62$

Root Elongation

Treatment	Weeks 1	2	3	4	5	6	7
2 Wks (1)	0.00a	5.29a	6.61a	6.94a	7.32a	4.12a	5.71a
4 Wks (2)	0.00a	6.82a	6.22a	5.71a	6.86a	5.45a	7.37a
6 Wks (3)	0.00a	8.77a	6.31a	8.55a	6.52a	8.24a	6.61a
8 Wks (4)	0.00a	5.25a	5.35a	3.87b	4.06a	4.42a	5.30a

	8	9	10	11	12	13	14
(1)	4.82a	4.47a	4.81a	3.89a	5.61a	4.44a	6.10ab
(2)	7.39a	4.20a	4.44a	7.00a	5.04a	7.96a	8.87a
(3)	3.66a	6.29a	5.36a	7.98a	3.54a	7.61a	4.52ab
(4)	3.47a	4.75a	6.36a	3.97a	4.54a	4.54a	2.87b

Table 5. The Effect of Partial and Complete Defoliation on Root Elongation. Measurements are in centimeters of new elongation. Treatments include: every other leaf removed (E.O. rem.), one half of each leaf removed (1/2 ea.), one third of each (1/3 ea.), control and defoliated (defol.).

	Weeks							
Treatment	1	2	3	4	5	6	7	8
E.O. Rem.	0.00	2.94	3.59	3.08	3.78	4.16	4.74	5.08
E.O. Rem.	0.00	4.21	3.26	5.06	4.69	3.88	2.90	5.91
1/2 ea.	0.00	2.90	5.78	4.60	3.54	4.22	4.22	4.89
1/3 ea.	0.00	5.12	6.86	6.46	6.84	5.39	8.61	6.13
Control	0.00	6.12	5.64	5.11	4.56	3.59	6.18	6.99
Defol.	0.00	.13	.17	.10	.09	.03	.00	.00

Table 6. The Effect of Daylength, Defoliation and Root Pruning on Root Elongation. Measurements are in centimeters of new elongation. Any two means in the same column having the same letter are not significantly different from each other by LSD at the 5% level. $LSD_{(.05)} = 2.90$

Table 6.

Short Days, Not Root Pruned

Treatment	Weeks 1	2	3	4	5	6
Foliated (1)	1.0a	4.46a	3.80a	5.17a	7.12a	4.45a
Defoliated (2)	1.0a	4.76a	3.62a	3.62a	5.70a	4.98a

	7	8	9	10	11	12
(1)	6.37a	4.57a	3.65a	4.43a	4.25a	4.70a
(2)	3.10b	1.12b	0.00b	0.00b	0.00b	.25b

	13	14	15	16	17	18
(1)	3.79a	4.42a	2.91a	2.51a	2.63a	7.0a
(2)	.50b	1.40b	.69a	2.77a	2.38a	2.33b

Short Days, Root Pruned

Treatment	1	2	3	4	5	6
(1)	1.0a	2.23a	2.65a	5.35a	5.87a	4.74a
(2)	1.0a	4.42a	6.72b	5.17a	7.28a	5.81a

	7	8	9	10	11	12
(1)	4.50a	3.75a	4.63a	5.09a	5.30a	4.82a
(2)	8.62b	1.02b	0.00b	0.00b	0.00b	2.06b

	13	14	15	16	17	18
(1)	3.77a	6.10a	2.01a	3.52a	3.87a	3.25a
(2)	2.33a	1.02b	.63b	.28b	1.40a	1.68a

Table 6. continued

Long Days, Not Root Pruned

Treatment	Weeks 1	2	3	4	5	6
Foliated (1)	1.0a	2.30a	4.42a	3.33a	5.91a	3.57a
Defoliated (2)	1.0a	5.31b	5.00a	3.91a	5.90a	3.92a
	7	8	9	10	11	12
(1)	6.64a	4.91a	5.40a	3.94a	4.95a	6.16a
(2)	5.57a	2.37a	1.31b	1.31b	1.32b	1.31b
	13	14	15	16	17	18
(1)	4.77a	3.92a	3.50a	4.67a	8.22a	8.25a
(2)	1.32b	3.37a	3.49a	2.01a	4.85b	6.47a

Long Days, Root Pruned

Treatment	1	2	3	4	5	6
(1)	1.0a	2.62a	5.01a	5.30a	5.25a	3.47a
(2)	1.0a	2.63a	2.77a	5.07a	4.94a	5.06a
	7	8	9	10	11	12
(1)	4.87a	4.85a	5.27a	3.64a	4.51a	6.11a
(2)	1.83b	1.34b	0.00b	0.00b	0.00b	1.00b
	13	14	15	16	17	18
(1)	4.42a	6.65a	3.91a	2.07a	5.03a	6.27a
(2)	1.20b	3.26b	3.25a	2.50a	2.92a	3.77a

Table 7. The Effect od Daylength, Defoliation and Root Pruning on Root Elongation. Measurements are in centimeters of new elongation. Treatments included: long days (LD), short days (SD), root pruned (r.p.), not root pruned (n.p.), foliated (fol.) and defoliated (Def.). Any two means in the same column having the same letter are not significantly different from each other by Tukey's test at the 5% level. $Tukey_{(.05)} = 2.31$

Table 7.

Treatment	Weeks 1	2	3	4	5	6	7	8	9
SD N.P.									
Fol.	1.0a	4.46ab	3.80bc	5.17a	7.12ab	4.45ab	6.37ab	4.57ab	3.65ab
Def.	1.0a	4.76ab	3.62bc	3.62a	5.70ab	4.98ab	3.10c	1.12c	0.00c
SD R.P.									
Fol.	1.0a	2.23c	2.65c	5.35a	5.87ab	4.74ab	4.50b	3.75ab	4.63a
Def.	1.0a	4.42ab	6.72a	5.17a	7.28a	5.81a	8.62a	1.02c	0.00c
LD N.P.									
Fol.	1.0a	2.30bc	4.42abc	3.33a	5.91ab	3.57ab	6.64ab	4.91a	5.40a
Def.	1.0a	5.31a	5.00ab	3.91a	5.90ab	3.92ab	5.57b	2.37abc	1.31c
LD R.P.									
Fol.	1.0a	2.62bc	5.01ab	5.30a	5.25ab	3.47b	4.87b	4.85a	2.27bc
Def.	1.0a	2.63bc	2.77bc	5.07a	4.94b	5.06ab	1.83c	1.34c	0.00c

Table 7. continued

Treatment	Weeks 10	11	12	13	14	15	16	17	18
SD N.P.									
Fol.	4.43a	4.25a	4.70	3.79a	4.42ab	2.91bc	2.51abc	2.63cde	7.0a
Def.	0.00b	0.00b	.25	.50b	1.40cd	.69c	2.77abc	2.38de	2.33b
SD R.P.									
Fol.	5.09a	5.30a	4.82	3.77a	6.10a	2.01c	3.52abc	3.87bcd	3.25b
Def.	0.00b	0.00b	2.06	2.33b	1.02d	.63c	.28c	1.40e	1.68b
LD N.P.									
Fol.	3.94a	4.95a	6.16	4.77a	3.92ab	3.50b	4.67a	8.22a	8.25a
Def.	1.31b	1.32b	1.31	1.32b	3.37bc	3.49b	2.01c	4.85bc	6.47a
LD R.P.									
Fol.	5.27a	3.65a	4.51	6.11a	4.42ab	6.65a	3.91ab	5.03b	6.27a
Def.	0.00b	0.00b	0.00	1.00b	1.20d	3.26b	3.25abc	2.29de	3.37b

Table 8. The Effect of Daylength, Defoliation and Root Pruning on Shoot Elongation. The measurements are in centimeters of cumulative shoot elongation. Any two means in the same column having the same letter are not significantly different from each other by LSD at the 5% level. $LSD_{(.05)} = 16.36$

Table 8.

Short Days, Not Root Pruned

Treatment	Weeks 1	2	3	4	5	6
Foliated (1)	18.57a	22.47a	32.31a	34.74a	35.11a	39.44a
Defol. (2)	21.10a	26.31a	32.27a	40.47a	44.09a	44.56a

	7	8	9	10	11	12
(1)	40.60a	39.82a	39.80a	40.15a	40.25a	40.17a
(2)	44.71a	44.85a	45.87a	45.50a	45.56a	45.56a

	13	14	15	16	17	18
(1)	40.16a	40.21a	40.36a	40.25a	40.41a	40.41a
(2)	43.67a	43.86a	45.80a	45.81a	45.81a	45.13a

Short Days, Root Pruned

	1	2	3	4	5	6
(1)	18.27a	22.54a	27.79a	34.62a	38.34a	38.81a
(2)	16.97a	19.14a	21.19a	23.55a	24.21a	24.45a

	7	8	9	10	11	12
(1)	38.82a	38.85a	38.83a	39.08a	39.19a	39.21a
(2)	24.55a	24.71a	24.60a	24.75a	24.94a	25.20a

	13	14	15	16	17	18
(1)	39.12a	39.11a	39.27a	39.24a	39.30a	39.30a
(2)	24.94a	24.82a	25.37a	25.31a	25.31a	25.25a

Table 8. continued

Long Days, Not Root Pruned

Treatment	Weeks 1	2	3	4	5	6
Foliated (1)	13.31a	16.01a	19.92a	17.74a	22.74a	24.65a
Defol. (2)	17.01a	21.06a	25.70a	31.74a	35.87a	39.12a
	7	8	9	10	11	12
(1)	28.19a	30.89a	35.62a	41.25a	46.87a	51.43a
(2)	39.54a	40.31a	41.00a	41.93a	42.69a	43.64a
	13	14	15	16	17	18
(1)	54.47a	60.56a	67.87a	74.81a	81.62a	86.45a
(2)	44.06a	45.03a	46.00b	46.75b	47.69b	48.58b

Long Days, Root Pruned

	1	2	3	4	5	6
(1)	26.80a	30.36a	34.19a	40.02a	46.24a	48.60a
(2)	19.16a	23.63a	28.25a	34.66a	40.16a	42.92a
	7	8	9	10	11	12
(1)	53.06a	62.14a	68.94a	76.77a	81.87a	87.66a
(2)	43.95a	45.24b	46.41b	47.90b	48.97b	49.77b
	13	14	15	16	17	18
(1)	90.00a	96.50a	102.19a	104.57a	107.56a	110.75a
(2)	50.27b	50.84b	52.30b	52.81b	54.00b	54.91b

Table 9. The Effect of Partial and Complete Coverage or Defoliation on Root Elongation. Measurements are in centimeters of new elongation. Treatments include: control (1), all covered (2), bottom half covered (3), every other leaf covered (4), top half covered (5), all removed (6), every other leaf removed (7), bottom half of stem defoliated (8), top half of stem defoliated (9) and control (10). Only the leaf blades were covered or removed. Any two means in the same column having the same letter are not significantly different from each other by Tukey's test at the 5% level. $Tukey_{(.05)} = 3.53$

Table 9.

Treatment	Weeks 1	2	3	4	5	6	7	8
(1)	0.00a	4.74b	5.74a	5.92a	7.30a	6.42a	5.92b	3.26b
(2)	0.00a	4.80b	5.46a	6.02a	1.98b	0.00c	0.00d	0.00b
(3)	0.00a	2.08b	4.58a	4.56a	3.20b	2.48b	3.96c	3.06b
(4)	0.00a	5.96a	4.24a	4.38a	4.12b	2.58b	5.96a	3.80a
(5)	0.00a	2.44b	4.70a	3.90a	1.02c	0.06c	2.22c	1.46b
(6)	0.00a	4.36b	5.36a	5.54a	1.10c	0.00c	0.00d	0.00b
(7)	0.00a	6.22a	4.50a	5.60a	4.26b	3.16b	5.04c	3.96a
(8)	0.00a	4.80b	4.80a	5.68a	4.94b	4.82a	5.48c	4.44a
(9)	0.00a	3.96b	6.46a	4.78a	2.60b	1.02b	2.20c	2.10b
(10)	0.00a	1.52b	3.98a	2.78a	3.94b	2.52b	3.70c	2.78b

Table 9. continued

Treatment	Weeks 9	10	11	12	13	14	15
(1)	1.12a	2.20b	3.72a	4.44a	3.30b	4.20a	11.64a
(2)	0.00a	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b
(3)	2.14a	1.36b	2.16b	3.58a	1.46b	1.62b	2.86b
(4)	1.94a	1.42b	1.20b	2.24b	3.92a	2.90b	3.12b
(5)	1.94a	1.28b	.78b	1.26b	.74b	.44b	.82b
(6)	0.00a	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b
(7)	1.98a	1.56b	1.30b	1.92b	.76b	1.74b	3.00b
(8)	3.46a	4.36b	3.22b	2.16b	3.80a	2.76b	1.28b
(9)	1.60a	2.28b	2.02b	1.04b	1.92b	4.26a	.90b
(10)	.70a	1.64b	1.28b	1.50b	2.02b	2.54b	1.18b

Table 10. The Effect of Partial and Complete Coverage or Defoliation on Shoot Elongation. Measurements are in centimeters of cumulative shoot elongation. Treatments included: control (1), all covered (2), bottom half covered (3), every other covered (4), top half covered (5), all removed (6), every other removed (7), bottom half of stem defoliated (8), top half of stem defoliated (9), control (10). Only the leaf blades were removed or covered.

Table 10.

Treatment	Weeks 1	2	3	4	5	6	7	8
(1)	24.40	26.92	27.88	27.98	27.90	28.00	27.90	27.90
(2)	23.72	25.24	26.20	26.38	26.30	26.30	26.40	26.40
(3)	25.18	26.64	27.40	27.60	27.60	27.70	27.60	27.60
(4)	20.86	22.10	23.04	23.54	23.60	23.60	23.60	23.40
(5)	26.64	28.20	29.02	29.20	29.20	29.40	29.50	29.30
(6)	21.76	23.36	24.00	24.26	24.10	24.50	24.40	24.20
(7)	23.60	25.00	25.60	25.94	25.90	26.00	26.10	26.10
(8)	21.08	23.30	25.40	25.76	25.90	26.10	25.90	25.90
(9)	23.80	26.32	29.02	30.28	30.30	28.50	30.40	30.40
(10)	17.94	19.48	20.46	20.70	20.60	20.80	20.90	20.80

Table 10. continued

Treatment	Weeks 9	10	11	12	13	14	15
(1)	27.90	25.90	27.90	27.90	27.90	27.90	27.90
(2)	26.40	26.40	26.40	26.40	26.40	26.40	26.40
(3)	27.60	27.60	27.60	27.60	27.60	27.60	27.60
(4)	25.50	23.50	23.50	23.50	23.50	23.50	23.50
(5)	29.30	29.30	29.50	29.30	29.30	29.30	31.30
(6)	24.20	24.20	24.50	24.50	24.50	24.50	24.50
(7)	26.10	26.20	26.20	26.20	28.20	26.20	26.20
(8)	25.90	25.90	25.90	25.90	25.90	25.90	25.90
(9)	30.40	30.40	30.40	30.40	30.40	30.40	23.20
(10)	20.80	20.80	20.80	20.80	20.80	20.80	20.80

FIGURES

Figure 1. The effect of photoperiod on root elongation.

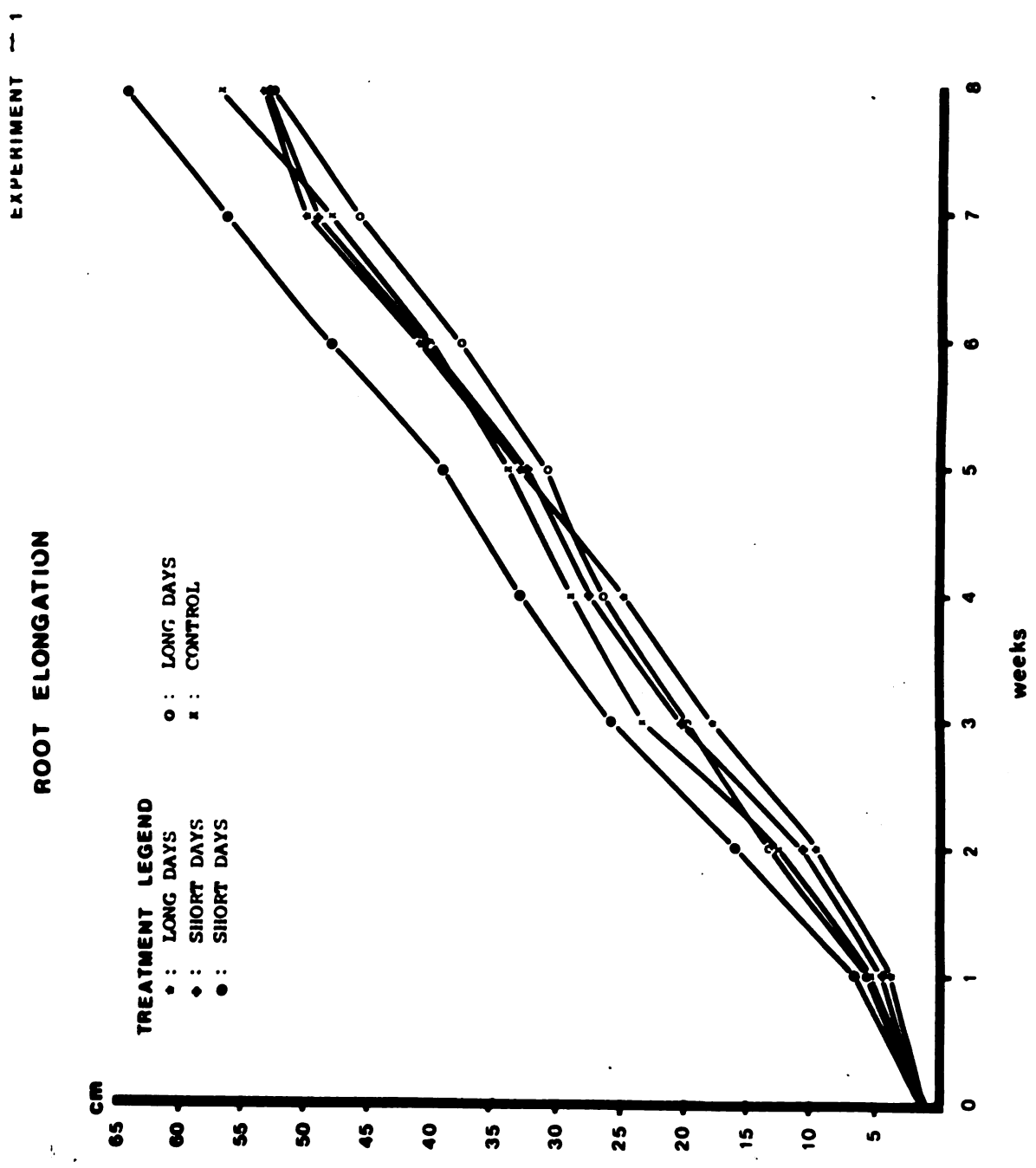
EXPERIMENT — 1
ROOT ELONGATION
TREATMENT LEGEND
• : LONG DAYS
◆ : SHORT DAYS
● : SHORT DAYS
o : LONG DAYS
x : CONTROL
cm
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
weeks

Figure 1.

Figure 2. The effect of photoperiod on shoot elongation.

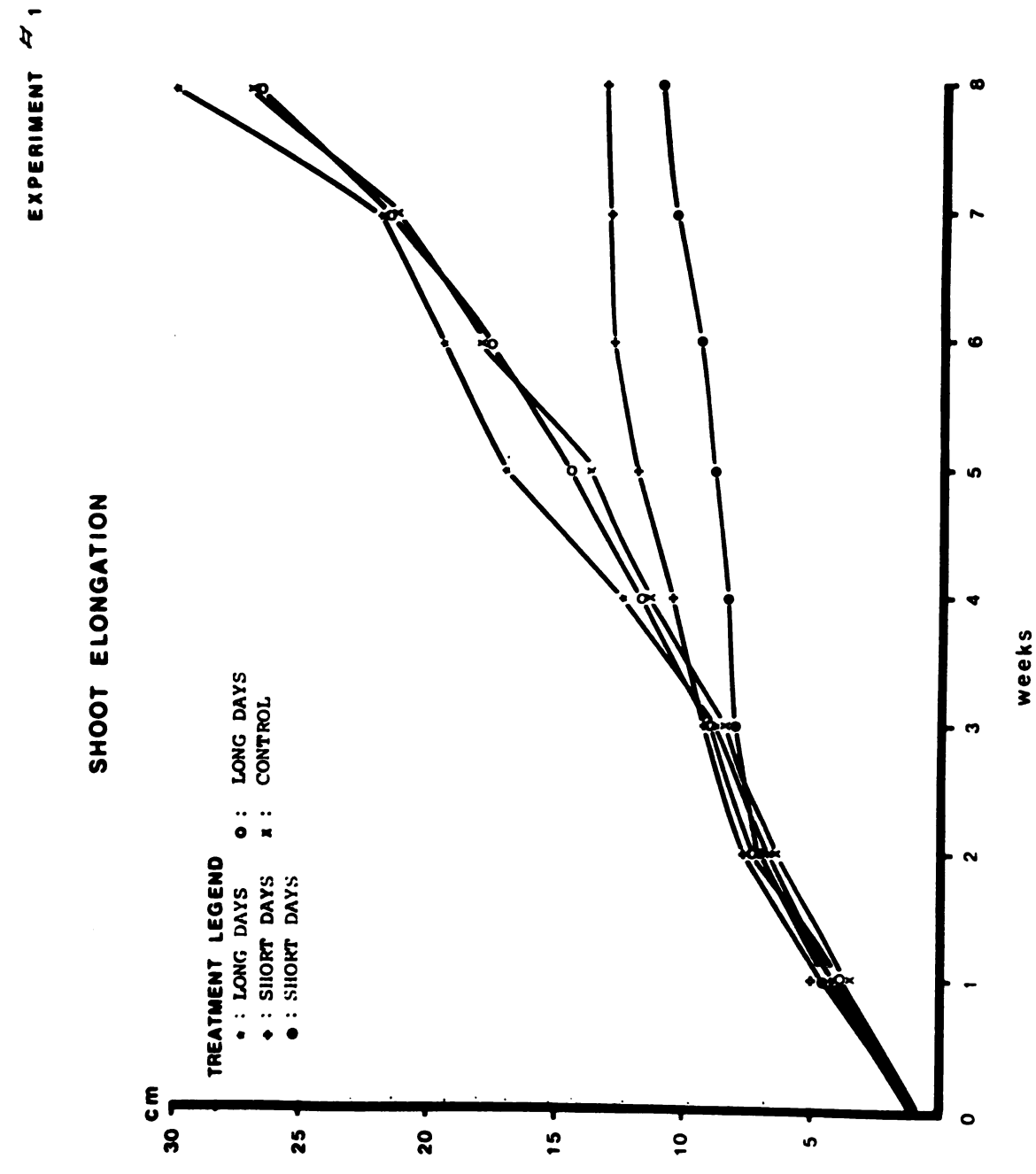
EXPERIMENT #1
SHOOT ELONGATION
TREATMENT LEGEND
• : LONG DAYS
◆ : SHORT DAYS
● : SHORT DAYS
o : LONG DAYS
x : CONTROL
cm
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
weeks

Figure 2.

Figure 3. The effect of root pruning on root elongation.

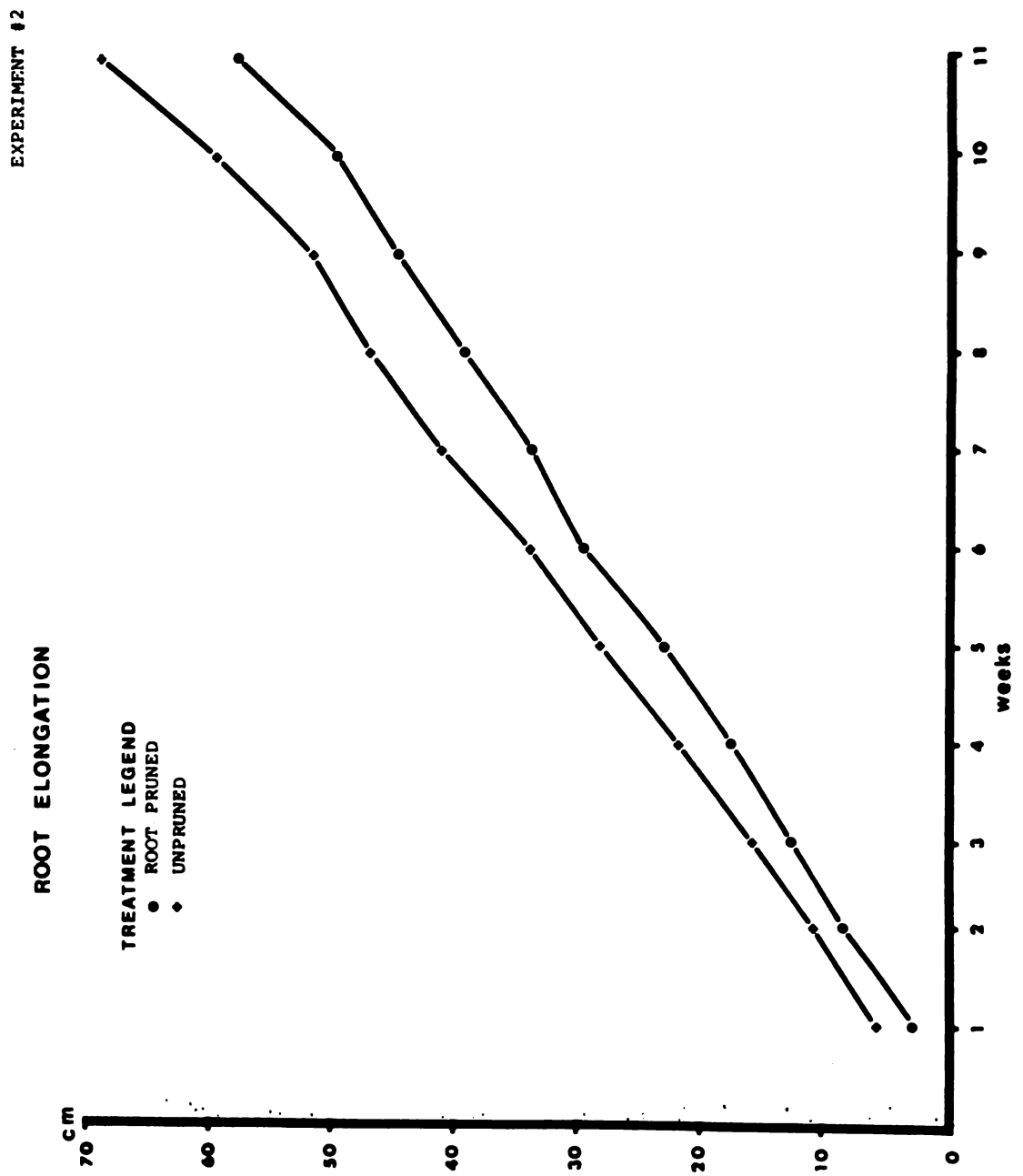
EXPERIMENT #2
ROOT ELONGATION
TREATMENT LEGEND
● ROOT PRUNED
◆ UNPRUNED
cm
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
weeks

Figure 3.

Figure 4. The effect of daylength and daylength transferral on shoot elongation.

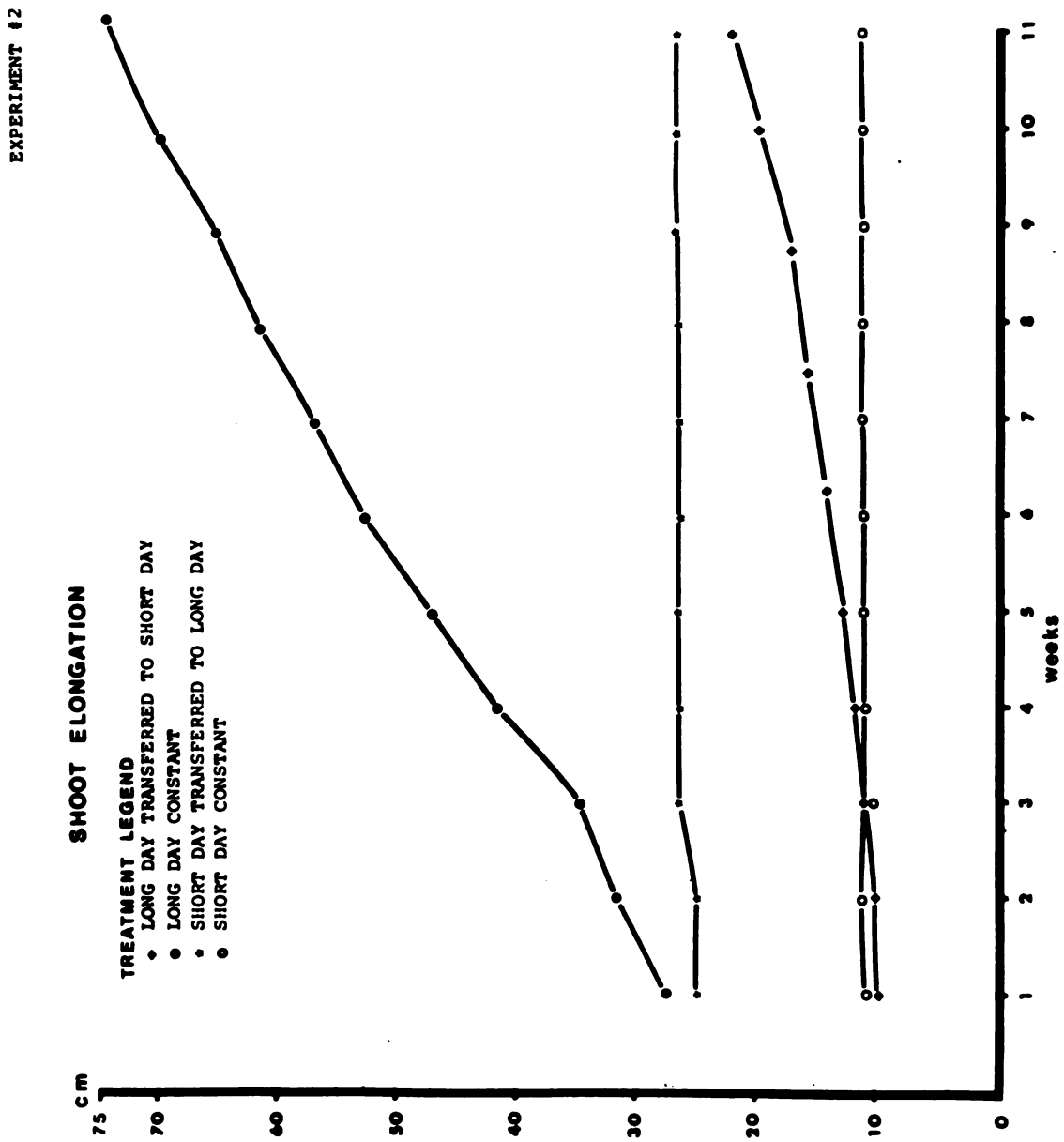
EXPERIMENT #2
SHOOT ELONGATION
TREATMENT LEGEND
LONG DAY TRANSFERRED TO SHORT DAY
LONG DAY CONSTANT
SHORT DAY TRANSFERRED TO LONG DAY
SHORT DAY CONSTANT
cm
75
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
weeks

Figure 4.

Figure 5. The effect of accumulated short days to promote dormancy on root elongation.

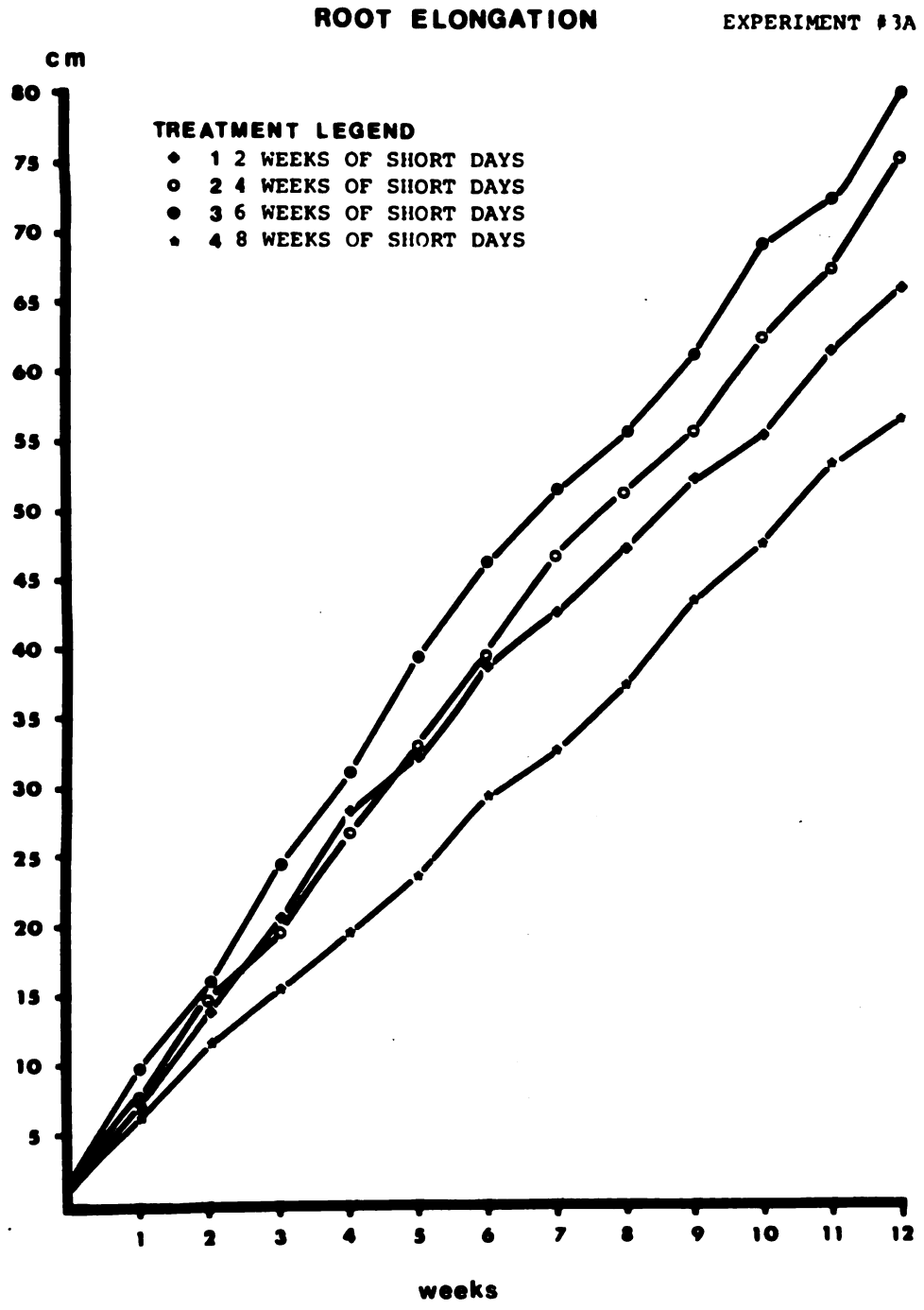
ROOT ELONGATION
EXPERIMENT #3A
cm
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
TREATMENT LEGEND
1 2 WEEKS OF SHORT DAYS
2 4 WEEKS OF SHORT DAYS
3 6 WEEKS OF SHORT DAYS
4 8 WEEKS OF SHORT DAYS
1
2
3
4
5
6
7
8
9
10
11
12
weeks

Figure 5.

Figure 6. The effect of partial and complete defoliation on root elongation.

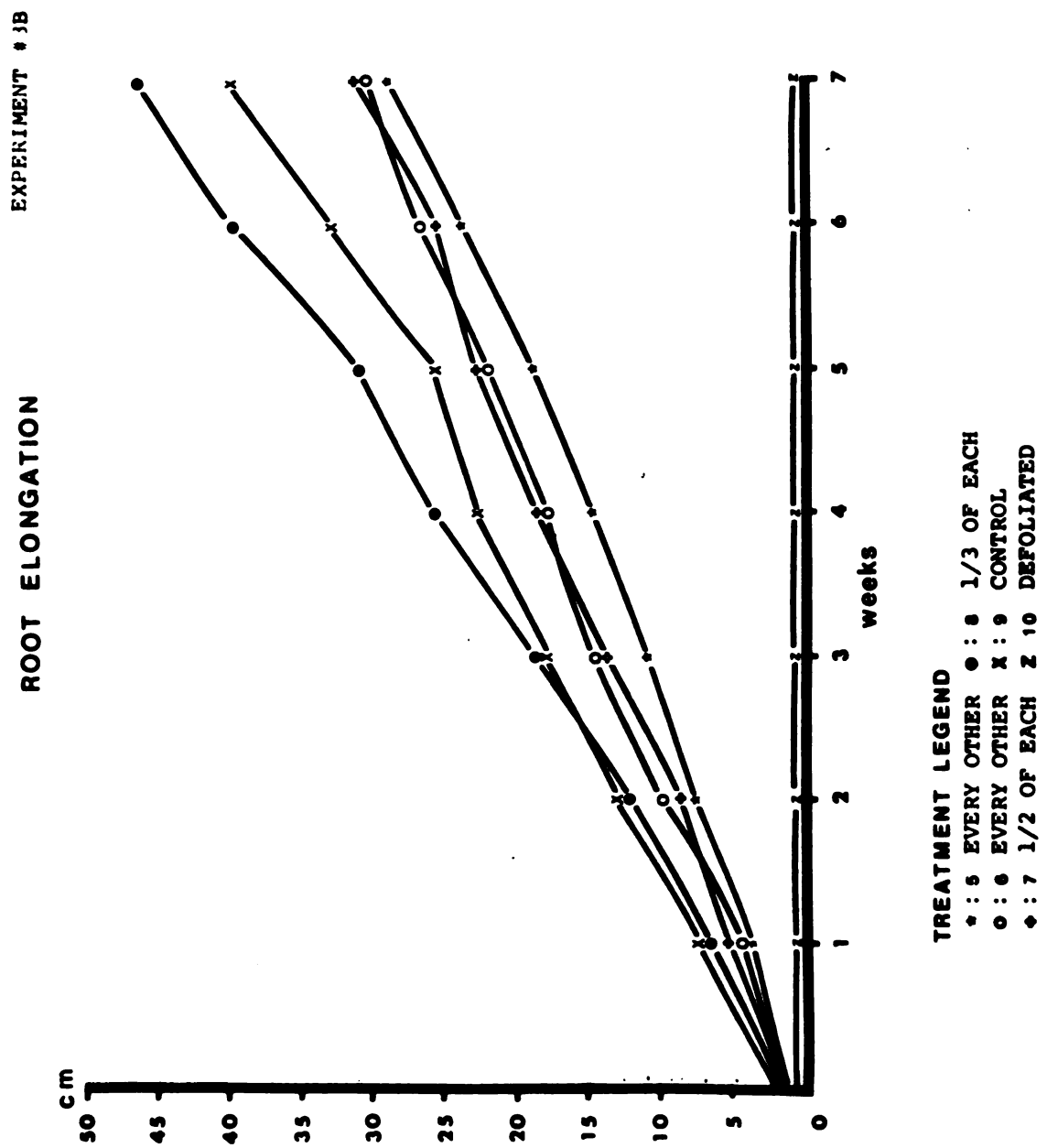
EXPERIMENT #3B
ROOT ELONGATION
cm
50
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
weeks
TREATMENT LEGEND
♦ : 5 EVERY OTHER ● : 8 1/3 OF EACH
o : 6 EVERY OTHER X : 9 CONTROL
◆ : 7 1/2 OF EACH Z 10 DEFOLIATED

Figure 6.

Figure 7. The effect of daylength, defoliation and root pruning on root elongation.

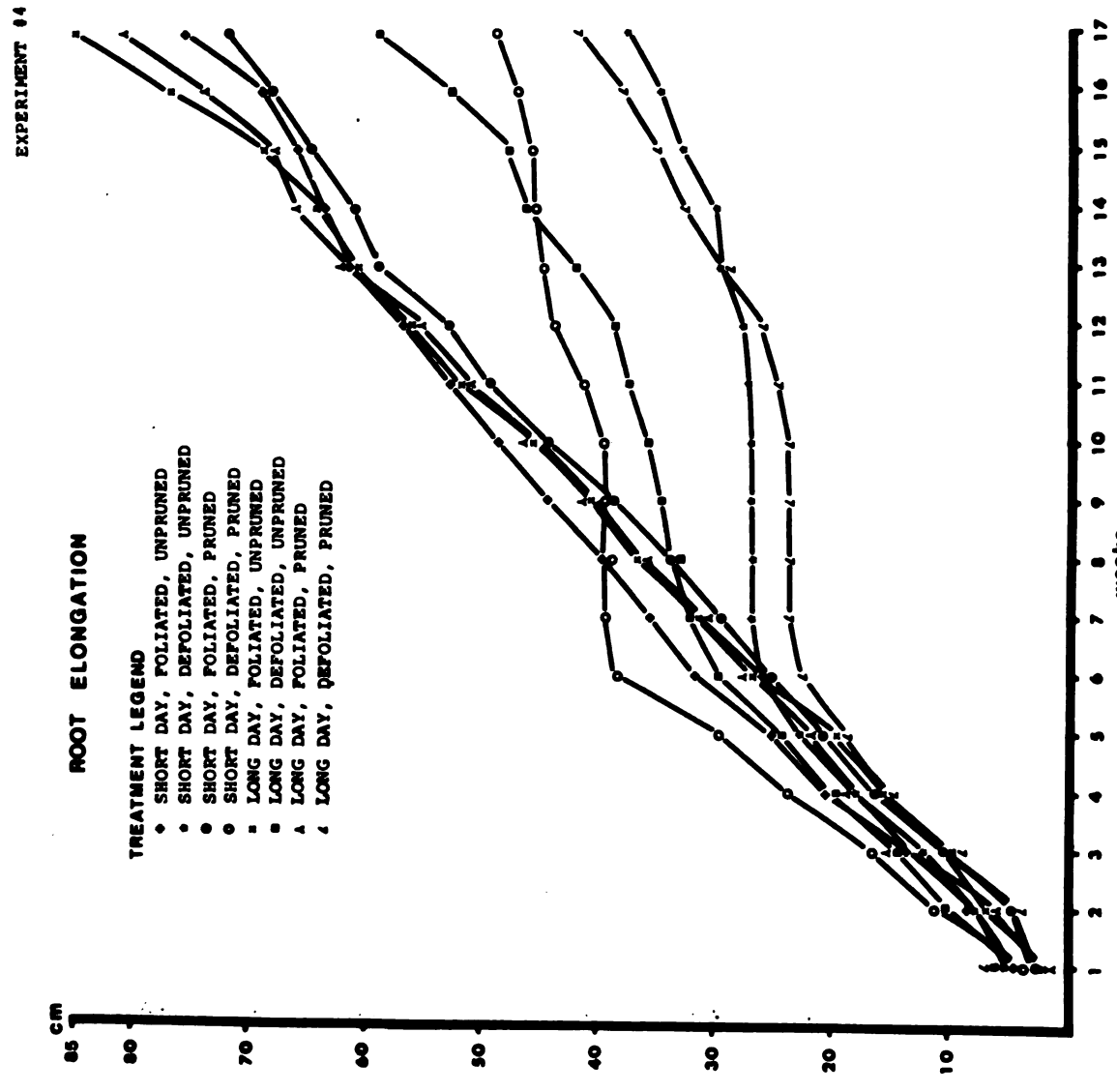
EXPERIMENT 84
ROOT ELONGATION
TREATMENT LEGEND
◆ SHORT DAY, FOLIATED, UNPRUNED
• SHORT DAY, DEFOLIATED, UNPRUNED
● SHORT DAY, FOLIATED, PRUNED
● SHORT DAY, DEFOLIATED, PRUNED
▪ LONG DAY, FOLIATED, UNPRUNED
■ LONG DAY, DEFOLIATED, UNPRUNED
▲ LONG DAY, FOLIATED, PRUNED
◢ LONG DAY, DEFOLIATED, PRUNED
cm
85
80
70
60
50
40
30
20
10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
weeks

Figure 7.

Figure 8. The effect of daylength and defoliation on shoot elongation.

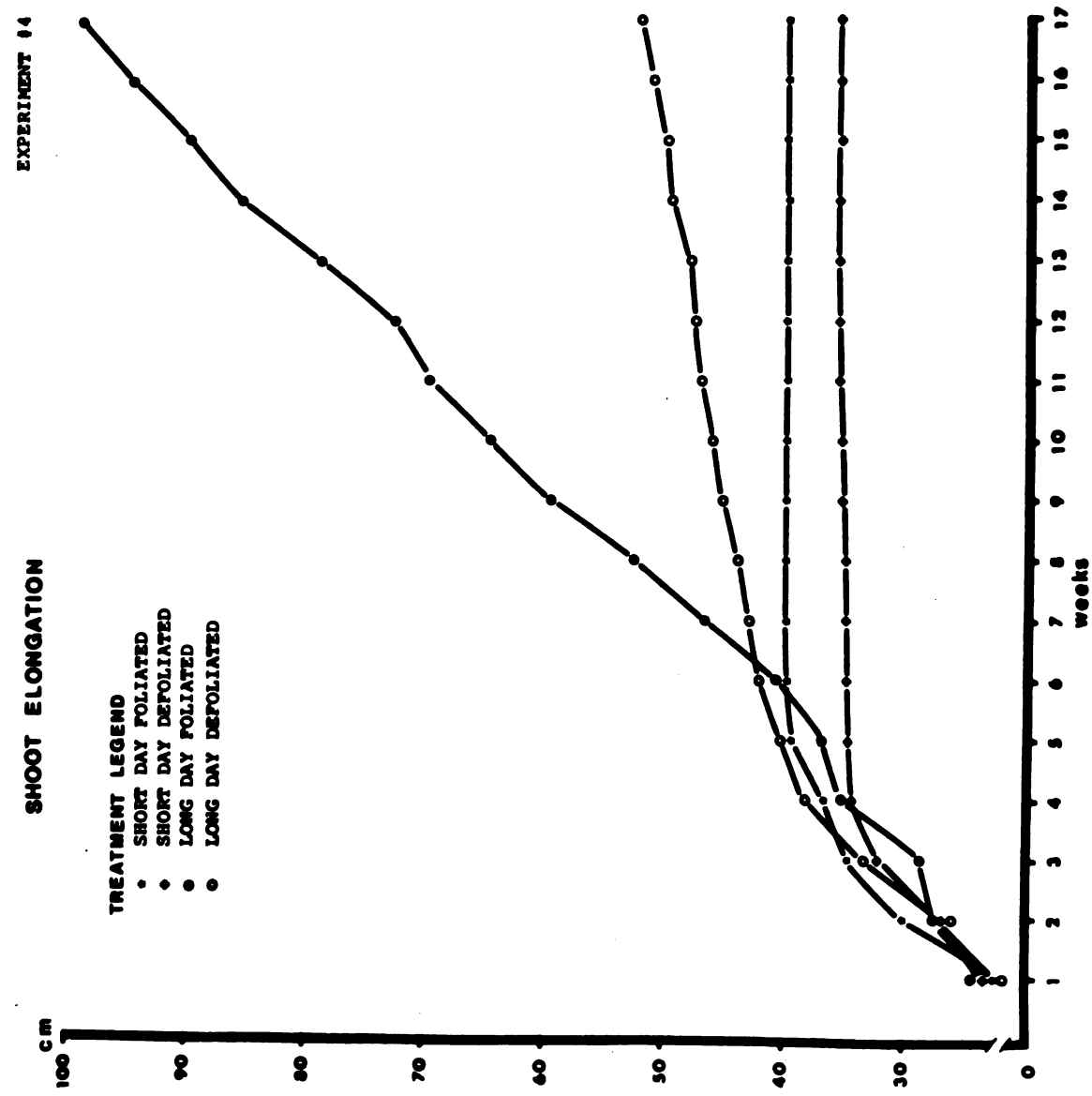
EXPERIMENT 14
SHOOT ELONGATION
TREATMENT LEGEND
SHORT DAY FOLIATED
SHORT DAY DEFOLIATED
LONG DAY FOLIATED
LONG DAY DEFOLIATED
cm
100
90
80
70
60
50
40
30
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
weeks

Figure 8.

Figure 9. The effect of daylength, defoliation and root pruning on shoot elongation.

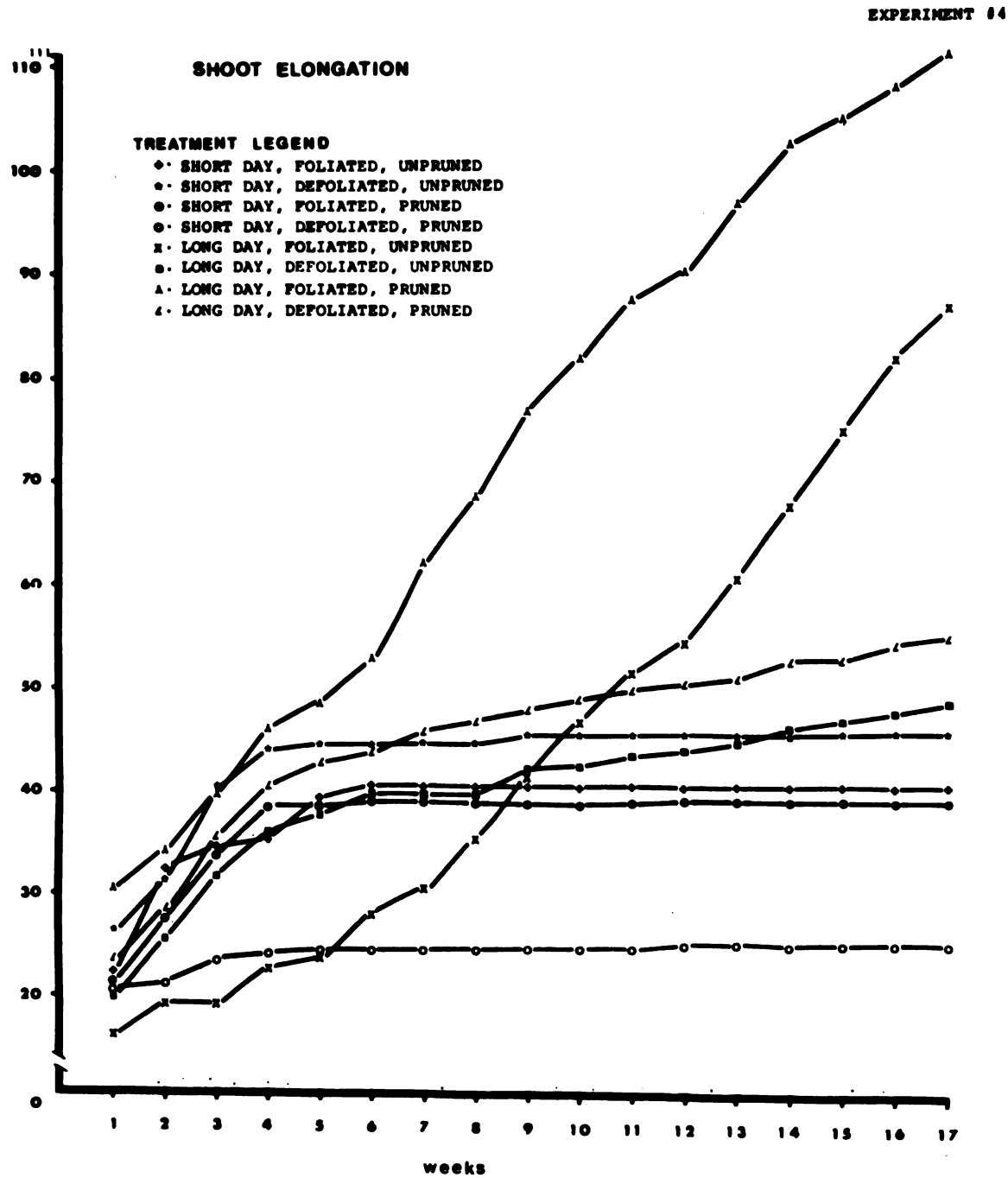
EXPERIMENT 84
SHOOT ELONGATION
TREATMENT LEGEND
SHORT DAY, FOLIATED, UNPRUNED
SHORT DAY, DEFOLIATED, UNPRUNED
SHORT DAY, FOLIATED, PRUNED
SHORT DAY, DEFOLIATED, PRUNED
LONG DAY, FOLIATED, UNPRUNED
LONG DAY, DEFOLIATED, UNPRUNED
LONG DAY, FOLIATED, PRUNED
LONG DAY, DEFOLIATED, PRUNED
110
100
90
80
70
60
50
40
30
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
weeks

Figure 9.

Figure 10. The effect of partial and complete coverage or defoliation on root elongation.

APPENDIX

Table A.1 The Effect of Photoperiod on Root and Shoot Elongation.

Analysis of Variance

(Root Elongation)

Source	Df	M.S.	F	Sig
Total	599			
Treatment	4	34.96	.569	.68
Error (a)	56	61.42		
Weeks	7	129.12	10.94	.0005
Treat * Weeks	28	22.08	1.87	.005
Error (b)	504	11.80		

(Shoot Elongation)

Source	Df	M.S.	F	Sig
Total	599			
Treatment	4	994.01	3.81	.008
Error (a)	56	260.51		
Weeks	7	2404.51	111.90	.0005
Treat * Weeks	28	158.24	7.36	.0005
Error (b)	504	21.49		

Treatments

1. Long Days (2 Groups)
2. Short Days (2 Groups)
3. Control (1 Group)

Table A.2 The Effect of Daylength, Transferral, and Root Pruning on the Root and Shoot Elongation.

Analysis of Variance (Shoot Elongation)

Source	Df	M.S.	F.STAT	Sig
Total	287			
Daylength (Days)	1	12331.04	13.63	.002
Root Pruned (Pruned)	1	549.18	.61	.447
Transferred (Trans)	1	7111.27	7.86	.013
Days * Pruned	1	633.98	.70	.415
Days * Trans	1	43112.71	47.66	.0005
Pruned * Trans	1	439.81	.49	.496
Days * Pruned * Trans	1	748.52	.83	.376
Error (a)	16	904.55		
Week	11	751.75	24.62	.0005
Days * Weeks	11	607.77	19.90	.0005
Pruned * Weeks	11	29.24	.96	.487
Trans * Weeks	11	227.03	7.43	.0005
Days * Pruned * Weeks	11	24.43	.80	.640
Days * Trans * Weeks	11	324.09	10.61	.0005
Pruned * Trans * Weeks	11	2.36	.08	1.00
Error (b)	176	30.54		

Treatments

1. Daylength
   a. Long days
   b. Short days
2. Root Pruning
   a. Pruned
   b. Unpruned
3. Transferred
   a. Long days transferred to short days
   b. Short days transferred to long days

Table A.2 continued

Analysis of Variance (Root Elongation)

Source	Df	M.S.	F.STAT	Sig
Total	287			
Daylength (Days)	1	2.19	.04	.843
Root Pruned (Pruned)	1	122.59	2.26	.152
Transferred (Trans)	1	37.63	.69	.417
Days * Pruned	1	28.44	.52	.480
Days * Trans	1	9.21	.16	.686
Pruned * Trans	1	2.55	.05	.831
Days * Pruned * Trans	1	50.75	.94	.348
Error (a)	16	54.27		
Weeks	11	54.78	6.27	.0005
Days * Weeks	11	4.16	.47	.966
Pruned * Weeks	11	16.13	1.85	.050
Trans * Weeks	11	8.85	1.01	.437
Days * Pruned * Weeks	11	10.83	1.24	.264
Days * Trans * Weeks	11	7.05	.807	.633
Pruned * Trans * Weeks	11	8.20	.938	.505
Days * Pruned & Trans * Weeks	11	6.47	.741	.698
Error (b)	178	8.73		

Table A.3A The Effect of Acculuated Short Days to Promoted Dormancy

Analysis of Variance

(Root Elongation)

Source	Df	M.S.	F	Sig
Total	447			
Treat	3	132.99	3.81	.025
Error (a)	21	34.82		
Weeks	13	12.56	1.32	.196
Treat * Weeks	39	16.89	1.78	.004
Error (b)	371	9.49		

(Shoot Elongation)

Source	Df	M.S.	F	Sig
Total	447			
Treat	3	258.67	.61	.615
Error (a)	21	423.42		
Weeks	13	32.96	.35	.983
Treat * Weeks	39	17.85	.19	1.00
Error (b)	371	93.67		

Treatments

1. Two weeks of short days then moved to long days.
2. Four weeks of short days then moved to long days.
3. Six weeks of short days then moved to long days.
4. Eight weeks of short days then moved to long days.

Table A.3B The Effect of Partial and Complete Defoliation on Shoot and Root Elongation

Analysis of Variance

(Root Elongation)

Source	Df	M.S.	F	Sig
Total	359			
Treatment	4	91.29	3.04	.031
Error (a)	32	32.01		
Weeks	7	15.61	2.36	.023
Treat x weeks	28	7.44	1.12	.305
Error (b)	288	6.60		

(Shoot Elongation)

Source	Df	M.S.	F	Sig
Total	359	324.15		
Treat	4	324.15	.35	.83
Error (a)	32	903.78		
Weeks	7	13.40	.46	.86
Treat x Weeks	28	5.59	.19	1.0
Error (b)	288	28.91		

Treatments

5. Every other leaf blade removed.
6. Every other leaf blade removed.
7. One half of every leaf removed.
8. One third of every leaf removed.
9. Control.
10. Completely defoliated.

Table A.4 The Effect of Photoperiod, Defoliation and Root Pruning on Root and Shoot Elongation

Analysis of Variance (Root Elongation)

Source	Df	M.S.	F	Sig
Total	1151			
Daylength (Days)	1	65.98	2.04	.158
Root Pruned (Pruned)	1	6.92	.21	.645
Leaves Removed (Leaves)	1	760.66	23.57	.0005
Days * Pruned	1	53.69	1.66	.202
Days * Leaves	1	2.75	.08	.771
Pruned * Leaves	1	3.54	.11	.742
Days * Pruned * Leaves	1	80.59	2.50	.120
Error (a)	56	32.27		
Weeks	17	73.15	10.03	.0005
Days * Weeks	17	20.40	2.80	.0005
Pruned * Weeks	17	12.31	1.69	.039
Leaves * Weeks	17	71.64	9.83	.0005
Days * Pruned * Weeks	17	6.88	.94	.521
Days * Leaves * Weeks	17	8.18	1.12	.327
Pruned * Leaves * Weeks	17	6.35	.87	.610
Days * Pruned * Leaves * Weeks	17	15.38	2.11	.005
Error (b)	952	7.29		

Treatments
1. Daylength
    a. Long days
    b. Short days
2. Root Pruning
    a. Unpruned
    b. Pruned
3. Leaf Removal
    a. Foliated
    b. Defoliated

Table A.4 continued

Analysis of Variance (Shoot Elongation)

Source	Df	M.S.	F	Sig
Total	1151			
Daylength (Days)	1	59440.65	13.96	.0005
Root Pruned (Pruned)	1	3416.89	.80	.374
Leaves Removed (Leaves)	1	26948.75	6.33	.015
Days * Pruned	1	46662.58	10.96	.002
Days * Leaves	1	9846.72	2.31	.134
Pruned * Leaves	1	27889.32	6.55	.013
Days * Pruned * Leaves	1	580.27	.136	.713
Error (a)	56	4256.55		
Weeks	17	7752.68	256.96	.0005
Days * Weeks	17	3013.73	99.89	.0005
Pruned * Weeks	17	38.96	1.29	.190
Leaves * Weeks	17	1398.41	46.35	.0005
Days * Pruned * Weeks	17	182.63	6.05	.0005
Days * Leaves * Weeks	17	1180.96	39.14	.0005
Pruned * Leaves * Weeks	17	119.94	3.97	.0005
Days * Pruned * Leaves * Weeks	17	23.85	.790	.706
Error (b)	952	30.17		

Table A.5 The Effect of Partial and Complete Coverage or Defoliation on Root and Shoot Elongation

Analysis of Variance

(Root Elongation)

Source	Df	M.S.	F	Sig
Total	749			
Treatment	9	96.45	11.22	.0005
Error (a)	36	8.60		
Weeks	14	94.30	34.41	.0005
Treat X Weeks	126	8.33	3.04	.0005
Error (b)	564	2.74		

(Shoot Elongation)

Source	Df	M.S.	F	Sig
Total	749			
Treatment	9	542.17	1.12	.374
Error (a)	36	483.83		
Weeks	14	39.67	8.59	.0005
Treat X Weeks	126	2.89	.626	.999
Error (b)	564	4.61		

Treatments

1. Covered
   a. Control
   b. Completely covered
   c. Bottom half of the shoot foliage covered
   d. Every other leaf covered
   e. Top half of the shoot foliage covered

2. Removed
   a. Control
   b. Completely defoliated
   c. Bottom half of the shoot foliage removed
   d. Every other leaf removed
   e. Top half of the shoot foliage removed

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