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Influence of temperature variation within the Forestry School greenhouse upon development of container-grown Pinus ponderosa seedlings

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INFLUENCE OF TEMPERATURE VARIATION WITHIN THE FORESTRY SCHOOL GREENHOUSE UPON DEVELOPMENT OF CONTAINER-GROWN *PINUS PONDEROSA* SEEDLINGS

By

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Influence of Temperature Variation Within the Forestry School Greenhouse Upon Development of Container-Grown Pinus Ponderosa Seedlings (66 pp.)

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Pinus ponderosa seedlings were grown at each of twelve locations in the Forestry School Greenhouse at the University of Montana. The seedlings were reared under uniform conditions except for the existing variation in microclimatic parameters. Temperature was monitored and six seedling parameters were recorded: height growth, total dry weight, shoot dry weight, root dry weight, root/shoot ratio, and percent water content. A one-way analysis of variance indicated that temperature and seedling development varied significantly between test locations during a ninety-six day study period. Statistically significant correlations were found between temperature and total dry weight, root dry weight, and root/shoot ratio. Rotation of seedlings on a four-day interval helped minimize, but did not eliminate, influences of microclimate. Computer graphics were used to illustrate the relationship between temperature and stationary seedlings and to provide contrasts between the influence of stationary and rotated treatments.

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PREFACE

The University of Montana Forestry Greenhouse has not been used to its fullest potential as a research or instructional facility in recent years. Reasons for this have been numerous and complex. However, this project was concerned with only one of the problems--temperature variation within the structure and the possible influences this has upon development of Pinus ponderosa seedlings.

The impetus for a greenhouse evaluation and renovation project, as well as some of the funding for it, was provided by Wayne Hite, Land Use Planning Division, Champion Timberlands Corporation. Mr. Hite had observed that the Forestry Greenhouse might be improved, particularly when compared to greenhouses where recent advances have been made in mechanization associated with production of containerized seedlings. Incorporating his assessment with the observations of others, I chose to conduct analytical work in order to evaluate the Forestry Greenhouse. Observations within the structure suggested that definite variations in microclimate did occur. Significant variations would cast doubt on any conclusions reached from other research conducted under existing greenhouse conditions.

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CHAPTER I

LITERATURE REVIEW

Experimental Design

Backlund and Perttu (1971) discussed an extensive, complex, analytic system in which they monitored twenty-six environmental and two plant growth parameters (species not mentioned but assumed, from illustrations, to be in genus *Pinus*). A large volume of data was collected through time and fed directly into a computer for analysis. The authors' objectives were to describe nursery climate, greenhouse climate, plant climate, and the connection between environmental factors and plant growth. Some of their observations included: shoot elongation; increases in stem caliper; temperature of air, needles, roots, and soil surface; air pressure; precipitation; air movement; soil moisture; and solar radiation.

Whittle and Lawrence (1960) evaluated temperature variations in several greenhouses heated by steam. The steam heat in all cases was controlled by motorized on-off valves connected to centralized thermostats. Temperature variation within the greenhouses was monitored fifty-four times daily at each location by a multi-channel temperature recorder modified to accommodate forty-five thermocouples. In one experiment, designed to evaluate uniformity of temperature, variations within one of the greenhouses never exceeded 1.4^{o}C from September 7 to October 10 when compared on a static time bases.

Kimball (1973) used thermocouples to determine differential inside temperatures while comparing a computer prediction of greenhouse energy balance with a real situation. However, other than reporting that he took four daily temperature readings on three days of distinct climatic characteristics, he does not detail his study design because it was secondary to the main work.

Ekblad (1973) listed five factors to be considered when temperature measurements are made in the greenhouse: 1) shielding of sensors, 2) soil temperature, 3) leaf temperature, 4) radiometer readings, and 5) air temperature gradients. Kelsoe (1975) contended that shielded sensors should be located near plant level at locations chosen to represent the extremes of probable temperature distribution. He added that the most extreme temperature changes occurred during the winter months and that recordings every thirty minutes were sufficient to analyze both slow and rapid changes. Tanaka and Timmis (1974) used average daytime temperatures from three positions: 1) the tip of the seedling, 2) the bottom of the stem, and 3) 6 cm into the soil. Averages were computed from sixteen readings made at hourly intervals. Backlund and Perttu (1971) noted that their system logged the data at twenty minute intervals.

Steinbrenner and Rediske (1964) conducted work on Pinus ponderosa and Pseudotsuga menziesii to determine the relative importance and interrelationships of several environmental factors. Seed source was from one tree and seedling uniformity was established after germination and before seedlings were placed in the growth chamber. Each of the following environmental parameters was evaluated in terms of low and high conditions: soil productivity, light intensity, temperature, humidity, soil temperature, soil moisture, and nitrogen level. The high and low values were based upon conditions which could be encountered by trees growing in a natural environment. The research work was conducted in four, ten-week periods. Four groups of 128 seedlings of each species were subjected to one of four combinations of either low or high temperature and humidity. The 128 seedlings were subject to other climatic variations by means of partitions, water baths, and differential care. Because of limited space and the large number of environmental factors, any one combination of all factors allowed for only two sample measurements per species.

Cochran (1972) studied the effects of soil fertility and temperature upon Pinus ponderosa and Pinus contorta. He grew seedlings in the same soil type at four different nutrient levels. Using three growth chambers at different daytime temperature, he grew three groups of seedlings to obtain nine combinations with three different nighttime temperatures. Cochran used daily degree hours as one factor related to seedling growth.

Brix (1967) analyzed dry matter production of Pseudotsuga menziesii in relation to nine combinations consisting of three temperatures and three light intensities. He obtained twenty samples for dry weight calculations from each of the nine combinations at sixty-five days and 100 days. Larson (1967) evaluated the influence of different soil and air temperatures on initial growth of Pinus ponderosa from three different locations. Larson assumed that soil temperature for one test would be the same as the room temperature. Seedlings from the three sources were germinated ahead of time and selected for uniformity.

The time element involved in the study designs described above is listed here by increasing increments of time. Time periods allowed for tree growth, before harvesting in conjunction with data analysis, were as follows: Larson (1967)--forty-two days plus germination time, Brix (1967)--sixty-five days and 100 days, Steinbrenner and Rediske (1964)--seventy days plus pregermination, and Cochran (1972)--133 days plus germination.

Seed Size and Germination Rates

Tests involving seed size and initial seedling development, according to Duffield (1960), yielded direct correlations between the two. He contended that screen size and air column separation were unsatisfactory for obtaining seed uniformity. Larson (1963) noted three important observations from studies involving seed size and germination data in nursery plantings. They were: 1) differences among seedlings from various size classes were not significant, 2) variation in seedlings with only seven days difference in germination data were statistically significant, 3) all seed sizes exhibited uniform germination percentages. Larson contended that variation in seedling growth due to seed size was minor compared with variation in germination date and other environmental factors for seedlings grown under nursery conditions. Different germination ratios were observed by Fowells (1953). He found that medium size seed showed the greatest percentage of germination. Some of Larson's earlier work (1961) also pointed to problems of seed size and germination. He reported that field tests had shown approximately the same germination rates as Fowell's work. However, he stated the large seed in a greenhouse test exhibited only 41% germination, whereas medium seed had 78% germination.

Plant Growth Parameters

Measurement of seedling dry weight is a straightforward procedure. All references found in this search listed a temperature of 70^{o}C for obtaining dry weights (e.g., see Larson 1967). Edgren and Trappe (1970) dried the seedlings until they reached a constant weight. Steinbrenner and Rediske (1964) used a period of forty-eight hours which presumably would produce a constant weight. Measurements sometimes included more than total dry weight. Tinus (1972), to cite the extreme, measured the individual weights of stems, roots, and leaves, both wet and dry. Total dry weight measurements were usually expressed in milligrams.

Two procedures dominate in the measurement of height growth. The first involves measurement of the epicotyl growth, i.e., from the cotyledonary node to the tip of the terminal bud (e.g., see Betts 1969). This method was used exclusively if the seedling had been transplanted for some reason (e.g., see Trappe and Edgren 1970). The second and more widely used procedure is that of measuring from the growth medium to the terminal bud. Tinus (1972) used a slight variation of this second procedure by measuring from the root collar to the terminal bud. Height growth was usually expressed in millimeters. Backlund and Perttu (1971) measured height growth on a continuous basis. All other authors measured height growth only at the end of the study period, with the exception of Betts (1969). He measured height growth biweekly.

Environmental Parameters

Greenhouses modify the climate to provide more uniform environmental conditions for plant growth. Ekblad (1973) noted that modifying the climate in a structure to provide uniformity of climatic conditions is always a complex problem. He stated that greenhouses present several problems which are unique: rapid heat build up, rapid cooling due to poor insulation, internal cooling and high humidity due to evapotranspiration, and differential shielding of sunlight due to equipment. Evaluations of variation in *Pinus ponderosa* growth due to climatic conditions within the greenhouse, unique or otherwise, have not been located. However, the influences of many environmental parameters upon tree growth have been analyzed by use of growth chambers.

Interrelationships

Steinbrenner and Rediske (1964) contended that plant growth was influenced by a delicate intertwining of environmental parameters within their potential ranges. They stated that any factor at its extremes could severely limit or stop plant growth. However, even at these extremes, other environmental factors would still be exerting some interactions upon plant processes. Larson (1967), discussing interactions of soil and air temperature, specifically pointed out an interesting observation from his results. He stated that when either soil or air temperature was at optimum the variation in the other had the greater magnitude of effect upon the seedlings. In a discussion of the upper limits of seedling growth, Larson (1974) stated that there were very complex interactions among individual environmental factors and between those factors and the genetic constitution of the seedlings.

Augsburger, et al. (1975) discussed in detail the interrelationships of temperature and humidity. The main relationship is that, at constant moisture, relative humidity decreases proportionally as temperature increases. Larson (1967) assumed in his experimental design that soil temperature would be the same as the air in a constant temperature room. Steinbrenner and Rediske (1964) found that air temperature was more important to evaporation than soil type and that light intensity showed significant correlation with moisture reduction regardless of temperature. Whittle and Lawrence (1960) noted that temperature variation was much easier to control in a greenhouse when strong solar radiation was absent. Tinus (1971) pointed out that, with high light intensities, photosynthesis was limited by the low concentrations of carbon dioxide. Air movement, according to Satoo (1962), can result in an increase or decrease in photosynthesis depending on velocity. Satoo related these phenomena to interrelationships with carbon dioxide and soil moisture, respectively.

Relations to Plant Growth

Steinbrenner and Rediske (1964) emphasized that interaction among environmental parameters was always present. Based on this assumption, their study was conducted to evaluate growth responses of *Pinus ponderosa* and *Pseudotsuga menziesii* seedlings to high and low levels of several factors. Growth response was used to rank the relative importance of environmental parameters. Their results were as follows: 1) air temperature had the greatest influence on height growth; 2) the influence of air temperature was evident in the interaction with the other environmental factors; 3) air temperature increased the top weight by the same magnitude as height growth, although light intensity had the strongest influence on top weight; 4) light intensity was most influential on the total dry weight, but temperature was responsible for consistent weight increases; 5) air temperature and light intensity were also important to increased root weight.

Backlund and Perttu (1971) stated that radiation and temperature were the main factors linked to an appropriate analysis of plant growth. Many authors have found direct relationships between temperature and both height and dry weight; however, there is little agreement on which combination of day and night temperatures is optimum for growth of Pinus ponderosa seedlings. Tinus (1971) listed the following day-night temperature combinations as optimum: height growth, day-25°C, night-25°C; caliper, day-23°C, night-25°C; dry weight, day-21°C, night-25°C. Tinus (1974) discussed a specific seed source of Pinus ponderosa from Nebraska and stated that: 1) the trees grew best at daytime temperatures of 25°C and nightime temperatures of 18.5°C; 2) growth dropped off rapidly above daytime temperatures of 25°C; 3) with daytime temperatures near optimum, nighttime temperatures within reason had little effect on height growth; and 4) dry weight increased with increasing nighttime temperatures reaching optimum at 25°C.

Cochran (1972) did not measure dry weight. His findings were as follows: 1) best growth occurred at daytime temperatures of 23°-30°C and nighttime temperatures of 8°C; 2) daytime temperature, nighttime temperature, and degree days all showed significant effects upon growth. Schubert and Baron (1965), working with shoot elongation in nursery beds, presented the following observations: 1) mean minimum air temperature influenced root development greatly, and 2) best growth occurred when diurnal range between night and day was approximately 10-14^{o}C and the mean temperature was above 5^{o}C. Larson (1967) noted that seedlings from three separate seed source locations (Arizona, California, and South Dakota) all grew best at a constant day-night temperature of 23^{o}C.

Humidity, as an influence upon seedling growth in a greenhouse, was considered to be of only limited importance. Steinbrenner and Rediske (1964) found some correlations of seedling growth with variation in relative humidity. However, they considered humidity to be more important in comparing Pinus ponderosa with Pseudotsuga Menziesii than to describe the influence upon growth of the individual species. Ekblad (1973) stated that, as an environmental factor, humidity becomes a problem only at extremes; e.g., high humidity increases disease and mold problems and low humidity, due to increased evaporations, can increase salt accumulation and can lower soil temperatures as much as 8^{o}C. Larson (1974) stated that humidity fluctuation within reasonable limits would not seriously affect general tree growth. He also stated that as long as relative humidity does not exceed the 40-70% range, very little is gained by trying to control the fluctuation. He noted that relative humidity below 40% can inhibit growth. Ekblad (1973) presented two criteria used in evaluating humidity fluctuations: 1) day and night levels, and 2) fluctuations outside established ranges.

In a general discussion of seedling growth, Larson (1974) listed several influences related to light intensity: 1) low light intensity could limit growth in closely grouped containerized seedlings due to shading; 2) young needles may become saturated with light intensities of

1,500-3,000 foot candle, whereas other needles may not reach saturation until intensities of two to three times that magnitude; and 3) light intensity may influence height and dry weight differently, i.e., up to 45% light produces tall seedlings, greater than 45% produces heavy seedlings. The important results presented by Steinbrenner and Rediske (1964) were noted above. They found that variation in light intensity had the greatest influence upon total seedling weight. Tinus (1971) hinted at one of the most serious problems of greenhouse climate control. He noted that *Pinus ponderosa* seedlings could utilize high intensities of solar radiation as long as carbon dioxide concentrations were maintained at a high level. He explained that the greenhouse must be a closed system in order to maintain high concentrations of carbon dioxide. This was where the problem became evident. In a closed greenhouse the temperature under conditions of high solar radiation can severely limit seedling growth.

The concentration of carbon dioxide in the air during periods of photosynthesis, even on the best site, could have easily become a limiting factor to tree growth according to Spurr and Barnes (1973). Increased concentrations of carbon dioxide, as noted by several authors, can produce increased rates of seedling growth (e.g., see Tinus 1972). The variability of carbon dioxide in an empty, nonmanipulated greenhouse would have to have been theoretically nonexistent. However, variation in carbon dioxide concentration in a greenhouse in which *Pinus ponderosa* seedlings were being produced could be influenced by two factors: 1) the variability of air circulation and 2) the rate of carbon dioxide assimilation associated with photosynthesis. The variability of air movement would have been related to numerous engineering features. Satoo (1962) pointed out that, for plants in general, movement of air at low velocities can increase photosynthesis by increasing carbon dioxide availability. He also stated that air movement could have adverse effects. Higher velocities of air movement quickly cause a reversal of photosynthetic activity due to increasing transpiration, except in some rare cases where large volumes of water are readily accessible.

CHAPTER II

OBJECTIVES AND PROBLEM STATEMENT

The objective of this project was to determine if seedling growth, as quantified by six parameters, was significantly influenced by variation in microclimate as quantified by temperature. Statistical analyses were performed to ascertain the variability of growth and temperature, as well as to determine the degree of association between temperature and the six parameters.

Environmental parameters which have been shown to influence seedling growth include: air temperature, humidity, evaporation, light intensity (both natural and artificial), carbon dioxide concentration, soil temperature, nutrient availability, and moisture content of the growth medium. Temperature has been singled out by numerous authors as being highly influential upon seedling development. Air temperature has been shown to have direct interrelationships with humidity, evaporation, soil temperature, and moisture content. The principal factors which cause variation in temperature are solar radiation, artificial heat, and air circulation. Air movement, as noted above, has been shown to be responsible for variation in plant growth by causing an increase in availability of carbon dioxide and by causing higher rates of transpiration.

This research project was based upon the following assumptions: 1) moisture and nutrients would be supplied as uniformly as possible;

2) air temperature would be one of the main factors influencing seedling growth; 3) air temperature would have a direct effect upon variation in humidity, evaporation, soil temperature, and soil moisture; 4) variation in air temperature would be directly related to variation in solar radiation, supplementary light, artificial heat, and air circulation; 5) carbon dioxide concentrations would be fairly uniform, based on a normal atmospheric value of 325 parts/million; 6) influence of air movement would be negligible during the winter growing season; and 7) variation in the artificial lighting systems would be an unavoidable shortcoming.

Two null-hypothesis statements were postulated in this research project: 1) *Pinus ponderosa* seedling development and temperature do not vary significantly within the east room, and 2) seedling development is not dependent on temperature.

CHAPTER III

EXPERIMENTAL DESIGN

Planting Methods

Seeds of Pinus ponderosa obtained from a single stand in Ryan Gulch[1] were soaked in water for eight hours and then spread onto wetted cotton pads laid in metal pans. The metal pans were bagged in plastic and placed in a growth chamber set for sixteen-hour days, with a 29°C temperature setting for light periods and 18°C temperature for dark periods. After seven days, seeds which had a radicle length of between 0.1 and 0.4 cm were sown one per cavity into thirty randomly assigned holes in each of twenty-four #2A styroblocks. The styroblocks had been filled ahead of time with a wetted peat-vermiculite mixture. The additional 210 cavities were seeded with the remaining seed. All cavities were covered with approximately 0.3 cm of #2 granite grit.

The twenty-four containers were randomly placed in pairs at each of twelve locations within the east room of the Forestry Greenhouse (Figure 1). The styroblocks were labeled according to location number and with either the letter A or B. The "A" styroblocks, which were positioned to alternate between the north and south edge of the benches, were left in the same location for the length of the study period. The "B" styroblocks were rotated every fourth day according to the following

[1]Ryan Gulch is located in section 6, T 11 N, R 15 W. Montana Principal Meridian.

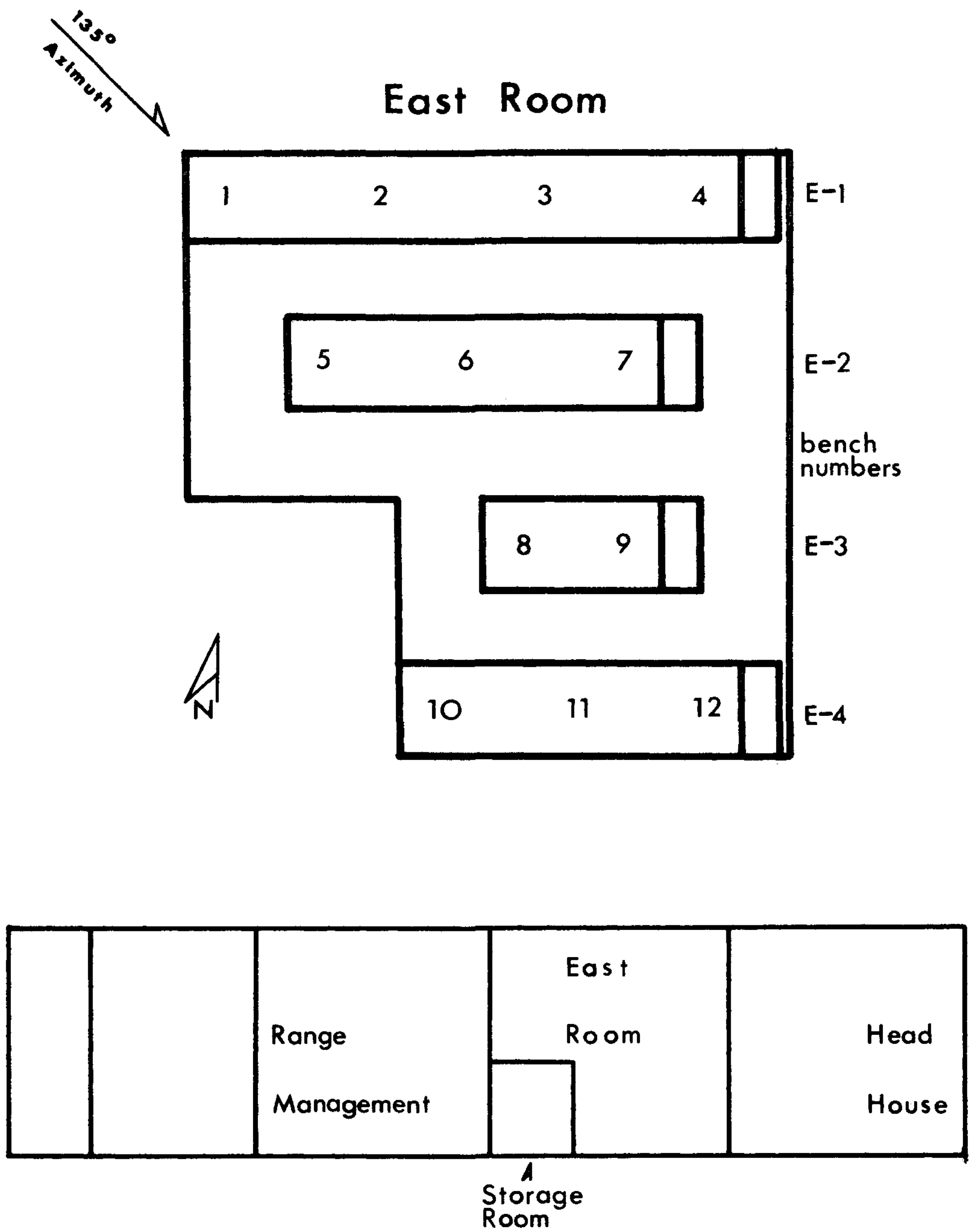

Figure 1. Data point locations and orientation of east room within the Forestry School Greenhouse.

pattern obtained from a random number table: 10, 3, 2, 5, 9, 4, 6, 1, 11, 12, 7, 8. The remaining space on the benches was filled with seeded #2A styroblocks to simulate normal greenhouse conditions when filled with containers. The study period ran from October 6, 1976 to January 10, 1977--a total of ninety-six days.

Parameter Measurements

On January 11 the "B" styroblocks were moved for the last time, returning them to their original placements. All seedling parameter measurements were obtained as soon as possible thereafter. Height growth of the first ten seedlings in each container (i.e., twenty seedlings/ location or 240 total) was measured in millimeters (±0.5 mm). Measurements were made by placing a ruler on the growth medium next to the stems and determining the height of the shoot apex. (All of the test emergents had been chosen for uniform radicle length. Height of the individual seedlings should have been a result of the environmental conditions encountered during the ninety-six day period. Thus, the term height growth has been used to express the amount of hypocotyl and stem elongation which occurred during the study).

The same ten seedlings from each styroblock were lifted to obtain weight measurements. The growth medium was gently washed from the roots, and the seedlings were severed at the root collar. The wet weight of the shoot was measured, and the shoot and root were placed into individually numbered kraft bags. All plant materials were oven-dried at 70^{o}C for forty-eight hours. Dry weight measurements, expressed in milligrams (±0.5 mg), were obtained for shoots and roots as well as the total weight for each group in a particular styroblock. The kraft bags were removed from the oven one at a time to reduce water uptake before measurement.

Temperature readings were collected throughout the research period with a Honeywell model #370790-999 multi-channel temperature recorder. Twelve copper-constantin thermocouples were placed at 5.08 cm (2.0 inches) above the plant level between the two containers at each of the twelve locations shown in Figure 1. The average daily temperature was calculated for each location. Several unexplained malfunctions of the temperature recorder occurred during the period of study. Therefore, temperature data are not complete for all ninety-six days (Table 1).

TABLE 1

DATES OF MISSING AND INCOMPLETE TEMPERATURE DATA

Dates	Status
October 6 and 7	Complete
October 8 and 10	Partial
October 11-13	Complete
October 14 and 15	Partial
October 16-26	Complete
October 27	Partial
October 28-November 17	None
November 18	Partial
November 19-December 19	Complete
December 20 and 21	Partial
December 22-January 9	Complete
January 10	Partial

In addition to temperature and the aforementioned seedling parameters of height growth, total dry weight, shoot dry weight, and root dry weight; two other seedling parameters were calculated--root/shoot ratios and percent water content of the shoot. The root/shoot ratios were obtained by dividing root dry weight by shoot dry weight for each seedling. Percent water content was calculated for individual seedlings by dividing the weight of water contained in the succulent shoot by the dry weight of the shoot.

Statistical Design

The null hypothesis of no position effect,

$$H_0: \; P_1 = P_2 = \ldots = P_{12} \quad \text{vs} \quad H_1: \text{ not all the same, at } \alpha = .05$$

for the seedling paramters was tested by analyses of variance and assuming the statistical model (Table 2):

$$Y_{ij} = \mu + P_i + e_{ij} \qquad i = 1, \ldots, 12; \quad j = 1, \ldots, 10$$

Y_{ij} ↓ Parameter; P_i ↓ ith position effect; e_{ij} ↓ random error

TABLE 2

DEGREES OF FREEDOM USED IN ANALYSIS OF VARIANCE CALCULATIONS OF THE PLANT GROWTH PARAMETERS

Source of Variation		d.f.[a]
Plant Growth Parameters (Rotated)		
Position (12)	(a-1)	11
Number of seedlings/position	a(n-1)	108
		119
Plant Growth Parameters (Stationary)		
Position (12)	(a-1)	11
Number of seedlings/position	a(n-1)	108
		119

[a]The number of positions is indicated by "a", and "n" refers to number of seedlings measured at each position.

Bench E-3 was lighted by a bank of eight fluorescent lights, whereas the other three benches were lighted by regularly spaced incandescent lights. Therefore, measurements of growth parameters were separated by light type, and groups grown under incandescent lights were subjected to another analysis of variance (Table 3). (Locations eight and nine on bench E-3 were considered to have a known source of variation, due to the fluorescent lights, which was inconsistent with the normal greenhouse conditions. Thus, the group data for the incandescent lights were tested individually to make sure the statistically significant position effects were not confounded by the influence of the fluorescent light).

TABLE 3

DEGREES OF FREEDOM USED IN ANALYSIS OF VARIANCE CALCULATIONS FOR INCANDESCENT GROWTH PARAMETERS

Source of Variation		d.f.[a]
Incandescent (Rotated)		
Position (10)	(a-1)	9
Number of seedlings/position	a(n-1)	90
		99
Incandescent (Stationary)		
Position (10)	(a-1)	9
Number of seedlings/position	a(n-1)	90
		99

[a]The number of positions is indicated by "a", and "n" refers to number of seedlings measured at each position.

Average temperature in the greenhouse for each of the locations was also subjected to an analysis of variance. The null hypothesis stated that no temperature variation existed between locations where: H_0: $T_1 = T_2 = . . . = T_{12}$ vs H_1: not all the same, at $\alpha = .05$ (Table 4).

TABLE 4

DEGREES OF FREEDOM USED IN ANALYSIS OF VARIANCE CALCULATIONS FOR TEMPERATURE

Temperature (Average Daily Temperature) Source of Variation		d.f.
Position (12)	(a-1)	11
Readings/position	a(n-1)	840
		851

Correlation coefficients were calculated to quantify the degree of association between temperature and each of the six plant growth parameters. These correlation coefficients were calculated for rotated stationary treatments, as well as the stationary incandescent grouping.

CHAPTER IV

RESULTS

Analysis of Variance

F-values for temperature and the seedling parameters for both treatments and both groupings of data, with the exception of rotated root/shoot ratios, were statistically significant at the 95% level (Table 5). Therefore, the null hypothesis was rejected and the alternative accepted: temperature and seedling development was not the same at all positions within the east room of the greenhouse. The significant differences from one location to the next for temperature and seedling development implies that uniform environmental conditions were not maintained during the study period.

Comparisons of F-values between stationary and rotated seedlings revealed several important observations. Even though the F-values for rotated parameters (except root/shoot ratios) were statistically significant, these values were smaller in magnitude than the stationary values. The significant rotated values were most likely attributable to two causes: 1) the large degrees of freedom, resulting in a sensitive F-test; and 2) constantly changing environmental conditions within the structure, which provided some seedling groups better growth conditions than others. For example, if styroblock "x" was at location nine (one of the better locations for dry weight production) for a four-day

TABLE 5

F VALUES ASSOCIATED WITH LOCATION SOURCE OF VARIATION

Data Grouping	d.f.[a]	F Values for Different Variables[b]						
		Temperature	Height	Total Dry Weight	Shoot Dry Weight	Root Dry Weight	Root/Shoot Ratio	Percent Water Content
Location	(11,840)	F=54.33***						
Stationary								
All locations	(11,108)		9.97***	25.51***	15.73***	32.93***	8.64***	17.68***
Incandescent	(9,90)		4.91***	14.49***	9.92***	16.05***	6.50***	23.04***
Rotated								
All locations	(11,108)		2.58**	3.13**	2.68**	2.81**	1.05	2.50**
Incandescent	(9,90)		2.41**	2.95**	2.76**	2.61**	0.77	3.00**

[a]The number of positions is indicated by the digits to the left of the comma, and the digits to the right represent the number of seedlings measured at each position.

[b]Levels of statistical significance are as follows for various values of "F":
* Significant at p less than 0.05
** Significant at p less than 0.01
*** Significant at p less than 0.001

interval characterized by warm sunny days, and styroblock "y" was at the same location during a period of cold and cloudy days, weight increase should have been better for styroblock "x".

This problem of seedling growth could have been further complicated by the ontogenetic stage of the seedlings in relationship to when certain combinations of environmental factors were encountered. Larson (1974) contended that seedlings in different stages of development have distinct environmental optima which result in maximum growth. (For example, the seedlings in rotated styroblock four produced the second lightest total, shoot, and root dry weights [see Figures 5, 7, and 9 in the computer graphics section]. During the first sixteen days of the study period, styroblock four was at each of the three coldest locations. From October 6 to October 22, the seedlings were located at positions four, one, six, and three for four days each. Thus, during the period of seedling establishment and hypocotyl elongation, the seedlings were subjected to the longest cold period and exhibited the second lowest dry weights. The rotated styroblock from location seven had the lowest average total dry weight. However, styroblock 7B had one seedling which was exceedingly small and affected the average substantially. Removal of this minimum data point brought the average total dry weight for styroblock 7B well above the average for 4B minimum value).

The rotated seedlings, it was hoped, would not have shown a significant difference; while the stationary group would have shown statistical significance. Thus, the procedure of rotation could have been presented as a way to eliminate seedling growth variation caused by the greenhouse environment. Rotation of the styroblocks reduced the positional differences even though significance was not achieved, due in part to the high degrees of freedom associated with the error term. Thus, rotation of research material was only responsible for minimizing variation within the greenhouse.

The experiment was designed to control as many known sources of variation as possible to avoid confounding the effects due to position of the styroblocks. To achieve this, seeds were selected from a single stand origin and separated for uniformity of size. Enough seed to fill fifty-four styroblocks was pregerminated and test emergents were selected for uniform radicle length. Some of the environmental factors were held as constant as possible. Water and fertilizer treatments were uniformly applied with hand-held spray-fan and watering can. Due to the known variation in the lighting system, computations were made with and without data from locations eight and nine (bench E-3). Corrections of the thermostat setting controlling the heat, roof vent, and exhaust fan were made as frequently as necessary to help maintain uniformity of micro-climate. Therefore, it seemed unlikely that the observed variations among locations occurred at random or were related to seed size, genetics, or water and fertilizer. Seedling parameters also exhibited significant variation with or without locations eight and nine. Temperature, which showed significant variation among locations, was considered as one of the more important influences upon seedling growth. Therefore, the variation within seedling parameter development, in the greenhouse, would appear to have been either influenced by temperature or a temperature-related phenomenon such as soil temperature or light intensity.

Correlation Coefficients

Correlation coefficients between average location temperature and averages of the six seedling parameters were calculated for five different groupings of data: temperature and the size stationary parameters, temperature and the six rotated parameters, temperature and the six stationary parameters without the E-3 data, temperature and the six seedling parameters without E-3 and location eleven data, and temperature and percent water content for stationary seedlings without location eleven (Tables 6, 7, 8, 9, 10).

The correlations between temperature and the six stationary seedling parameters are statistically significant at the 95% level for: total dry weight, root dry weight, and root/shoot ratio (Table 6). In comparison, the correlations between temperature and the rotated parameters were not significant (Table 7). These observations tend to substantiate the theory that temperature variation is directly related to seedling development. However, when the explained relationships for light intensity and temperature at locations eight and nine are removed and the correlation coefficient reevaluated, the situation is altered dramatically. No significant correlations between temperature and stationary seedling parameters were obtained for the ten nonfluorescent locations (Table 8).

Examination of the computer maps indicated a hidden relationship (see computer graphics section). Location eleven was subjected to a temperature change unlike the remaining study positions. On the temperature map (Figure 2 in the computer graphics section) there is a depression at location eleven which did not follow the normal relationship with

TABLE 6

CORRELATION COEFFICIENTS BETWEEN TEMPERATURE AND THE SIX STATIONARY SEEDLING PARAMETERS (d.f. 11)

Temperature	Height Growth	Total Dry Weight	Shoot Dry Weight	Root Dry Weight	Percent Water Content	Root/Shoot Ratios
1.000	-0.3711	0.5725*	0.5303	0.6201*	0.0562	0.6214*
	1.000	-0.5406	-0.4639	-0.6425*	0.3261	-0.6019
		1.000	0.9922*	0.9811*	-0.4465	0.8713*
			1.000	0.9493*	-0.4608	0.8215*
				1.000	-0.4105	0.9214*
					1.000	-0.4927
						1.000

*Significant at p less than 0.05

TABLE 7

CORRELATION COEFFICIENTS BETWEEN TEMPERATURE AND THE SIX ROTATED SEEDLING PARAMETERS
(d.f. 11)

Temperature	Height Growth	Total Dry Weight	Shoot Dry Weight	Root Dry Weight	Percent Water Content	Root/Shoot Ratios
1.000	-0.1946	0.2215	0.2105	0.2308	-0.4989	0.1570
	1.000	0.3666	0.4047	0.2765	0.2279	0.0329
		1.000	0.9906*	0.9665*	-0.5422	0.6699*
			1.000	0.9222*	-0.5095	0.5670*
				1.000	-0.5756*	0.8285*
					1.000	-0.4636
						1.000

*Significant at p less than 0.05

TABLE 8

CORRELATION COEFFICIENTS BETWEEN TEMPERATURE AND THE SIX STATIONARY PARAMETERS WITHOUT THE E-3 DATA (d.f. 9)

Temperature	Height Growth	Total Dry Weight	Shoot Dry Weight	Root Dry Weight	Percent Water Content	Root/Shoot Ratios
1.000	-0.0364	0.3635	0.3070	0.4537	0.0912	0.4734
	1.000	0.0375	0.1044	-0.0938	0.4645	-0.1641
		1.000	0.9909*	0.9655*	-0.6436*	0.8181*
			1.000	0.9216*	-0.6080*	0.7436*
				1.000	-0.6786	0.9193*
					1.000	-0.6841
						1.000

*Significant at p less than 0.05

the seedling parameters which were observable for the remaining locations. Temperatures at location eleven were above average until the outside conditions turned much colder in late November, at which time the temperature fell far below the average. Seedlings at location eleven were subjected to an intense cold air drainage associated with the adjacent exhaust fan. The deviations of seedling parameters from the norm may have occurred because seedlings began to harden off as a result of the change from warmer to colder temperature.

Hardening in the plants would have caused changes in cell chemistry, including increased solute and decreased water content. Initiation of the hardening process in nature has been attributed to a change in one or more of the following: day length, temperature, and soil moisture. The seedlings at location eleven are, therefore, considered to have a known cause of variation.

For these reasons, additional correlations were also calculated for the stationary treatment without the E-3 and location eleven data (Table 9). These correlations, similar to the earlier ones, showed significance at the 95% level for total dry weight, root dry weight, and root/shoot ratio. The occurrence of these significant values with and without the three locations of explainable variation (eight, nine, and eleven) indicates that a direct relationship exists between temperature and total dry weight, root dry weight, and root/shoot ratio. The second part of the null hypothesis is, therefore, rejected. Furthermore, even though not significant, there is a strong correlation between temperature and shoot dry weight for stationary seedlings both with and without the three locations of explainable variation.

TABLE 9

CORRELATION COEFFICIENTS BETWEEN TEMPERATURE AND STATIONARY SEEDLING PARAMETERS WITHOUT E-3 AND LOCATION ELEVEN DATA (d.f. 8)

Temperature	Height Growth	Total Dry Weight	Shoot Dry Weight	Root Dry Weight	Percent Water Content	Root/Shoot Ratios
1.000	-0.4994	0.6909*	0.6148	0.7990*	-0.5523	0.7770*
	1.000	0.1908	0.2693	0.0905	0.2161	-0.0806
		1.000	0.9902*	0.9633*	-0.6565*	0.8102*
			1.000	0.9165*	-0.6083	0.7317*
				1.000	-0.7128*	0.9165*
					1.000	-0.7556*
						1.000

*Significant at p less than 0.05

Other statistically significant correlations are exhibited which are worthy of explanation (Table 6, 7, 8, and 9). Strong correlations are apparent between root/shoot ratios, and total, shoot and root dry weights. They are statistically significant at the 95% level in all correlations for the four groupings of data. Strong inverse, but not significant, correlations can be observed between water content of the shoot and the four above mentioned parameters for the stationary data and for the rotated data (Tables 6 and 7). Without the E-3 data. the inverse associations between shoot water content and total, shoot and root dry weights plus root/shoot ratio were statistically significant for the stationary grouping (Table 8). The stationary grouping without position eight, nine, and eleven had significant inverse correlation between shoot water content and total dry weight, root dry weight, and root/shoot ratio (Table 9). In addition, shoot dry weight exhibited a strong inverse, but not significant, association with percent water content (Table 9).

The water content of the shoot, as defined earlier, was obtained by dividing the milligrams of water by the milligrams dry weight of the shoot. Thus, the relative amount of water in the seedling decreased as weights and root/shoot ratio increased. Since the correlations are statistically significant without the influence of locations eight and nine and significant in all but one case without eight, nine, and eleven; this appears to be a valid observation about seedling water content. The inverse correlation between water content and shoot dry weight may have been related to changes of shoot material from green succulence to woody stems as they increased in size and maturity.

However, the possible relationship between water content of the shoot and the root dry weight was not as easily rationalized until observations of the computer maps indicated the hidden relationship mentioned earlier.

Comparisons of the computer maps for temperature and stationary water content show an inverse relationship of the two parameters except at location eleven (Figures 2 and 12 in computer graphics section). Location eleven was subjected to a temperature change unlike the remaining study positions. Therefore, a correlation coefficient was calculated for temperature and stationary water content of the shoot without the data from position eleven, and this shows a strong inverse correlation (Table 10). Although the correlation is not significant, by removing the explained condition at position eleven, the correlation coefficient

TABLE 10

CORRELATION COEFFICIENTS BETWEEN TEMPERATURE AND PERCENT WATER CONTENT WITHOUT THE DATA FOR LOCATION ELEVEN (d.f. 10)

Temperature	Percent Water Content
1.000	-0.5554
	1.000

*Significant at p less than 0.05

changes from 0.056 to -0.555. This indicates that there was a strong inverse relationship between temperature and water content for the remaining locations. Thus, it would seem logical to conclude that when temperatures were low, root growth was slowed, shoot dry weight was low, and water content was high. Inversely, when average temperatures were high, root growth increased, total dry weight increased, and water content was low.

Comparison Between Rotated and Stationary Mean Values

Differences in average values were calculated by subtracting the rotated averages from the stationary averages for each of the parameters (Table 11). Comparison of the averages for all twelve locations between stationary and rotated groups underlined an interesting relationship. The average height growth, and total, shoot, and root weights were all greater for stationary seedlings than for rotated seedlings. These findings were somewhat contrary to expectation. It had been surmised that rotation would, on the average, have resulted in an increase in height and weight of the seedlings. The stationary treatment may have exhibited larger averages for heights and weights because the trees at each location were adjusted to the microclimate and produced the best possible growth under existing conditions. In contrast, the rotated seedlings would have been constantly readjusting to new situations and unable to maintain optimum growth at each location.

A two sample t-test was used to determine if the average values were significantly different from each other. Statistically significant differences were exhibited in the twelve location grouping for total dry weight, shoot dry weight, root/shoot rotios, and percent water content at the 95% level.

Removing the influence of the fluorescent lights changed the differences in parameter averages. Changes were noted when comparing incandescent averages with the twelve location averages: for incandescent, seedling height became significant at the 95% level and total and shoot

TABLE 11

ROTATED AND STATIONARY MEAN VALUES FOR THE SIX SEEDLING PARAMETERS

	Height (mm)	Total Dry Weight	Shoot Dry Weight (mg)	Root Dry Weight (mg)	Percent Water Content	Root Shoot Ratio
Twelve location						
Stationary	87.16	396.96	289.63	110.02	285.74	0.359
Rotated	83.86	359.88	258.13	101.75	296.96	0.391
Difference	3.30	37.08*	31.50**	8.29	-11.22*	-0.032*
Incandescent						
Stationary	91.94	359.92	266.73	92.19	285.69	0.332
Rotated	82.37	352.16	253.45	98.71	298.06	0.385
Difference	9.57***	7.76	13.28	-6.52	-12.37*	-0.053***
Incandescent without location eleven						
Stationary	93.70	352.44	261.67	89.66	293.63	0.327
Rotated	81.57	352.60	253.52	99.07	298.055	-0.060***
Difference	12.13***	-0.16	8.15	-9.41	-4.425	-0.060***

*Significant at p less than 0.05
**Significant at p less than 0.01
***Significant at p less than 0.001

dry weight lost significance (Table 11). Thus, the influence of the fluorescent lights was to produce shorter, heavier seedlings as suspected originally.

Removal of the location eleven data helped to substantiate one more suspected relationship. Average differences for percent water content for both the twelve location and incandescent data were statistically significant. Without location eleven, the difference in average water content was not significant. The water content at location eleven depressed the stationary average downward, producing a significant difference in the averages. This depression of water content was contradictory to the normal conditions, and thus it seems logical to conclude that the cold air drainage at location eleven was responsible for the change in water content.

From the standpoint of seedling production, these observations illustrate some trade-offs and possible advantages related to the rotation of styroblocks. The root/shoot ratios which developed at some of the locations within the greenhouse were very poor[2] in terms of preparing a seedling for outplanting (for example, location four had a ratio of 0.195). The rotation of styroblocks resulted in significantly better ratios and should be considered for future crops of coniferous trees grown in the Forestry Greenhouse. The stationary treatment, in contrast, without the fluorescent data was responsible for better height growth. Height growth alone, according to Larson (1974), is not considered a good indicator of readiness for outplanting. Total, shoot and root dry

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[2]The "very poor" root/shoot ratio is in reference to local conditions where summer drought and dry soil conditions dictate the need for seedlings with large root/shoot ratios.

weights were, however, considered better indicators of seedling development. Without the fluorescent data, the differences in parameter averages were not significant. Therefore, rotation has been cited as producing seedlings which were more uniform in size, had significantly better root/shoot ratios, and slightly but not significantly lower weights. On the other hand, stationary treatments produced seedlings which were significantly taller and heavier, but had less favorable root/shoot ratios and varied significantly in size and weight.

CHAPTER V

COMPUTER GRAPHICS

The statistical analysis of the temperature and plant growth parameters indicates that there was considerable variation in growth of _Pinus ponderosa_ seedlings within the Forestry School Greenhouse. Statistically significant values were obtained for most parameters for both rotated and nonrotated treatments. However, the graphic comparisons of rotated and stationary parameters show considerable constrasts among treatment variations. The graphics were created on the University of Montana DEC system 10 using a Calcomp plotter. The SYMVU mapping program was used and executed with a data file created by the SYMAP program. The SYMAP program generated the data file by interpolating values for coordinates between the specified data points. Thus, for the greenhouse study, a base map was created with twelve data points (Figure 1). Each of the thirteen maps were then created by inputting the appropriate location averages for each of the seedling parameter groups.

Data for all thirteen maps were truncated to allow for visual representation of the variation. The truncated ranges for each of the six seedling parameters were set equal for the rotated and stationary treatments. Thus, the truncation allowed for each pair of maps to be graphed on equal scales. Ranges were set slightly larger than the spread of the stationary data which, in all cases, were the greatest (Table 12). The stationary-to-rotated range ratios were obtained by dividing the range of the stationary parameters by the range of the rotated parameters. The value generated was an expression of how many times larger the stationary range was compared with the rotated range.

Maps were drawn using an azimuth of 135^{o}C (Figures 2-14). The projections were made as if the viewer were looking down from the north-west corner of the east room (i.e., from the top left hand corner of Figure 1).

Temperature

Coldest temperature occurred near the two outside walls and temperature generally increased from north to south (Figure 2). The highest temperature occurred on bench E-3 under the fluorescent lights. A severe temperature depression at position eleven was caused both by shading and by cold air drainage associated with the nearby exhaust fan. It is likely that temperature generally increased from the north to the south side of the room because of differences in daytime solar radiation. The further north in the structure, the more obstructions there were to light penetration.

High temperatures at locations eight and nine were probably related to three phenomena: radiation of heat from the lamps, reradiation of heat from lamps and fixtures of heat originating from the bench and steam pipes, and radiation of heat from the densely packed seedlings due to the high light intensity.

TABLE 12

TRUNCATION AND RANGE DATA FOR COMPUTER MAPS

Parameter	Treatment	Minimum and Maximum	Range	Truncated Range	Stationary Rotated Ratio	Figure #
Temperature		14.28°C - 19.92°C	5.64	6.14		2
Height	Stationary	58.5 - 116.9 mm	58.4	60		3
	Rotated	65.3 - 93.8 mm	28.5	60	2.05	4
Total dry weight	Stationary	153.4 - 682.9 mg	538.2	540		5
	Rotated	290.2 - 407.1 mg	116.9	540	4.60	6
Shoot dry weight	Stationary	120.6 - 455.1 mg	334.5	336		7
	Rotated	202.8 - 290.4 mg	87.6	336	3.82	8
Root dry weight	Stationary	24.1 - 227.8 mg	203.7	205		9
	Rotated	78.0 - 125.8 mg	47.8	205	4.26	10
Root/Shoot ratio	Stationary	0.195 - 0.496 mg	0.301	0.302		11
	Rotated	0.333 - 0.454 mg	0.121	0.302	2.52	12
Percent water content	Stationary	214.1 - 341.2 %	127.1	128		13
	Rotated	279.9 - 325.3 %	45.4	128	2.80	14

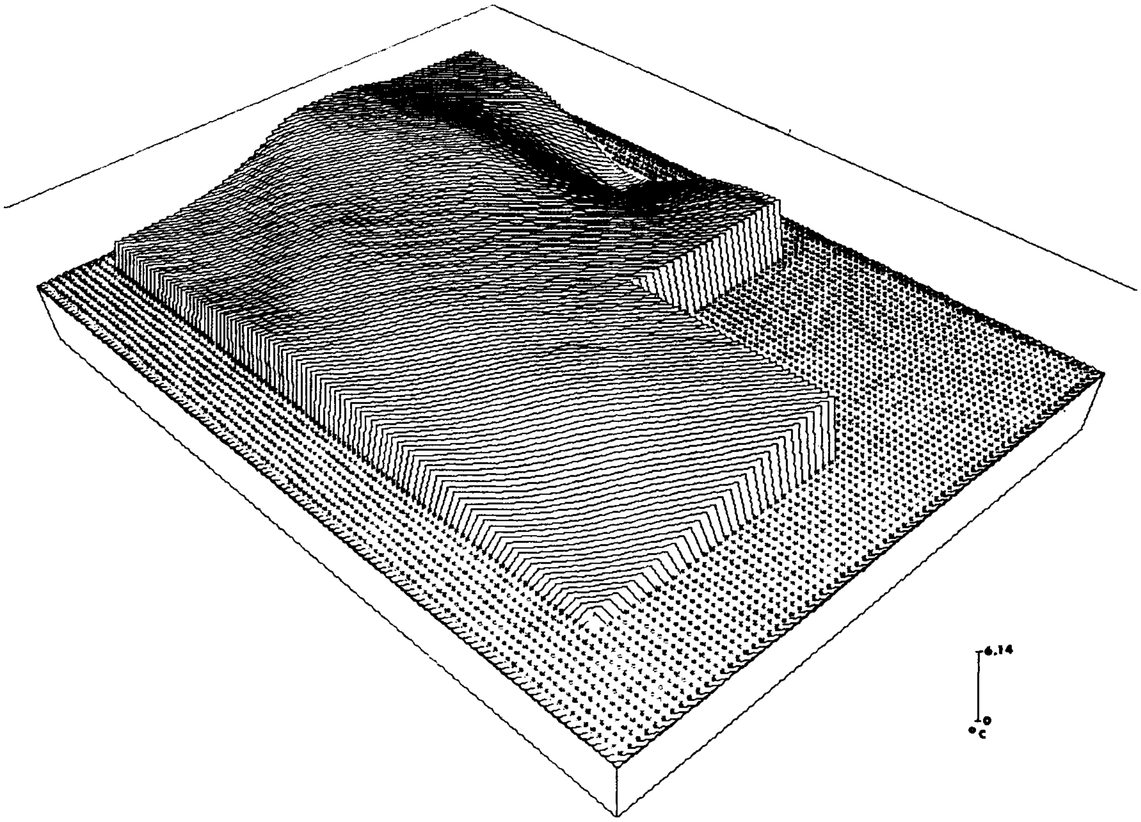

Figure 2. Average temperature in the east room of the Forestry School Greenhouse.

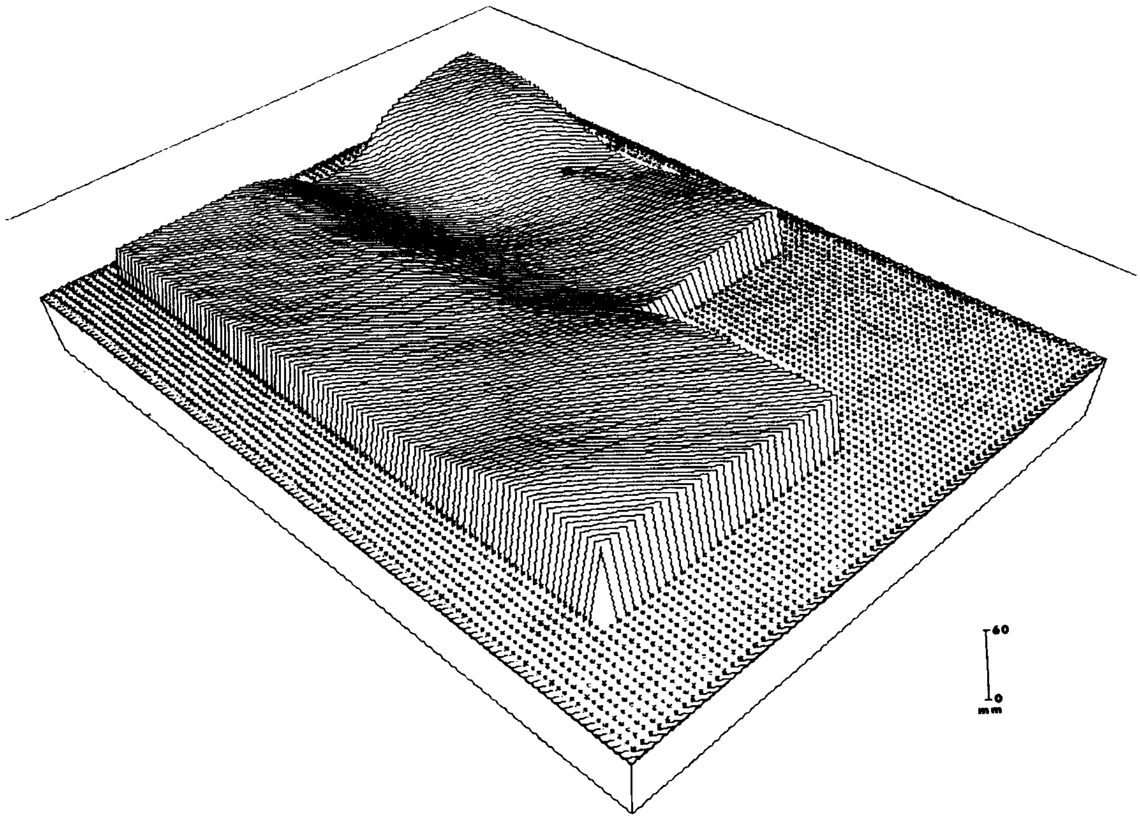

Figure 3. Stationary seedling height growth averages in the east room of the Forestry School Greenhouse.

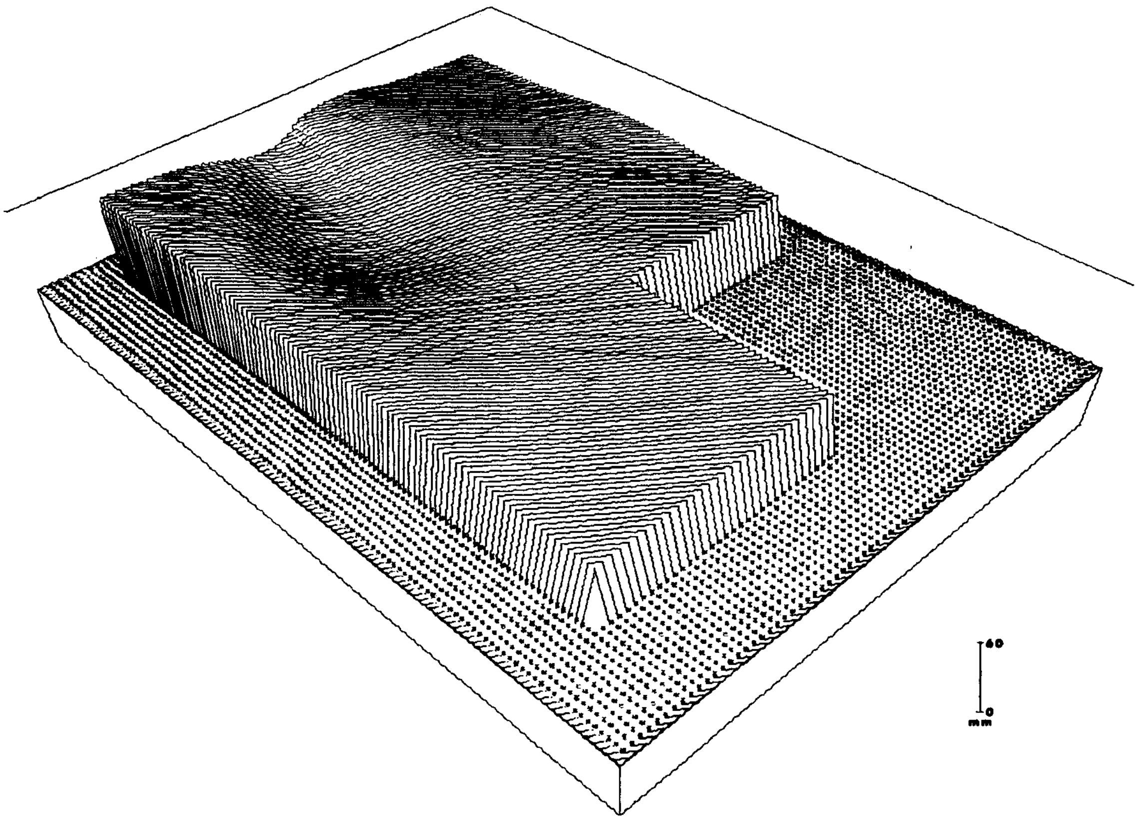

Figure 4. Rotated seedling height growth averages in the east room of the Forestry School Greenhouse.

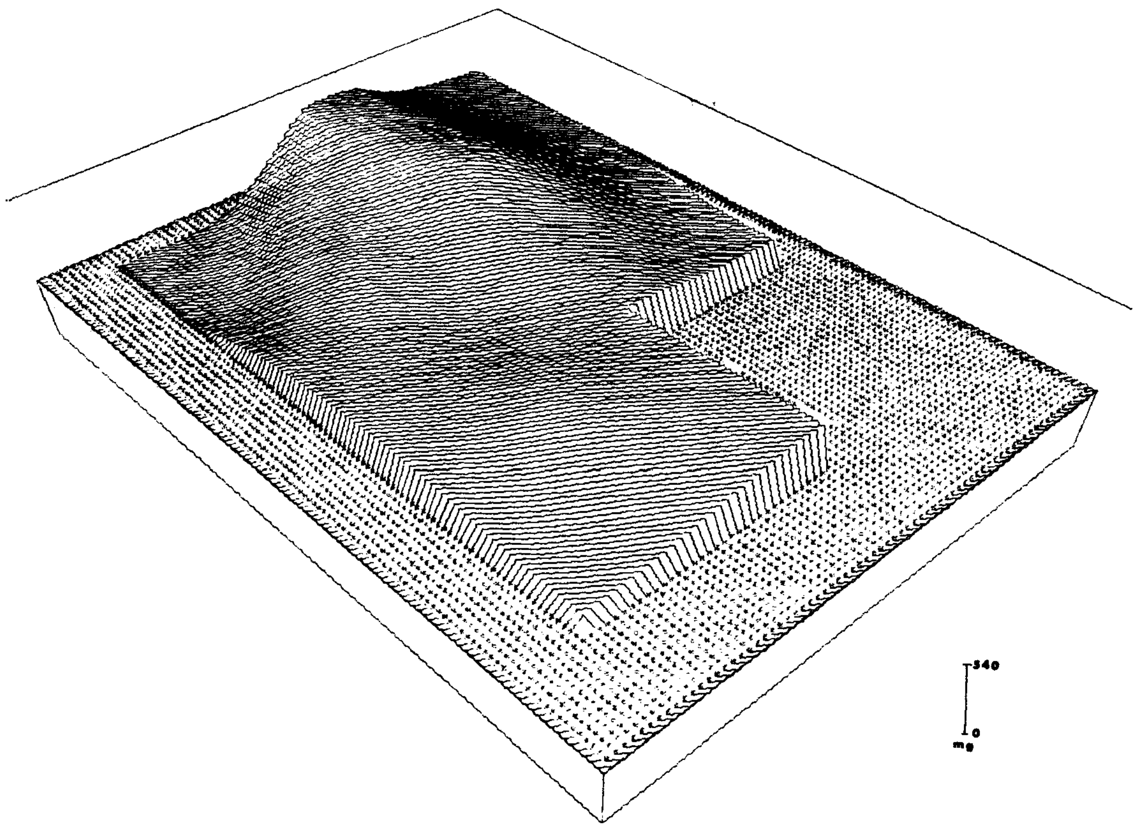

Figure 5. Stationary seedling total dry weight averages in the Forestry School Greenhouse.

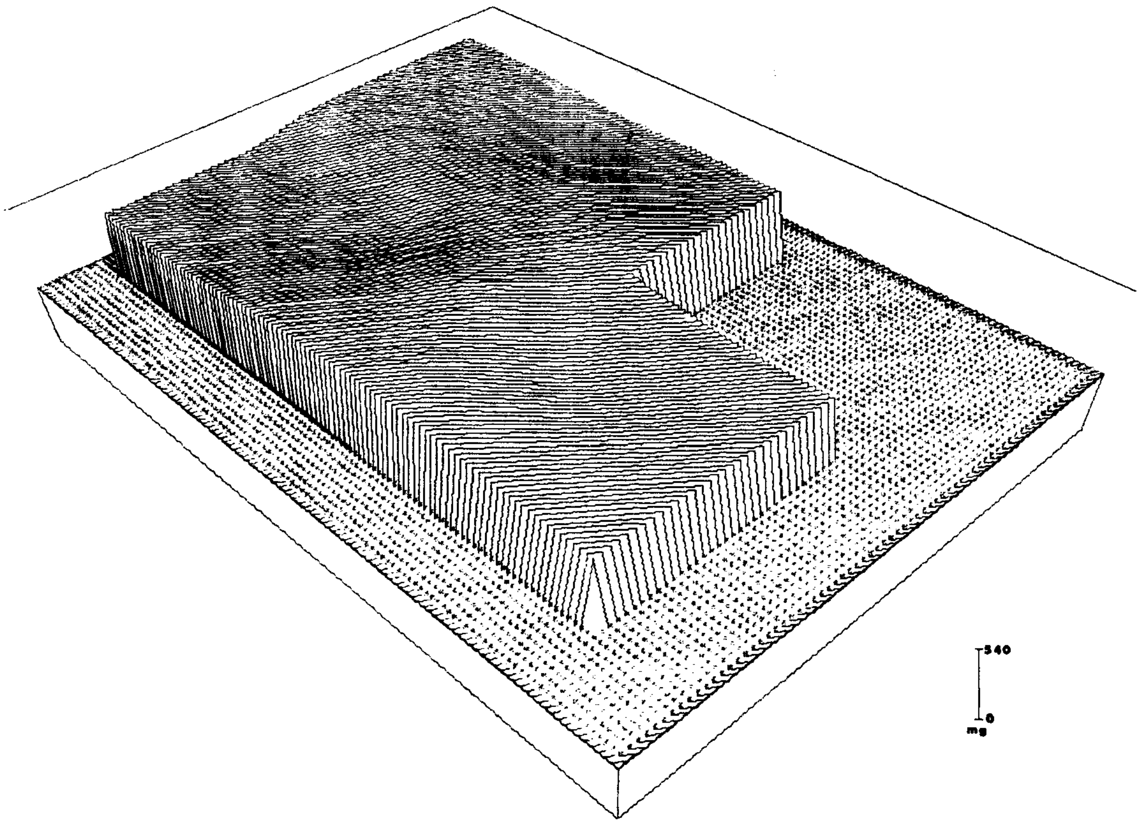

Figure 6. Rotated seedling total dry weight averages in the east room of the Forestry School Greenhouse.

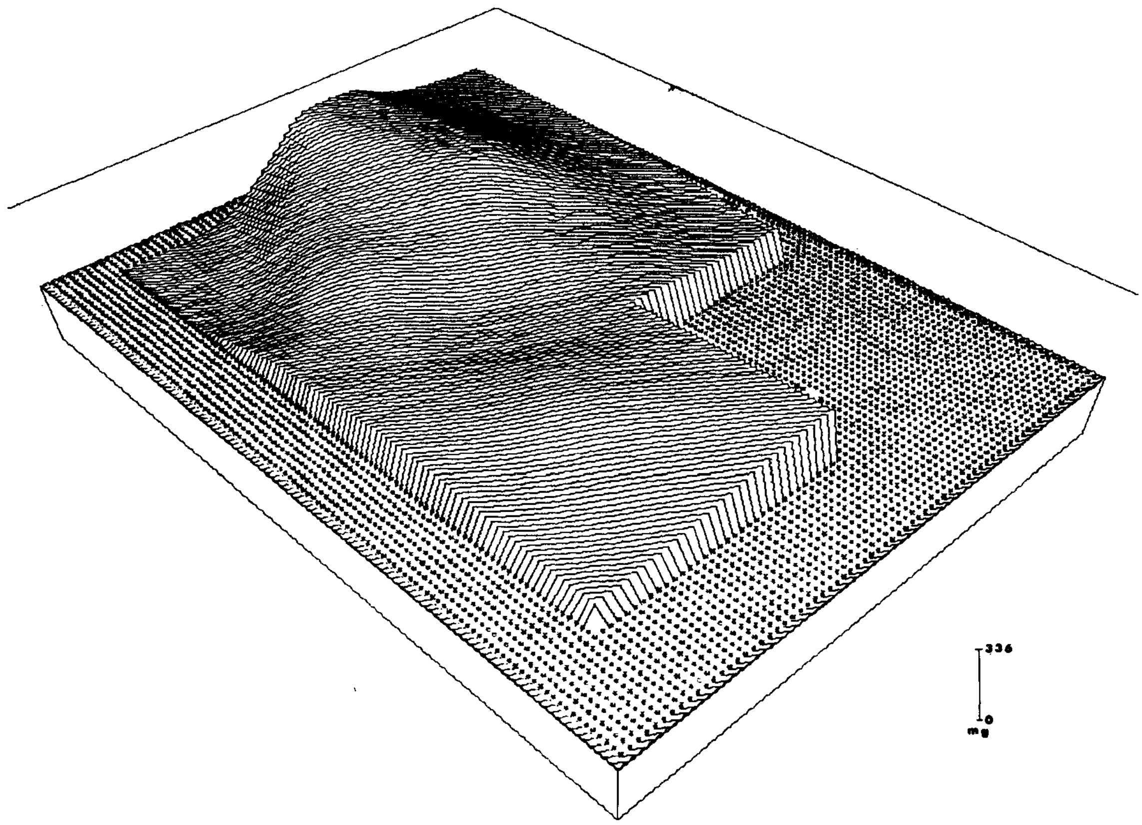

Figure 7. Stationary seedling shoot dry weight averages in the east room of the Forestry School Greenhouse.

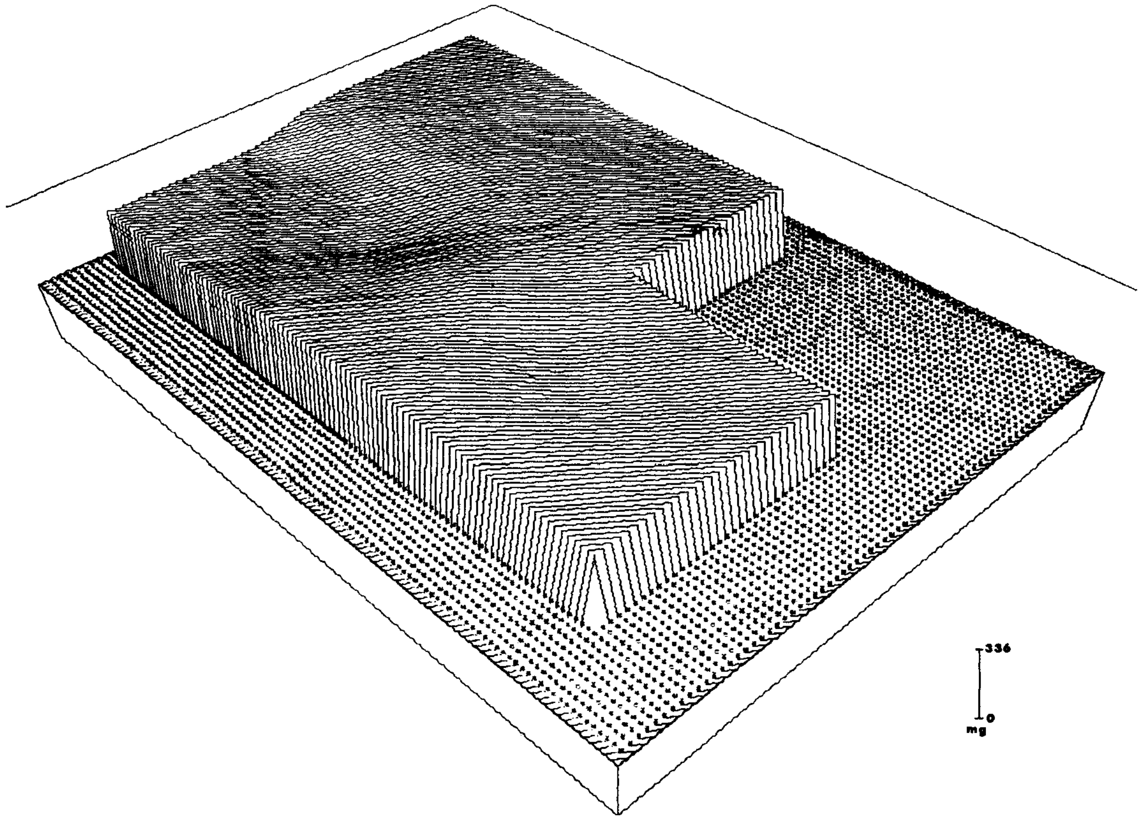

Figure 8. Rotated seedling shoot dry weight averages in the east room of the Forestry School Greenhouse.

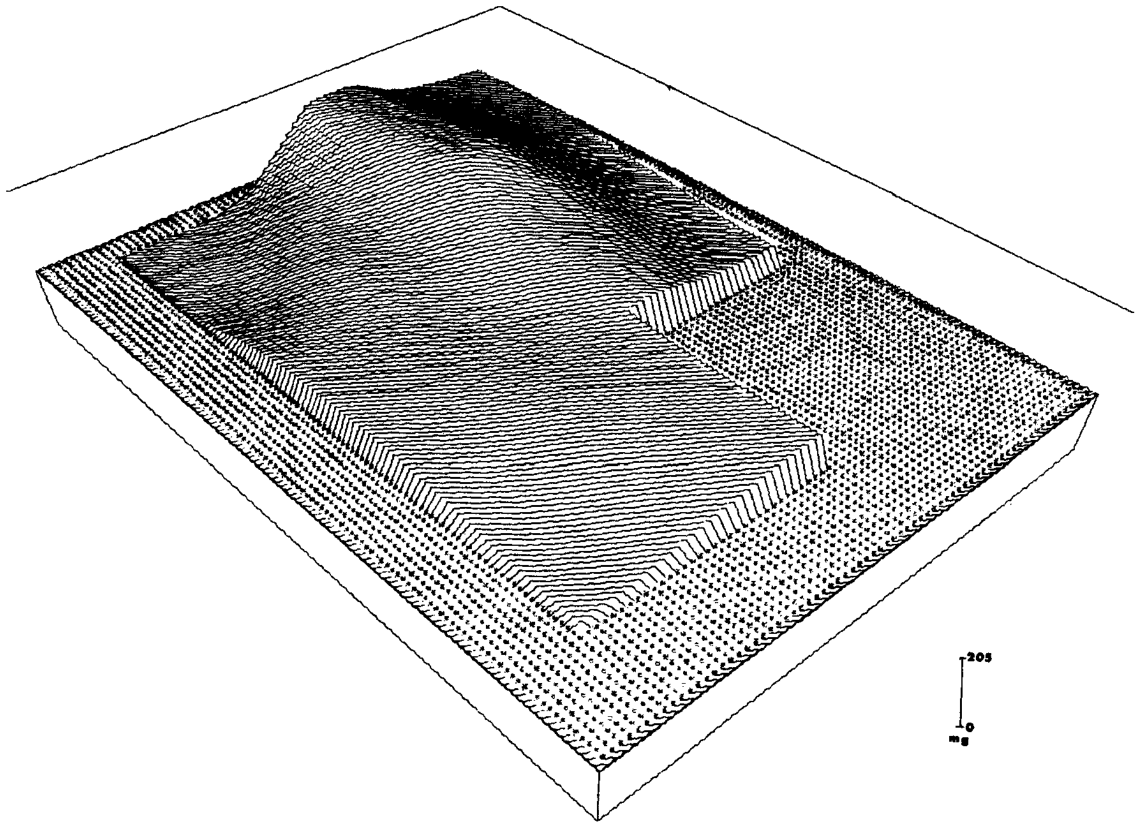

Figure 9. Stationary seedling root dry weight averages in the east room of the Forestry School Greenhouse.

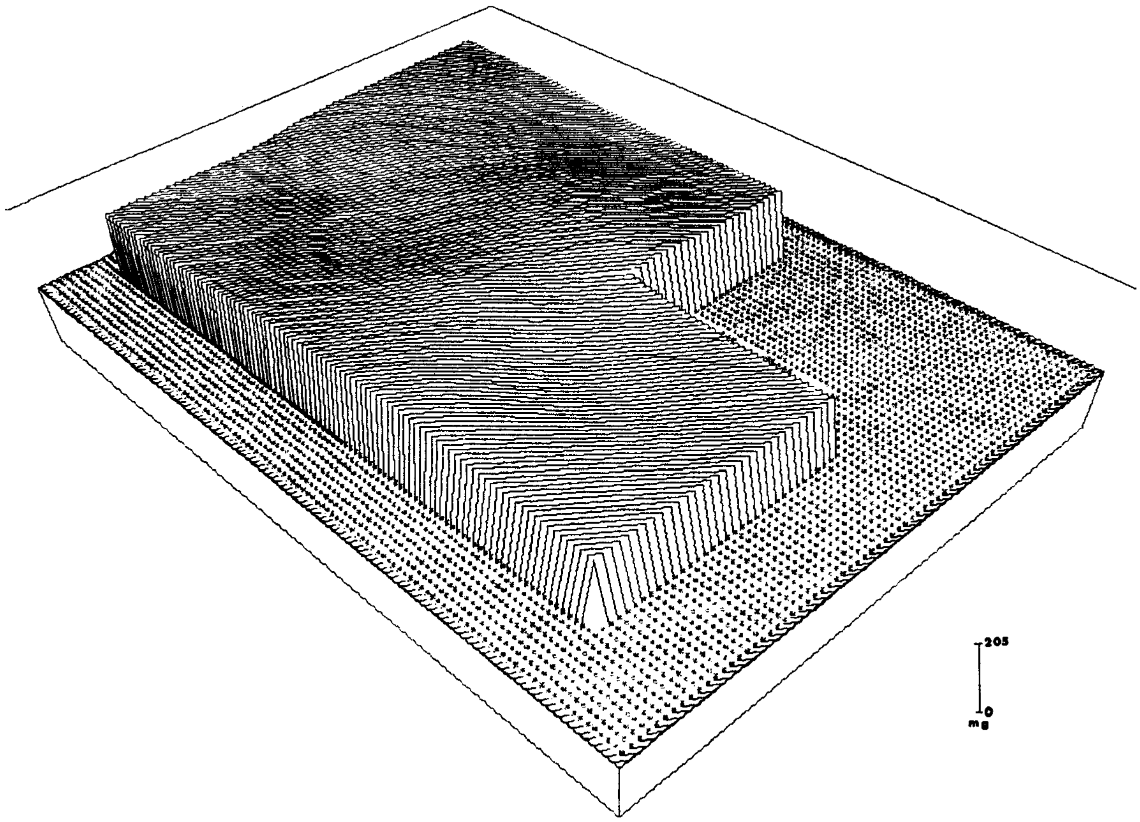

Figure 10. Rotated seedling root dry weight averages in the east room of the Forestry School Greenhouse.

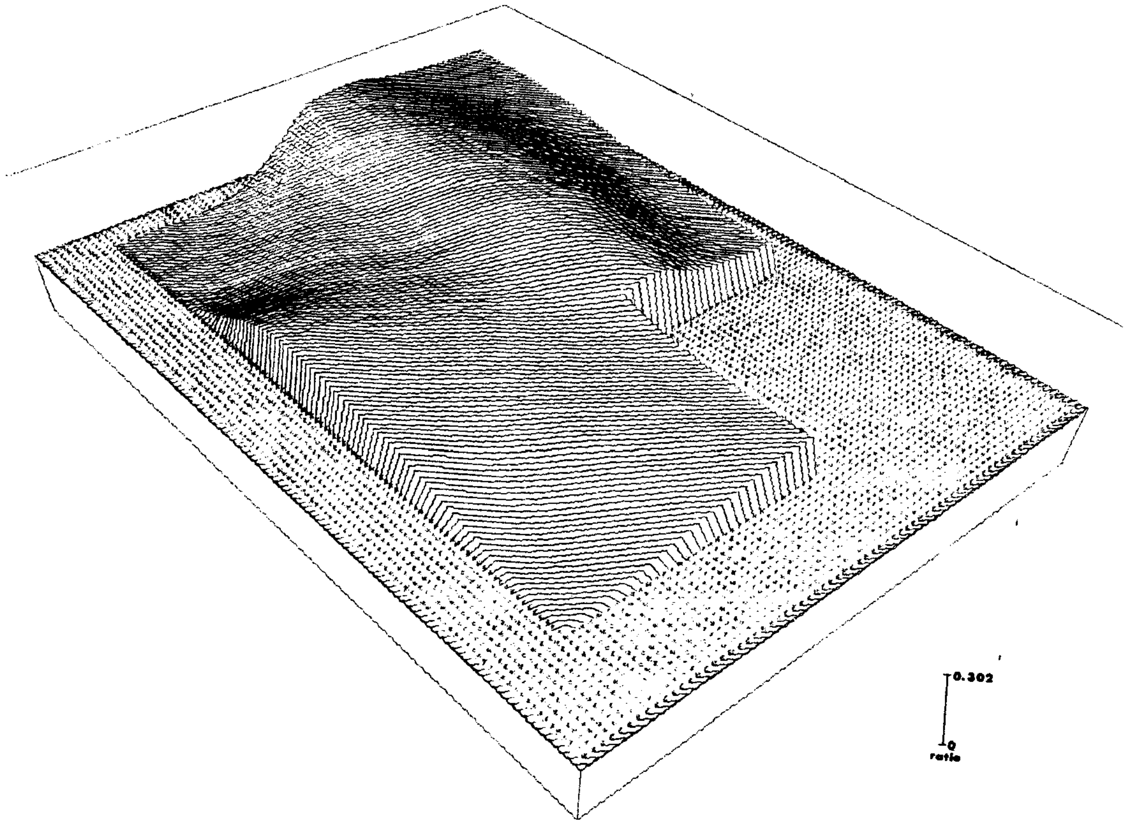

Figure 11. Stationary seedling root/shoot ratio averages in the east room of the Forestry School Greenhouse.

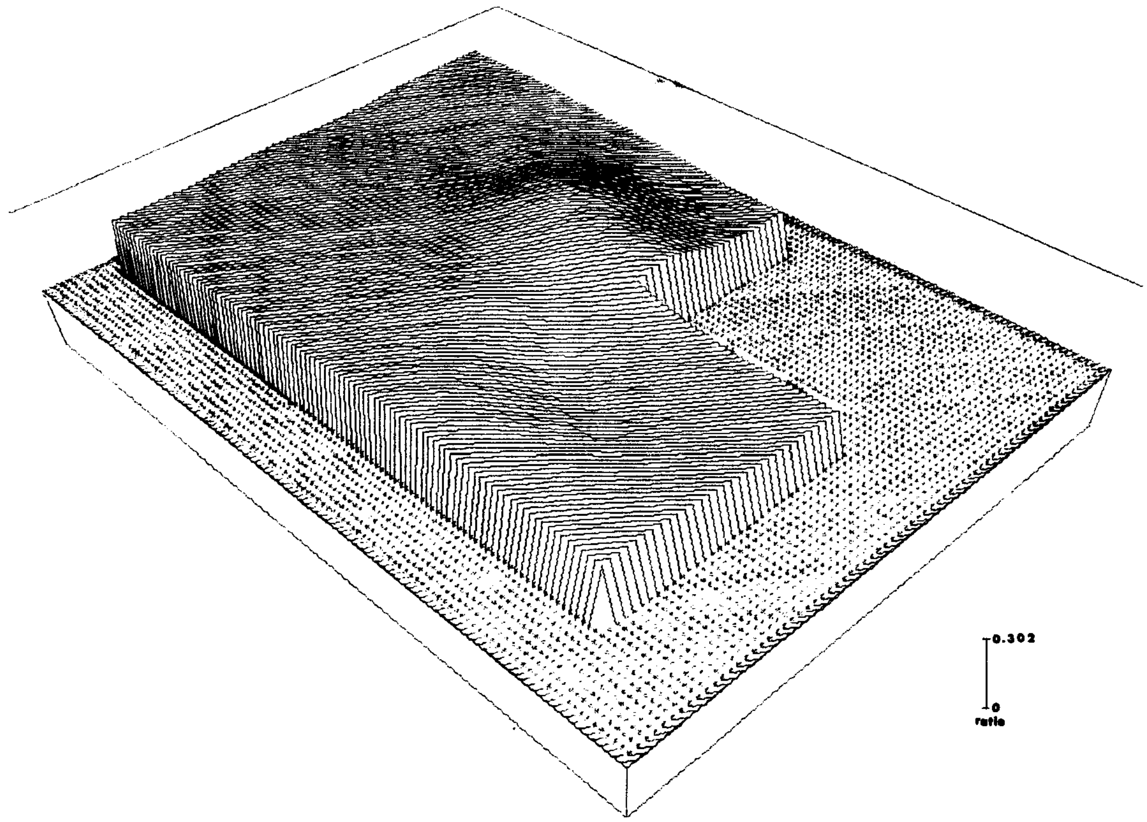

Figure 12. Rotated seedling root/shoot ratio averages in the east room of the Forestry School Greenhouse.

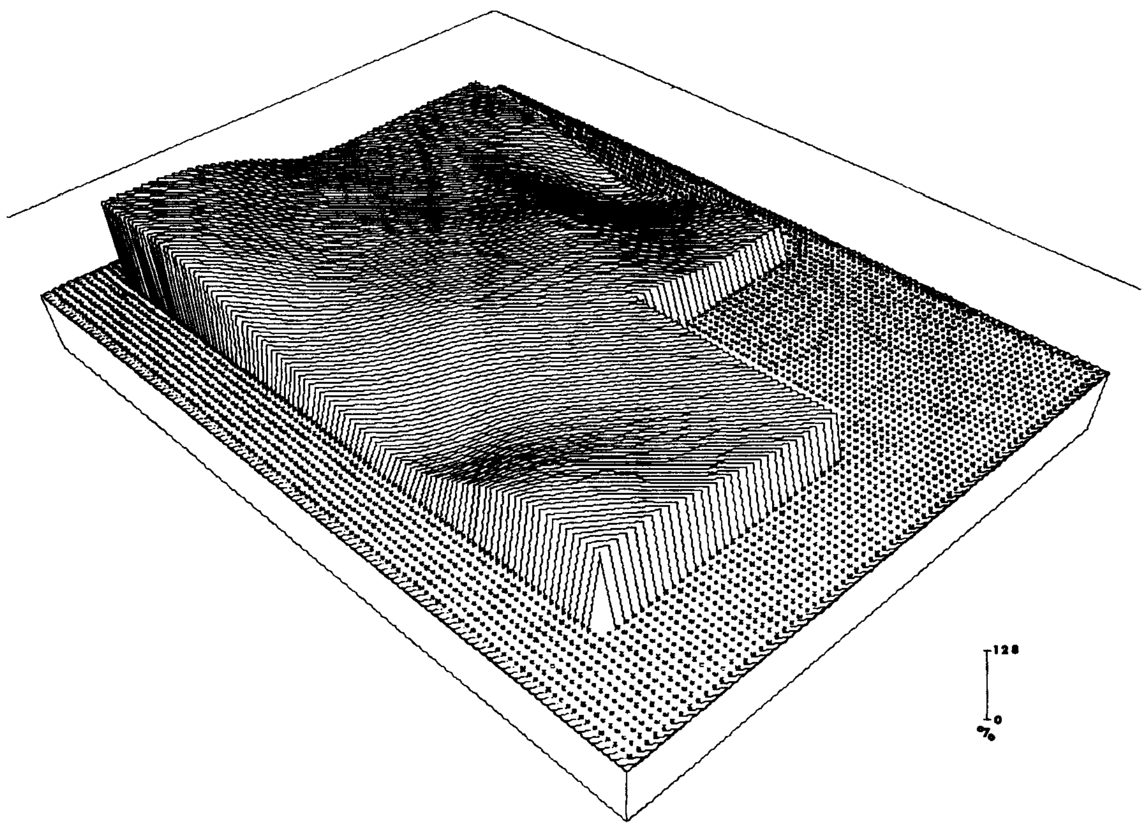

Figure 13. Stationary seedling percent water content of shoot averages in the east room of the Forestry School Greenhouse.

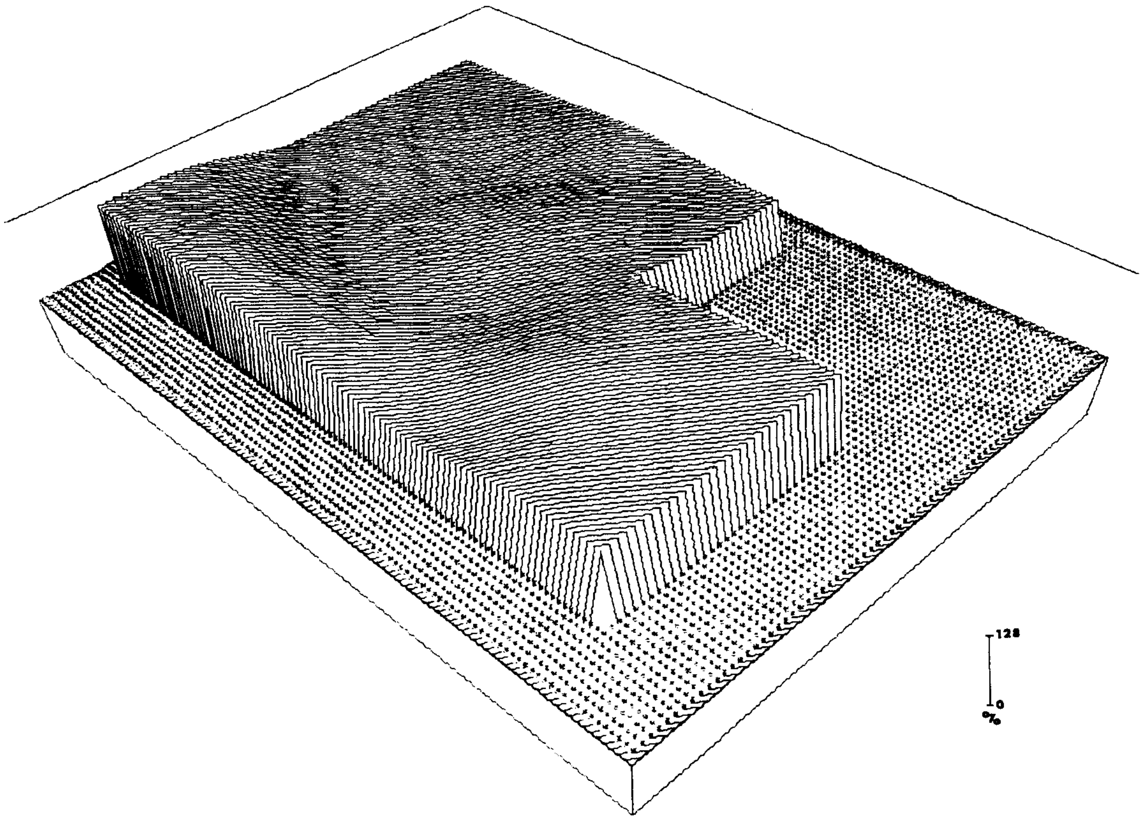

Figure 14. Rotated seedling percent water content of shoot averages in the east room of the Forestry School Greenhouse.

Height

Height growth of stationary seedlings showed a nonsignificant but inverse relationship with temperature. Bench E-3, for example, exhibited the highest temperatures and the lowest height growth. Location one, however, had a low temperature and the tallest seedlings. And, at location eleven, low temperatures and short seedlings were found. Part of the relationship between temperature and height may be better explained by including the variables of light quality and intensity. The fluorescent lights over bench E-3 emit most of their spectral energy within the 400-650 nm region; thus, shorter and heavier plants should have been produced. Incandescent lights, however, such as those located over benches one, two, and four, would have tended to produce elongated plants because the wavelength energy peaks in the 700-800 nm region associated with shoot elongation. (Substantiation for these relationships is available in several sources, including Ekblad 1973).

Conditions at location eleven are less easily explained. Temperatures during October and early November were in the same general range as those for locations ten and and twelve. However, when the outside temperatures turned colder from late November to January, the temperatures at location eleven dropped 3-6^{o}C below the other two locations on bench four. Thus, the first part of the growing period was consistent with locations ten and twelve and provided the seedlings with above average growth conditions. After the temperature turned colder, the seedlings appeared to have been stunted.

Comparisons of height growth for both stationary and rotated styroblocks reveal a pattern which was repeated for all of the seedling parameters (Figure 2 and 5). Stationary seedlings exhibited a far greater variation in growth than did seedlings within the rotated styroblocks. Each of the paired treatments, stationary and rotated, as noted above, was plotted on an equal scale showing maximum relief. Average height of the stationary seedlings ranged from 58.5 to 116.9 mm, compared with rotated seedlings which ranged from 65.8 to 93.8 mm tall. Ranges for the data were, respectively, 58.4 and 28.5; and a stationary/rotated ratio of 2.05 was found. Height growth of the seedlings exhibited the most visible fluctuation among the seedling parameters. This variation may have been the result of several factors, including temperature changes during the study period and temperatures during the first few days of the study.

Total, Shoot, and Root Dry Weights

Total dry weight of the stationary seedlings was directly correlated with temperature. The visualizations of temperature variation and total dry weight are, therefore, strikingly similar (Figures 2 and 5). Depressions occurred at locations one and four and a rise was obvious at bench three on both maps. A departure from the norm occurred at location eleven where total dry weight was about average and temperature was severely depressed. The map for rotated total dry weight is almost flat, thus exhibiting less variation than for the stationary weights (Figure 6). The stationary seedlings had location averages varying between 153.4 to 682.9 mg (a range of 538.2 mg). Rotated groups averaged from 290.2 to 400.1 mg (a range of 116.9 mg). The stationary/rotated ratio had the greatest value of 4.60.

The temperature correlation with root dry weight is significant. Correlation between temperature and shoot dry weight is not significant, however. Nevertheless, the similarities between maps of temperature and stationary shoot, root, and total seedling weights are readily apparent (Figures 2, 7, and 5). The reason for nonsignificant correlation between shoot dry weight and temperature is undetermined. Stationary shoot and root dry weights, which are combined to produce total dry weight, are similar in variation. Both root and shoot dry weights show depressions at locations one and four and the same rise at locations eight and nine (Figures 7 and 9). The rotated maps for root and shoot dry weight follow the norm in that they are relatively level in comparison with their paired counterparts (Figures 8 and 10). The range of average dry weight for stationary seedlings was from 120.6 to 455.1 mg and for rotated it was from 202.8 to 290.4 mg. The ranges were 334.5 and 87.6 mg and yielded a stationary/rotated ratio of 3.82. The respective ranges for stationary and rotated root weights were 24.1 to 227.8 mg and 78.0 to 125.8 mg, with ranges of 203.7 and 47.8 mg, respectively. The figure of 4.26 for stationary/rotated ratio was the second largest among the six seedling parameters.

Root/Shoot Ratios and Percent Water Content

The stationary root/shoot ratios (Figure 11) are highly correlated with temperature variation. Similar research, done at the Champion Timberlands Greenhouse in Bonner, Montana, during the winter of 1976-77, resulted in root/shoot ratio figures which averaged larger than the best ratios in the Forestry Greenhouse for equivalent periods of time. The Forestry Greenhouse, in general, produced an environment favorable to shoot development. The Bonner facility promoted root growth while also producing good shoot growth. The major heating differences between greenhouses were as follows: steam heat under cement benches in the Forestry Greenhouse and forced air heat under wire screen benches in the Bonner Greenhouse. Thus, in the Forestry School Greenhouse, warm air was forced out from under the benches, moved upward, and warmed the structure from the roof down to the seedlings. Moisture from watering of seedlings was often retained under the styroblocks even though the containers were supported above the benches to allow for air circulation. This indicated that the tops of the benches were remaining cold. In the Bonner facility, the warm air moved up under the styroblocks as well as between the benches. Thus, the seedlings were warmed from above and below. Because soil temperature has been shown to be directly related to root development (Larson 1967), the better root/shoot ratios in the Bonner Greenhouse may have resulted from the warmer temperature of the soil medium. Larson (1967) assumed that constant air temperature in a controlled environment would result in soil temperature being nearly the same as air temperature. Therefore, the soil medium temperature of the test styroblocks should have been directly related to the recorded air temperatures.

Most of the seedlings from locations one and four, when pulled out of the growing medium, exhibited only a single poorly developed root. Concurrently, the number one position produced the tallest seedlings. Positions one and four had the second and third lowest temperatures and second and first lowest root dry weight, respectively. The lowest average temperature occurred at location eleven. However, as noted earlier, the temperature at location eleven went from above average to below average when the outside temperatures dropped in late November. This contrasted greatly with locations one and four which maintained below average temperature throughout the study. The root/shoot ratios were better where dry weight production was better and temperature warmer. The rotated root/shoot ratio map followed the established pattern of exhibiting less variation than the stationary root/shoot ratio map (Figure 12). Stationary root/shoot ratios ranged from 0.195 to 0.496 and rotated ratios ranged from 0.333 to 0.454. The range of the data were 0.301 and 0.121, with an associated ratio of 2.52.

The percent water content of the shoots was obtained by dividing the weight of the water in the shoot by the dry weight of the shoot. It had been hypothesized that this parameter would vary directly with existing temperature. By comparing the stationary percent water and temperature maps without location eleven, the inverse relationship becomes readily apparent (Figures 13 and 2). Locations one and four were the coldest and had the highest water content. Bench three exhibited a depression of water content and a rise of temperature. The correlation between temperature and water content for all twelve locations was, however, almost nonexistent. This was due in part to the low temperature and water content at location eleven. Correlation between temperature and water content without location eleven exhibited a strong inverse relationship. The rotated percent water content map shows expected characteristics for rotated parameters by expressing far less variation than the stationary maps (Figure 14). The average water content of seedlings in stationary locations varied from 214.1 to 341.2%.

Rotated seedling water content ranged from 279.9 to 325.3%. The stationary range value of 127.1, divided by the rotated value of 45.4, yielded a ratio of 2.80.

CHAPTER VI

DISSCUSSION

The influences of environmental conditions within the Forestry School Greenhouse should be considered when seedlings are grown in the future. Rotating the styroblocks resulted in seedlings which were more uniform in size and weight and had better root/shoot ratios. The rotated seedlings were, as a group, much better suited for outplanting and survival than were seedlings not rotated.

Future research projects in the east room should be designed to minimize the microclimatic variation. The conditions existing from October 6, 1976 through January 10, 1977 did not promote uniform climatic conditions nor uniform seedling development. Statistically significant locations effects were observed even though the experimental material was treated alike. Temperature was shown to be significantly correlated with total dry weight, root dry weight, and root/shoot ratio. The rotation of seedlings on a four-day interval helped minimize, but did not eliminate, the influence of microclimate variation upon growth. A shorter rotation schedule might have reduced variation even more.

The Forestry School Greenhouse has the potential to produce a more uniform environment. Several renovations could make this possible. The following suggestions are presented with two limitations: the author is not trained in either engineering or architecture, and the renovation suggestions are based on personal observations which seem to be substantiated by this research work. These recommendations are presented for only one reason: to provide the Forestry School with ideas on how to improve the existing facility if a decision is made to do so.

General Recommendations

1. Paint windows yearly.
2. Make second set of vent windows automatic in all rooms.
3. Centralize thermostat controls in east room.
4. Install a thermostat for control of water circulation in evaporation cooling system.
5. Install outside coverings for evaporation cooling system which are thermostatically controlled.
6. Maintain all equipment regularly.

Specific Recommendations

1. For research work: install automated watering and fertilizing systems.
2. For seedling production:
    a. Remove cement benches in east room and replace with wood and/or metal bench supports with fencing wire tops.
    b. Lower steam heating pipes and install heat deflectors in conjunction with new benches.

CHAPTER VII

SUMMARY

Containerized ponderosa pine seedlings were grown for a ninety-six day period in the Forestry School Greenhouse. The seedlings received equivalent care so that the tested variable would be microclimatic variation. Seedlings were divided into two groups--stationary and rotated--and were placed in twelve locations. Values for six seedling parameters were obtained: height growth, total dry weight, shoot dry weight, root dry weight, percent water content, and root/shoot ratio. Temperature was measured at each location on a continuous basis excepting periods of recorder malfunctions. Four procedures were used in evaluating the data: analysis of variance, correlation coefficients, two-sample t-test, and computer graphics.

Temperature and the seedling parameters showed statistically significant differences among locations, with the exception of rotated root/shoot ratio; thus indicating that neither temperature nor seedling development was the same for the twelve locations. Even with rotation of test material, seedling development was not the same except for root/shoot ratios. (Since root/shoot ratio is important in seedling production for planting, this is a useful concept). The significant values for the five rotated parameters were the result of continuously changing conditions within the structure and a sensitive f-test. The f-values for rotated seedlings were all less than those for staionary seedlings. Comparison of paired computer maps for the six parameters also indicated that variation among rotated locations was less than variation among stationary locations.

Significant associations were found between temperature and total dry weight, root dry weight, and root/shoot ratio for all twelve locations. No significant associations were found between temperature and the rotated parameters. When the two locations of known variation, eight and nine, were removed from statistical analyses, no significant correlations were found for the stationary parameters. In contrast, after removal of the suspected source of variation at location eleven in addition to eight and nine, significant correlations between temperature and total dry weight, root dry weight, and root/shoot ratios were again exhibited. Thus, when combining the results of the f-values and correlation coefficients, the following conclusions appear reasonable: 1) temperature and seedling development were not equal among locations; 2) temperature was significantly associated with total dry weight, root dry weight, and root/shoot ratio. Therefore, variation in seedling development was probably directly related to temperature variation.

Significant associations were also found to exist between root/shoot ratios, total dry weight, shoot dry weight, and root dry weight for all comparison. Although results are inclusive, inverse relationships also seem to exist between percent water content and temperature, total dry weight, shoot dry weight, root dry weight, and root/shoot ratio.

On the average, rotated seedlings did not develop as well as stationary seedlings. It has been hypothesized that this was because the stationary seedlings adapted to the environment and grew at the fastest rate during the study period. In contrast, the rotated seedlings would have had to readjust to different growing conditions every fourth day. Fluorescent lights were shown to produce heavier, shorter seedlings, as expected. Location eleven was also shown to have significant influences upon percent water content of the shoot.

Computer graphics showed that the amount of variation among rotated parameters was less than the variation for stationary parameters. The computer graphics helped to visualize the influence of the fluorescent lights and to make comparisons between temperature and seedling parameters. The maps were also helpful in explaining the conditions at location eleven where there was an unusual temperature change.

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