AN ABSTRACT OF THE THESIS OF

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Title: Comparative Drought Tolerance Of Four Mexican Pine Species

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Forest tree nurseries in Mexico produce millions of seedlings per year. This is accomplished with high financial investment and unsatisfactory quality control of seedlings. Drought is a major stress factor in México. Thus, planting drought tolerant pine seedlings on dry sites will result in better survival and growth of seedlings.

The main objective of this research was to gain information on drought tolerance developed in containerized Mexican pine seedlings. Specific objectives were to compare 1. growth of four species subjected to different watering regimes in the greenhouse; 2. survival and growth of the same pre-conditioned seedlings at two outplanting locations; and 3. survival, growth, and transpiration rates of the pre-conditioned seedlings under three controlled levels of drought stress.

Seedlings were grown for one season under three distinct watering treatments arbitrarily called wet, intermediate, and dry regimes. Some of the seedlings were later subjected to three levels of drought stress called low, moderate, and high. Others were outplanted in the

Oregon Coast Range and in Central México.

Differences among seedling response to the watering regimes varied by species in the greenhouse. _Pinus patula_ was the species whose growth was most affected by the dry treatment.

Seedling performance of the two outplantings did not show interaction between watering regimes and species in any of the variables. The watering treatments previously carried out in the greenhouse did not have any effect on seedling field performance. Excellent survival in the Oregon Coast Range contrasted with poor survival in Mexico.

Seedlings in the various drought levels reacted differently depending on their previous watering regimes. Seedlings under high stress previously subjected to the dry treatment survived better than those of the other watering regimes.

The differences among the drought levels varied by species. The survival, as well as morphological and physiological characteristics of _Pinus greggii_ were the least affected by the levels of stress. _Pinus patula_ was the species most affected in terms of survival and diameter growth. Its transpiration rate was intermediate.

Pinus pseudostrobus var. _apulcensis_ transpired more than the other species. However, it was intermediate for most growth measurements. _Pinus montezumae_ transpired less than the other species and survival was intermediate.

Comparative Drought Tolerance Of Four Mexican Pine Species

by

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COMPARATIVE DROUGHT TOLERANCE Of FOUR MEXICAN PINE SPECIES

I. INTRODUCTION

STATEMENT OF THE PROBLEM

The reforestation programs carried out in México are mainly concerned with soil protection. Few programs are related to planting fast growing species for pulp production.

Of the total reforested areas, it has been estimated that less than 50% have produced satisfactory results in terms of high seedling survival (Cuevas, 1984). Some of the major factors responsible for the failures in reforestation are related to social problems, uncontrolled burning, lack of precipitation during most of the year, inadequate site preparation, poor handling of planting stock, and lack of maintenance at the planting site.

In the 1980's, the trend has been toward increasing the number of forest tree nurseries in the country rather than increasing seedling quality control. The container system predominates and is very labor intensive.

A few nurseries produce millions of seedlings per year. This is accomplished with high financial investment and unsatisfactory quality control of seedlings.

A survey of the operating practices of 140 nurseries in Mexico showed that irrigation is usually performed three times a week (Cuevas, 1984). Very often this cultural practice has been done without taking into account differences in species, soil texture, nursery climate, and lifting date.

Few studies in México have evaluated the physiological condition of forest tree seedlings as affected by nursery cultural practices and their impact on field survival and growth (Salinas, 1975; Vargas, 1985).

The ability of a plant to survive and grow on a particular site depends, in part, on physiological and morphological characteristics developed in the nursery by cultural practices. These practices, therefore, can be partly reflected in the seedling field performance; other factors are the genetic information of the species and the environment of the planting site.

It is essential to know how irrigation practices affect the tolerance of seedlings to drought and subsequent survival and growth for individual pine species. This information should provide Mexican nurserymen with an economical method of improving drought tolerance in pine species.

Drought is a major stress factor in México, because precipitation is often absent 7 to 8 months a year. Thus, planting drought tolerant pine seedlings on dry sites should result in better survival and growth of seedlings. Proper information will also help to foresters in Mexico to understand the range of conditions necessary for succesfully planting these species.

In this study, seedlings were grown in a greenhouse under three distinct watering regimes arbitrarily called wet, intermediate, and dry treatments. They were later subjected to three levels of drought stress called low, moderate, and high. These stress levels were used to simulate what occurs in natural conditions. Four Mexican pine species were used. Seeds were collected in the Central and Southern regions of México. Five thousand seedlings were grown in containers in a research greenhouse at Oregon State University and hardened-off at the Beaver Creek Nursery of the USDA Forest Service, 15 miles southwest of Corvallis, Oregon.

PURPOSE OF THE STUDY

The main objective of this research was to gain information on drought tolerance developed in containerized pine seedlings during the nursery period.

The specific objectives were:

1. To compare the survival and growth of *Pinus montezumae* Lamb., *P. pseudostrobus* var. *apulcensis* Martinez, *P. patula* Schl. et Cham., and *P. greggii* Engelm., subjected to three different watering regimes

while being grown in a greenhouse for one year.

2. To compare the field survival and growth of these species at two different locations, the Oregon Coast Range and Tlaxcala, State of México, 10 months following outplanting.
3. To conduct a drought study for the species mentioned above and to compare the survival, growth, and transpiration, among the species after being grown previously in a greenhouse under three different watering regimes.

The information obtained from the first and third objectives will be valuable to explain the field performance responses. All of the results will be used to develop recommendations to improve irrigation practices in Mexico's nurseries where these species are grown.

The null hypotheses under investigation were:

For objective 1:

a. Pine seedlings do not differ in survival and growth in the nursery over three different watering regimes.
b. Seedlings subjected to three different watering regimes do not differ in survival and growth in the nursery among species.

For objective 2:

a. Seedling survival and growth of these species, at two outplanting sites is not affected by being subjected previously to different watering regimes in the greenhouse.

b. Seedlings given different watering regimes do not differ in outplanting performance among species at two locations.

For objective 3:

a. Pine seedlings given different watering regimes do not differ in survival, growth, and physiological condition (transpiration) over the levels of drought stress induced.

b. Seedlings grown under different watering regimes do not differ among species in response to different levels of drought stress.

II. LITERATURE REVIEW

DROUGHT RESISTANCE

Drought resistance has been defined as "the ability of plants to survive drought" or as "the ability to endure severe water stress and recover with minimum reduction in growth and yield" (Maximov and Stocker, cited by Pharis and Kramer, 1964).

Drought resistance is also defined as "the capacity of a plant to withstand periods of dryness". This capacity is a complex characteristic. The prospects for survival under drought stress are better the longer a dangerous decrease in water potential of the protoplasm can be delayed (the avoidance of desiccation) and the more the protoplasm can dry out without becoming damaged (the capacity to tolerate desiccation) (Larcher, 1983).

The dehydration of plant tissue can occur because of (a) maturation and aging, (b) plant water content, and (c) sudden deficits for short periods when the vapor pressure gradients from leaf atmosphere are suddenly increased before stomatal closure can compensate for the sudden increase in water loss (Levitt, 1958).

DROUGHT RESISTANCE IN CONIFERS

There is a considerable amount of literature on the response of plants to water stress (Kozlowski, 1979;

Puritch, 1973). However, Hinckley and Running (1978) mentioned that few studies have been reported concerning the effects of moisture stress on conifers species, in particular the physiological mechanisms by which conifer seedlings respond to drought.

Species that have been studied include Pinus halepensis (Oppenheimer, 1947; Oppenheimer and Shomer-Ilan, 1963); Pinus taeda, Pinus echinata, and Pinus radiata (Heth and Kramer, 1975; Kaufmann, 1977); Pinus ponderosa, Pinus contorta, Abies grandis, and Picea engelmanni (Lopushinsky, 1969); Pinus cembra and Picea abies (Havraneck and Benecke, 1978); and Pseudotsuga menziesii (Zavitkovsky and Ferrell, 1968; Kaufmann, 1977; Tan et al, 1977; Johnson and Ferrell, 1982).

Very little is known about the pre-conditioning of seedlings in the nursery and drought tolerance of conifers in México. Salinas and Hernandez (1970) studied the effect of different watering regimes on seedling growth and mycorrhizae formation in containerized Mexican pine seedlings during the nursery period. Their findings showed that less frequent than normal watering cycles (12 days) induced high formation of mycorrhizae on seedling roots.

Rojas (1984) tested different pine species under three soil types and two different watering cycles. His findings showed that Pinus patula grew less under the less frequent watering cycle than did the other species.

Vargas (1985) mentioned that Pinus greggii not only had a greater transpiration rate during a drought study, it had a higher stomatal sensitivity than Pinus patula, Pinus montezumae, and Pinus leiophylla during critical levels of stress (soil water potential of less than -1.5 MPa). He described Pinus greggii as a species which has a higher internal water potential than the other species, and that it decreases slowly when drought conditions are imposed.

One possible way to induce greater drought tolerance in planting stock within a species is to pre-condition the seedlings during the greenhouse production period. Owston (1972a) showed that larger seedlings of Douglas-fir grown under a daily water cycle during the growing season in the greenhouse transpired at a greater rate than smaller seedlings under a dry treatment, because the larger ones had greater absorption and transpiration surface. He recommended not to water seedlings heavily in the greenhouse if they might be subjected to dry conditions soon after planting.

III. METHODS

PART 1. GREENHOUSE STUDY

STOCK DESCRIPTION AND GERMINATION

The site for this study was the research greenhouse of the USDA Forest Service on the Campus at Oregon State University in Corvallis, Oregon.

Seeds of four Mexican pines species: Pinus montezumae, Pinus pseudostrobus var. apulcensis, Pinus patula, and Pinus greggii were sown on March 12, 1985. In the interest of conciseness, these species will be referred to by standard alpha symbols (PIMO, PIPSA, PIPA, and PIGR respectively) in methods and result sections, and in the figures and tables (Garrison et al, 1976). The seeds were collected in the Central and Southern regions of Mexico. The elevation of these species ranges between 1550 to 2750 meters above sea level. The seeds of these species do not require stratification for germination improvement (personal communication, Villagomez, 1984).

Sowing was done by hand, and seven seeds per container were sown to help ensure that each container had at least one germinant. The container system consisted of 98 plastic-tube containers per tray, each container was 4 cm in diameter and 21 cm in length. This type and size of container is similar in size to those used in Mexico's nurseries. Although, it is not the most common. Seeds were sown in a total of 5,000 to 6,000 containers.

The containers were filled with commercial peat moss and vermiculite No.3 in equal proportions by volume. After germination, the seedlings were thinned to one seedling per container. The greenhouse temperature was set at a constant 24.0 ^{o}C during the day and 13.0 ^{o}C during the night, but variations occurred in the greenhouse environment (extreme temperatures: 10 ^{o}C-30 ^{o}C; mean temperature: 21.0 ^{o}C). Natural photoperiod was used for this experiment.

Seedlings were watered daily by hand and fertilized every fifteen days with a commercial 20-20-20 fertilizer corresponding to N-P-K, and additional chelated iron. The fertilizer was gradually increased as seedlings became larger and then decreased late in the growing season to promote dormancy and hardening.

WATERING REGIMES

Once the seedlings got an adequate foothold in the cavities and the true needles started to appear, the watering regimes were started.

Three distinct watering regimes were used, based on values determined from a moisture characteristic curve for a similar growing mixture (Personal communication, Owston, 1985). Water loss was determined daily by weighing a random sample of individual containers, using an electronic balance.

a. Wet treatment. Watering was done when soil moisture content reached approximately 485%, which kept the moisture near field capacity (-0.03 MPa). Water was applied once the soil in the plastic tubes lost an average of 15 g of water each after thorough irrigation.

b. Intermediate treatment. Watering was done when soil moisture content reached about 240%, which was assumed to be about -0.1 MPa of soil water potential. Watering was performed when the soil mixture of the container lost an average 37 g of water after thorough irrigation.

c. Dry treatment. Watering was done when soil moisture content reached about 120% (-0.5 MPa). Water was applied when the soil mixture lost an average of 54 g of water.

Cycles for the treatments ran approximately 5 days for the wet (3-7 days), 9 days for the intermediate (6-11 days), and 13 days for the dry (11-17 days) depending upon environmental conditions.

PHYSICAL ARRANGEMENT OF TREATMENTS AND ANALYSIS USED

The experimental design for the greenhouse study was a as a split plot design in randomized blocks with watering regimes as a whole factor and species as a subplot factor with four replications. Data were analyzed for differences among means by analysis of variance. The Statistical Analysis System (SAS) statistical package was used for the analysis. Where significance occurred, multiple pairwise comparisons were calculated, using Waller-Bayes Duncan (BLSD) test at the 95% level.

The BLSD test was used because it is conservative when the F-ratio in the ANOVA is low, and is more sensitive when the F-ratio is high. Another advantage of the BLSD is that its power to detect real differences does not decrease as the number of means increases (Petersen, 1985).

SEEDLING CARE AND MONITORING

Seedling height growth measurements were recorded on the following dates in 1985: May 30; June 19 and 26; July 2, 8, 15, 20, and 26; August 9 and 28; September 4 and 28; October 19; November 9; and January 6.

The measurements were taken on 30 seedlings per species and per treatment. These seedlings were chosen initially at random and marked in their containers so that the same seedling sample could be measured on each measurement date. Height measurements were recorded from the top of the container to the terminal growing tip of the seedling.

By mid-August, the three distinct watering regimes were suspended, and the watering schedules were tailored to produce moderate plant moisture stress.

On September 6, all seedlings were moved to the Beaver Creek Nursery and placed in an open area to harden-off. On September 28, the seedlings were transferred to a greenhouse to protect them from frost.

On January 6, observations of number of seedlings with buds surrounded by cataphylls, by watering regimes were recorded in a greenhose of Beaver Creek.

By mid-February of 1986, seedling growth measurements of top height (measured to the nearest 0.5 cm), stem diameter (measured to the nearest 0.5 mm), and shoot and root dry weights (measured to the nearest 0.01 g) were recorded for 30 seedlings of three species (PIGR, PIPA, and PIPSA) per watering regime.

PART 2. OUTPLANTING TESTS

SEEDLING HANDLING AND STORAGE

In mid-February, 1986, 1,400 seedlings of PIGR, PIPA, and PIPSA were placed in plastic bags, packed in wax boxes and stored in a cold room maintained at approximately 1 ^{o}C to 4 ^{o}C until time of planting. Because too few seedlings of PIMO were available, this species was not used for the outplanting test.

OUTPLANTING TRIALS

Field plantings were conducted at two different locations. By early March 1986, 700 seedlings of P. greggii, P. patula and P. pseudostrobus var. apulcenesis were planted in the Oregon Coast Range, The site was 10 miles from Yachats, Oregon, on the Waldport Ranger District of the Siuslaw National Forest at 200 meters above sea level.

The planting site had been burned for site preparation in September 1985.

The planting consisted of four plots with nine rows of 20 seedlings in each. The rows within each plot were randomly assigned a species and watering regime combination. Seedlings were planted 2 meters apart.

By late June 1986, another group of 435 seedlings were planted in the Central part of México (Matlalohcan, Tlaxcala, State of México) at 2,530 meters above sea level.

These seedlings, packed in wax boxes, were placed in a small trailer and covered with canvas to protect them from direct sunlight and turbulent air flow. They were transported by vehicle from Corvallis, Oregon, to México City. During the trip, seedlings were watered daily and exposed to open air with the boxes opened and the canvas removed during the night.

Most of the seedlings arrived to México in apparent good condition. There was some physical damage to P. greggii and P. patula (due to their large size, some tops were broken). On the other hand, Pinus pesudostrobus var. apulcensis did not show any physical damage.

The rainy summer season (June) had started in Central México, so watering was not necessary. Seedlings were left in their boxes and exposed to the weather conditions for two weeks before they were planted.

The planting site was churned with a shovel to improve soil aeration.

The field planting consisted of three plots, each one with nine randomized rows of 16 seedlings. Each row corresponded to a species and a watering treatment combination. Seedlings were planted 1 m apart.

SEEDLING PERFORMANCE AND EVALUATION

Seedling survival and top height, measured to the nearest 0.5 cm, were determined for the total population. Also a brief description of vegetation were recorded ten months after the establishment of the plantations. Shoot, lateral root, and tap root dry weight (to the nearest 0.01 g), and shoot/root ratio, were determined on 6% of the total population. The 6% corresponded to 42 seedlings for the Oregon Coast Range site and 26 seedlings for the Tlaxcala site.

EXPERIMENTAL DESIGN

The experimental design for both field studies was a two-factor randomized block design with factor A as watering regimes and factor B as species, with four replications for the Oregon Coast Range site and with three replications for the Tlaxcala site.

Data were analyzed for differences among means by analysis of variance. The Statistical Analysis System (SAS) program was used for the analysis. Where significance occurred, multiple pairwise comparisons were calculated using the BLSD test at the 95% level.

PART 3. DROUGHT STUDY

STOCK DESCRIPTION

The site for this study was the research greenhouse in which the seedlings were initially grown. A randomized group of 576 seedlings of each species that had previously been subjected to each of the three levels of watering regimes were used for the drought test in early March of 1986. The seedlings were removed from their containers and transplanted into pots 25 cm in diameter and 25 cm deep, with a commercial peat moss and vermiculite No. 3 in equal proportions by volume. The seedlings were fertilized once with a full dose of commercial 20-20-20 fertilizer.

DROUGHT LEVELS

Three different levels of drought stress were applied to the seedlings. The drought levels were determined by weighing the loss of soil moisture in the pots using a mechanical pan balance.

Three distinct levels of drought stress were established:

a. Low stress. Rewatering after the soil lost 1,000 g of water.

b. Moderate stress. Rewatering after the soil lost 2,000 g of water.

c. High stress. Rewatering after the soil lost 3,000 g of water.

These levels were designed to yield different soil moisture stresses. Treatment levels were determined on observations of the potting media dryness. Observations such as soil color as well as weather conditions gave an indication of when to weigh the seedlings.

Cycles for the drought levels ran approximately 14 days for the low stress, 28 days for the moderate, and 64 days for the high stress treatment, corresponding to moisture contents of 210%, 115%, and 18% respectively.

EXPERIMENTAL DESIGN

The experimental design for the drought study was a split-split-plot design in randomized blocks with drought levels as a whole factor, watering regimes as a subplot factor, and species as a sub-subplot factor with four replications.

Data were analyzed for differences among means by analysis of variance. The SAS program was used for the analysis. Where significance occurred, multiple pairwaise comparisons were calculated using the BLSD test at the 95% level.

SEEDLING EVALUATION

Once the drought study started, seedling height growth measurements were made on the following dates: April 19, May 23, August 2, and October 26 of 1986.

During the drought study, seedling transpiration from current seedling growth were recorded on three needle fascicles of each species using the LI-1600 steady state porometer during August and early September.

After recording those readings, needles were collected for each watering regime, drought level, and species. Needle surface area within the cuvette was determined with a surface area meter (Licor, model LI-3100, Lincoln, Nebraska) using lenses of 105 mm with 0.1 mm^2 resolution. Transpiration was then computed on the basis of projected (one-sided) leaf area.

At the end of the drought study, survival and growth measurements from 70% of the total sample were recorded, because greenhouse conditions were homogenous.

Seedlings were unpotted, the soil was loosened from around the root mass, and roots were washed free of soil. Growth measurements consisted of top height measured to the nearest 0.5 cm (from cotyledon scars to the terminal growing tip), stem diameter measured to the nearest 0.5 mm (below cotyledon scars), lateral root and tap root dry weights (recorded to the nearest 0.01 g), shoot dry weight (recorded to the nearest 0.01 g) and shoot/root ratios (determined by dry weight).

IV. RESULTS

PART 1. GREENHOUSE STUDY

SEEDLING HEIGHT PERFORMANCE DURING APPLICATION OF THE WATERING REGIMES IN THE GREENHOUSE

Analysis of variance on height growth of the same individuals was done on June 19, July 20, and September 4. Thus, individual sampling was not truly independent for each date.

The ANOVA results showed that on June 19, differences among species were highly significant (P = 0.0001), but no significant difference was found for watering regimes (P = 0.4). PIGR was tallest, PIMO was shortest, and the other two species were intermediate (Figure 1) (Table A1).

On July 20, both watering regime and species differences were highly significant (P = 0.008 and P = 0.0001, respectively). There was no indication that differences between watering regimes varied by species. The BLSD test showed that top height of seedlings subjected to the wet treatment was significantly greater than of the intermediate and dry treatments. In regard to species, the pattern remained the same as in June (Figures 1 and 2) (Table A2).

FIGURE 1. SEEDLING HEIGHT GROWTH UNDER THE WATERING REGIME TREATMENTS BY SPECIES

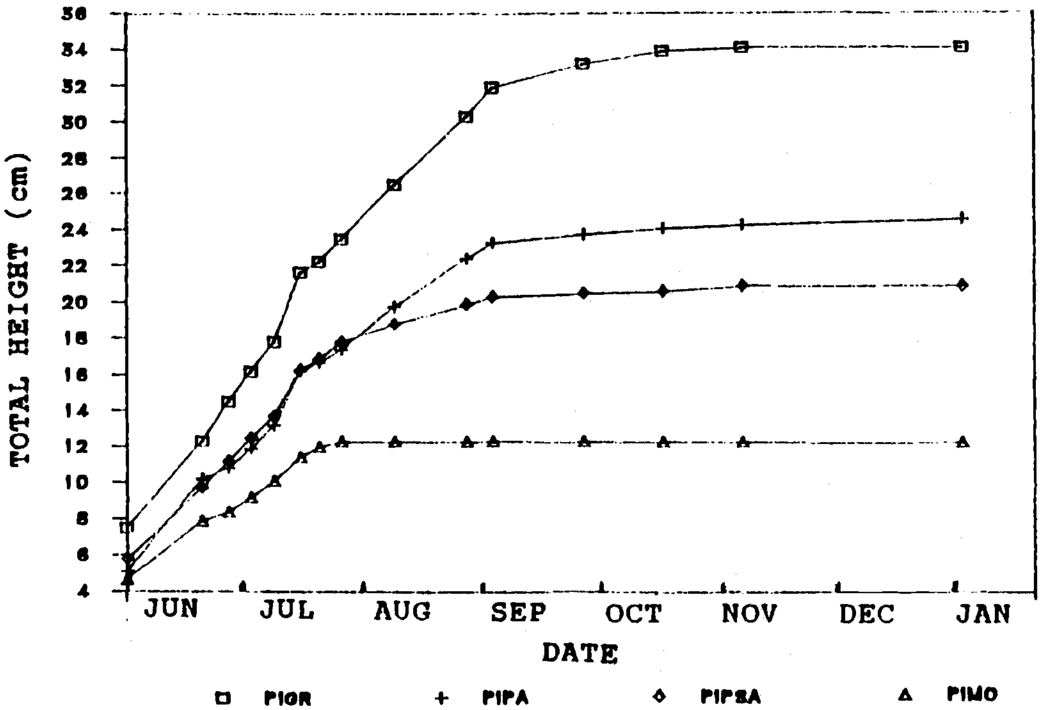
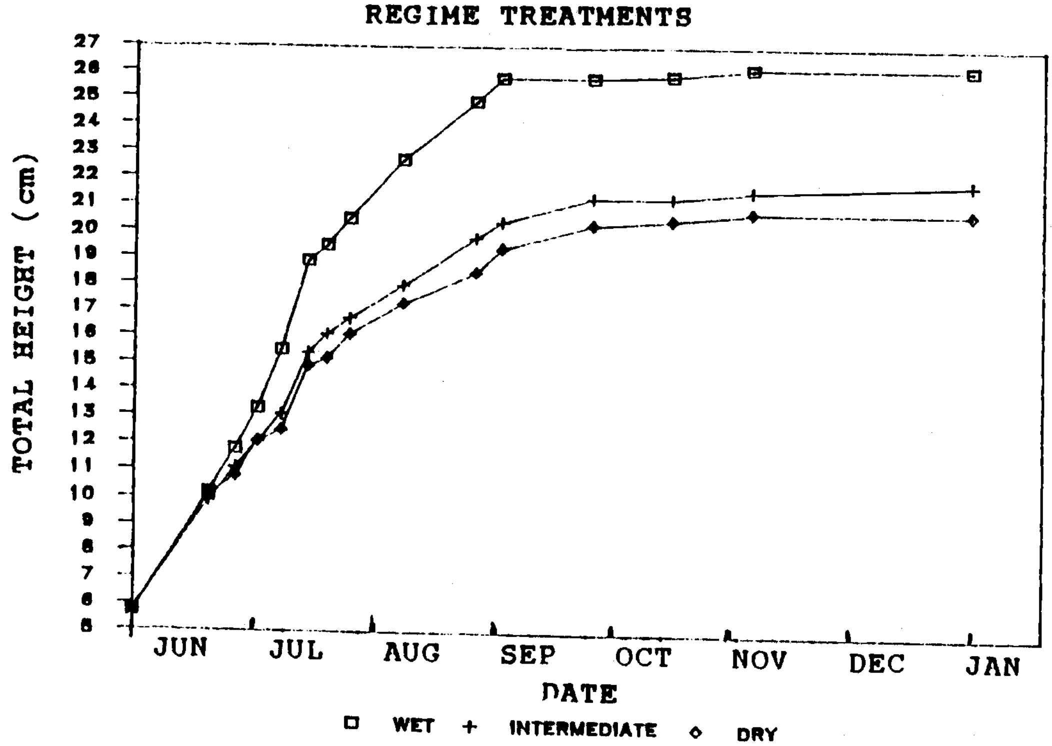


FIGURE 2. SEEDLING HEIGHT GROWTH BY WATERING REGIME TREATMENTS



By September 4, there was an indication that differences among watering regimes varied by species (P = 0.034). Top heigth of PIGR and PIPA decreased when subjected to the intermediate and dry treatments, whereas PIPSA and PIMO showed consistent values in all treatments (Tables 1 and A3). Over all watering regimes, the original height pattern was maintained, and each species was significantly different from each other.

TABLE 1. MEAN HEIGHTS ON SEPTEMBER 4, 1985, BY TREATMENT AND SPECIES.

species	watering regimes			mean
	wet	intermediate	dry	
		height (cm)		
PIGR	36.1 a	27.2 b	27.7 b	30.3
PIPA	28.4 b	21.3 cd	17.6 d	22.4
PIPSA	22.1 c	19.3 cd	18.3 cd	19.9
PIMO	13.0 e	11.5 e	10.5 e	11.6
mean	24.9	19.8	18.5	

$S\bar{y}AB$ = 1.367 with 27 df

Values not followed by the same letter are significantly different from each other (BLSD test, P = 0.05).

There were more seedlings with cataphylls in the wet and intermediate treatments (71% and 65% respectively), and less seedlings with the same characteristic in the dry treatment (55%) in January of 1986.

SEEDLING MORPHOLOGY EARLY IN THE FOLLOWING GROWING SEASON FOR PIGR, PIPSA, AND PIPA

HEIGHT

Significant interaction was found between the watering regimes and species (P = 0.032). The BLSD test showed that heights of PIGR and PIPSA were not affected by watering regimes. However, height PIPA was reduced by the dry treatment; no significant differences in height were shown between the wet and intermediate treatments (Tables 2 and A4).

TABLE 2. MEAN HEIGHTS ON FEBRUARY 12, 1986, BY TREATMENT AND SPECIES.

species	watering regimes			mean
	wet	intermediate	dry	
		height (cm)		
PIGR	39.6 a	35.7 ab	36.8 a	37.3
PIPA	35.9 ab	32.6 bc	28.1 d	32.2
PIPSA	27.1 d	29.0 cd	27.4 d	27.8
mean	34.2	32.4	30.7	

$S_{\bar{y}AB}$ = 1.23 with 12 df

Values not followed by the same letter are significantly different from each other (BLSD test, P = 0.05).

DIAMETER

The ANOVA results showed that species reacted differently to the watering regimes (P = 0.04). PIGR and PIPSA showed consistent values in all watering regime treatments and did not differ from each other. However, PIPA did show a decrease in diameter about 0.4 to 0.5 mm when it was under the dry treatment. Species were significantly different from each other, but the differences were to small to be of any practical importance (0.2 to 0.3 mm) (Tables 3 and A5).

TABLE 3. MEAN DIAMETERS ON FEBRUARY 12, 1986, BY TREATMENT AND SPECIES.

species	watering regimes			mean
	wet	intermediate	dry	
		diameter (mm)		
PIGR	4.1 a	4.0 a	4.0 a	4.0
PIPA	4.1 a	4.0 a	3.6 b	3.9
PIPSA	4.2 a	4.2 a	4.2 a	4.2
mean	4.1	4.0	3.9	

$S\bar{y}AB$ = 0.078 with 12 df

Values not followed by the same letter are significantly different from each other (BLSD test, P = 0.05).

SHOOT WEIGHT

Analysis of shoot dry weight indicated that the interaction between watering regime and species was significant (P = 0.01). The BLSD test indicated that PIGR showed consistent values among the watering regimes. PIPSA had greater shoot dry weight in the intermediate and dry treatments than in the wet treatment. Shoot weight of PIPA decreased in the dry treatment (Tables 4 and A6).

TABLE 4. MEAN SHOOT DRY WEIGHTS ON FEBRUARY 12, 1986, BY TREATMENT AND SPECIES.

species	watering regimes			mean
	wet	intermediate	dry	
	shoot dry weight (g)			
PIGR	3.4 a	3.3 ab	3.3 ab	3.3
PIPA	3.2 ab	3.0 bc	2.6 d	3.0
PIPSA	2.6 cd	3.1 ab	3.1 ab	3.0
mean	3.1	3.2	3.0	

$S_{\bar{y}}AB$ = 0.126 with 12 df

Values not followed by the same letter are significantly different from each other (BLSD test, P = 0.05).

TOTAL ROOT WEIGHT

There was no significant interaction between watering regime and species (P = 0.34). However, differences in root dry weight among species were highly significant (P = 0.0007). The BLSD test showed that PIPA had greater root dry weight than the other species (Tables 5 and A7).

TABLE 5. MEAN ROOT DRY WEIGHTS ON FEBRUARY 12, 1986, BY SPECIES.

species		
PIGR	PIPA	PIPSA
	root dry weight (g)	
1.4 b	1.6 a	1.4 b

$S\bar{y}B$ = 0.039 with 12 df

Values not followed by the same letter are significantly different from each other (BLSD test, P = 0.05).

SHOOT/ROOT RATIO

The results of ANOVA for shoot/root ratio did not show any interaction between watering regimes and species (P = 0.06). However, differences were highly significant among species (P = 0.0001), and all species were significantly different from each other (Tables 6 and A8).

TABLE 6. MEAN SHOOT/ROOT RATIOS ON FEBRUARY 12, 1986, BY SPECIES.

species		
PIGR	PIPA	PIPSA
	shoot/root (ratio)	
2.3 a	1.7 c	2.0 b

$S\bar{y}B$ = 0.059 with 12 df

Values not followed by the same letter are significantly different from each other (BLSD test, P = 0.05).

PART 2. OUTPLANTING TESTS

SEEDLING GROWTH PERFORMANCE IN THE FIELD (OREGON COAST RANGE)

SURVIVAL

The results of ANOVA did not show any significant difference among watering regimes or species. In general, however, seedling survival was excellent (96.5%). Little damage by frost occurred in the area (0.8%), and deer browse damage to the seedlings was also low (3.73%) (Tables 8 and A9).

HEIGHT

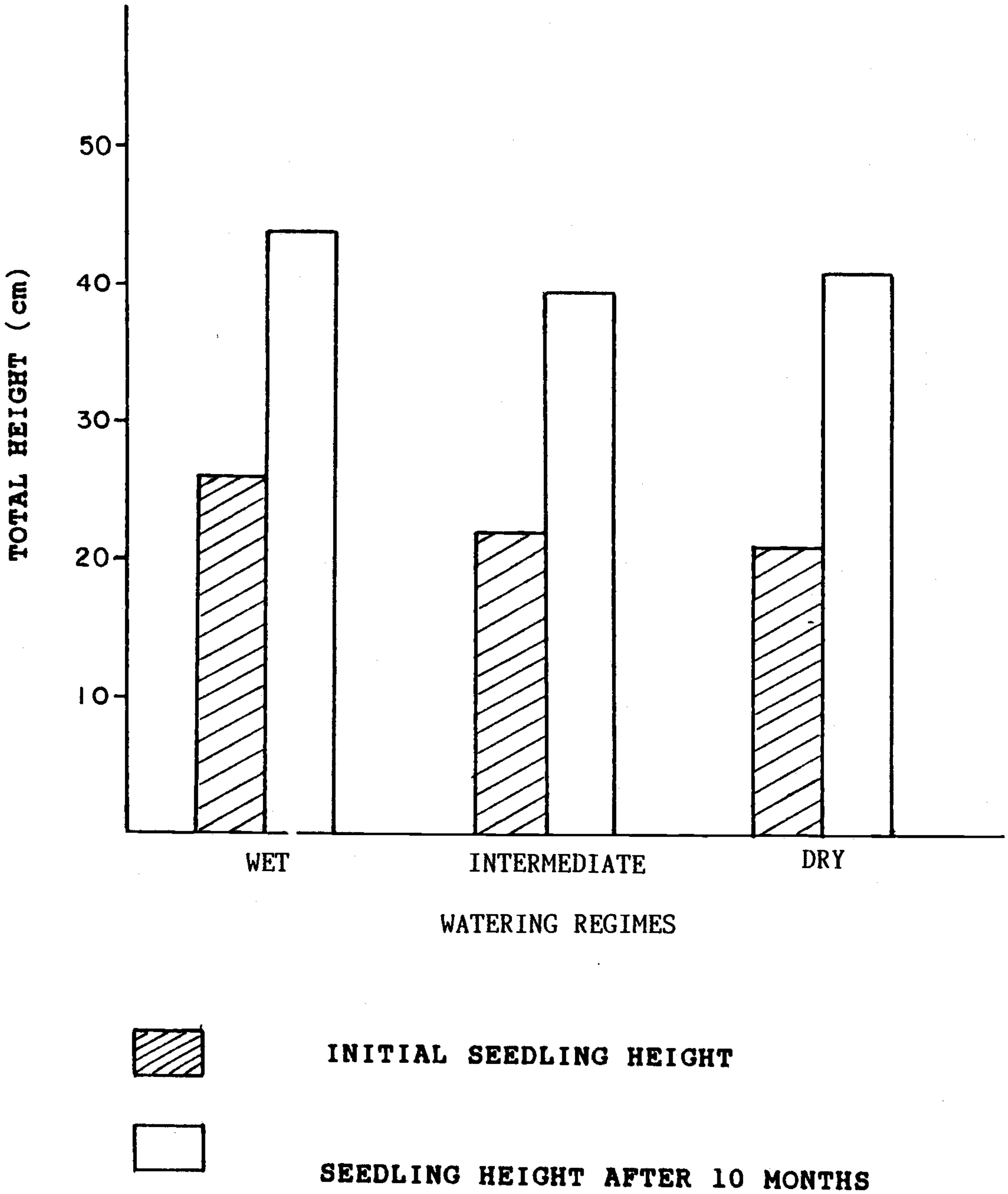
The total height differences by watering regimes were significant (P = 0.02). Seedlings from the wet regime had the greatest mean height, but it was not significantly greater than those from the dry treatment. Furthermore, the 1 to 4 centimeters differences were of little practical importance on this site (Tables 7a, and A10) (Figure 3).

TABLE 7a. MEAN HEIGHTS OF THE SEEDLINGS OUTPLANTED IN THE OREGON COAST RANGE BY PREVIOUS WATERING REGIME TREATMENTS.

	watering regimes	
wet	intermediate	dry
	height (cm)	
43.8^{a}	39.6^{b}	41.3^{ab}

$S_{\bar{y}A}$ = 0.960 with 24 df
cv = 7.99%
Values not followed by the same letter are significantly different from each other (BLSD test, P = 0.05).

FIGURE 3. TOTAL HEIGHT OF SEEDLINGS OUTPLANTED IN THE OREGON COAST RANGE



The differences among species means were highly significant (P = 0.0001). The BLSD test showed all the species different from each other (Tables 7b and A10) (Figure 4).

TABLE 7b. MEAN HEIGHTS BY SPECIES OF THE SEEDLINGS OUTPLANTED IN THE OREGON COAST RANGE.

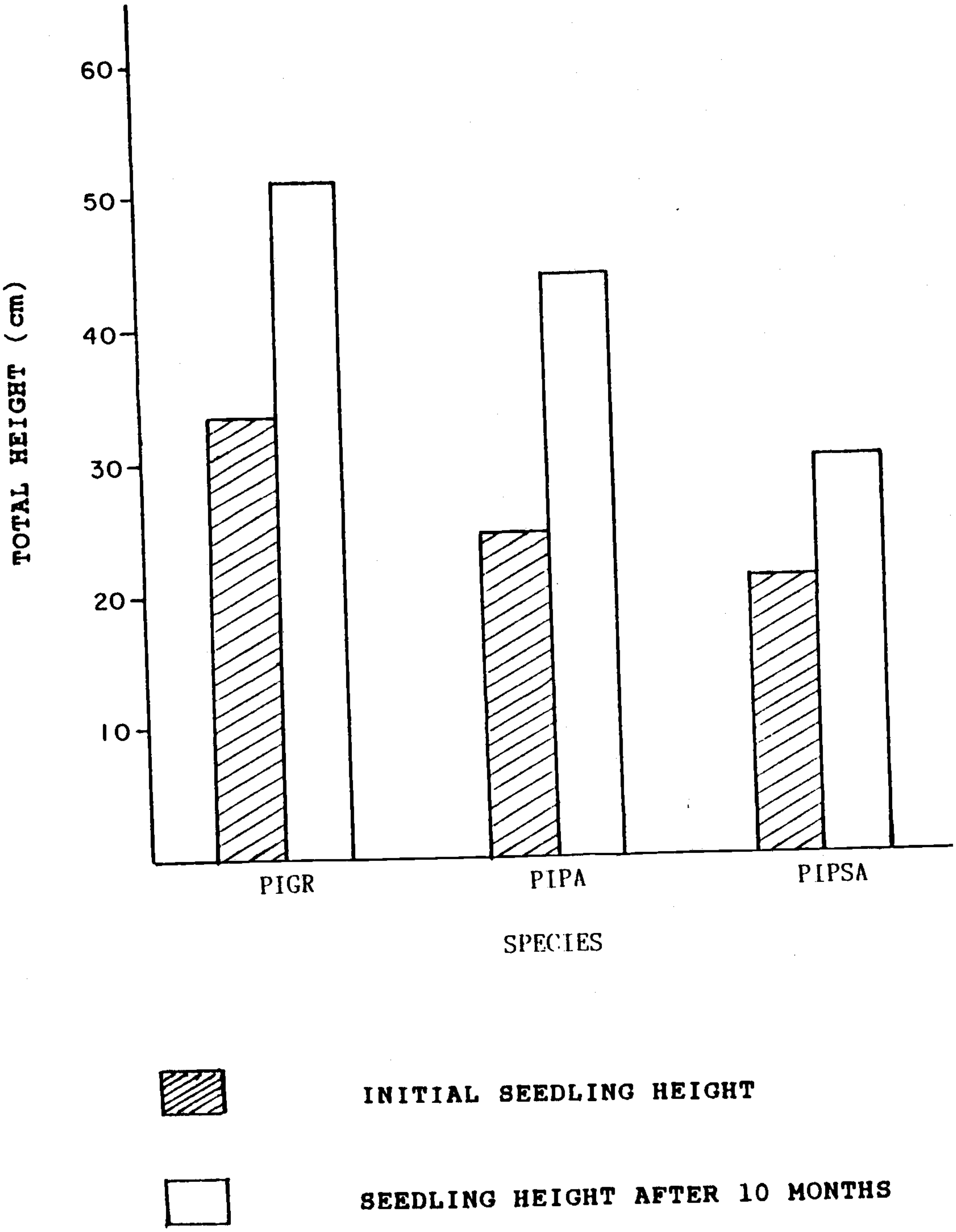
species		
PIGR	PIPA	PIPSA
height (cm)		
51.0 a	44.1 b	29.7 c

$S\bar{y}B$ = 0.960 with 24 df

cv = 8.0%

Values not followed by the same letter are significantly different from each other (BLSD test, P = 0.05).

FIGURE 4. TOTAL HEIGHT OF SEEDLINGS OUTPLANTED IN THE OREGON COAST RANGE BY SPECIES



DIAMETER, SHOOT WEIGHT, AND LATERAL ROOT WEIGHT

The ANOVA results showed no indication that watering regime differences or species differences were significant for diameter, shoot dry weight, or lateral root dry weight (Tables 8, A11, A12, and A13).

TABLE 8. MEANS OF SURVIVAL, DIAMETER, SHOOT DRY WEIGHT, AND LATERAL ROOT DRY WEIGHT OF THE SEEDLINGS OUTPLANTED IN THE OREGON COAST RANGE BY WATERING REGIMES AND SPECIES.

	watering regimes			species		
	W	I	D	PIGR	PIPA	PIPSA
survival (%) cv = 10.2%	95.8	96.6	97.0	97.9	96.2	95.4
diameter (mm) cv = 17.8%	7.6	8.1	7.8	7.4	7.6	8.5
shoot (g) cv = 36.3%	16.7	17.5	17.4	15.8	17.2	18.6
lateral root (g) cv = 53.3%	2.0	2.7	2.1	1.6	2.7	2.5

Note: Means not significantly different at the 95% level.

TAP ROOT

Differences in dry weight of tap roots among the watering regimes were not significant, but highly significant differences were found among species ($P = 0.007$). PIPSA had significantly greater tap root dry weight than PIGR or PIPA (Tables 9 and A14).

TABLE 9. MEAN TAP ROOT DRY WEIGHTS BY SPECIES OF SEEDLINGS OUTPLANTED IN THE OREGON COAST RANGE.

species		
PIGR	PIPA	PIPSA
tap root dry weight (g)		
0.8 [b]	0.8 [b]	1.3 [a]

$S\bar{y}B$ = 0.111 with 24 df
cv = 38.9%

Values not followed by the same letter are significantly different from each other (BLSD test, P = 0.05).

SHOOT/ROOT RATIO

Results of ANOVA for shoot/root ratios showed that differences among the watering regimes were not significant. Differences were only detected among species (P = 0.036). PIGR showed a greater shoot/root ratio than PIPSA, but it did not differ from the mean of PIPA (Tables 10 and A15).

TABLE 10. MEAN SHOOT/ROOT RATIOS BY SPECIES OF SEEDLINGS OUTPLANTED IN THE OREGON COAST RANGE.

species		
PIGR	PIPA	PIPSA
shoot/root (ratio)		
6.4 [a]	5.3 [ab]	4.7 [b]

$S\bar{y}B$ = 0.446 with 24 df
cv = 27.9%
Values not followed by the same letter are not significantly different form each other (BLSD test, P = 0.05).

VEGETATION ANALYSIS

Total cover vegetation was 35%, 50%, 70% and 37% corresponding to plot 1,2,3, and 4.

Rubus spectabilis was in all plots sometimes scattered throughout the area and sometimes in patches.

Gaultheria shallon was only in plots 1 and 4 but was a dominant species there.

Several large plants and clumps of Digitalis purpurea were present in plot 2.

Dominant species such as Pteridium aquilinum and Senecio vulgaris were present in plot 3 and 4 respectively (Table 11).

In general, pine seedlings were not overtopped by competing vegetation when the final evaluation was carried out. But the potential for overtopping exists, and it could be expected in subsequent years.

TABLE 11. TOTAL COVER AND HEIGHT SPECIES BY PLOTS.

plots	species	height (cm)	cover (%)
1	Gaultheria shallon Pursh. (salal)	12.7	55.0
1	Rubus spectabilis Pursh. (salmonberry)	12.7	55.0
1	Senecio vulgaris L. (common groundsel)	2.6	40.0
1	Mahonia nervosa Nutt. (Oregon grape dwarf)	14.0	35.0
1	Polistichum munitum (Kaulf.) Presl (fern)	28.6	20.0
1	Digitalis purpurea L. (foxglove)	20.2	20.0
1	Salix sp. L (willow)	9.0	25.0
2	Digitalis purpurea L. (foxglove)	19.2	65.0
2	Rubus spectabilis Pursh. (salmonberry)	19.0	60.0
2	Senecio vulgaris L (common groundsel)	33.0	40.0
2	Polystichum munitum (Kaulf.) Presl (fern)	24.5	10.0
2	Pteridium aquilinum (L.) Kuhn In von cer cecken. (fern)	32.4	10.0
2	Salix sp. L (willow)	12.6	15.0
3	Pteridium aquilinum (L.) Kuhn In von cer cecken. (fern)	35.4	75.0
3	Rubus spectabilis Pursh. (salmonberry)	20.2	60.0

TABLE 11. TOTAL COVER AND HEIGHT SPECIES BY PLOTS (CONTINUED).

plots	species	height (cm)	cover (%)
3	*Senecio vulgaris* L. (common groundsel)	48.3	40.0
3	*Gaultheria shallon* Pursh (salal)	11.0	40.0
3	*Salix sp*. L (willow)	16.0	20.0
3	*Rubus vitifolius* Focke (blackberry)	6.0	20.0
3	*Polystichum munitum* (kaulf.) Presl. (fern)	31.0	15.0
3	*Senecio sp*. L.	45.5	10.0
4	*Gaultheria shallon* Pursh. (salal)	14.0	80.0
4	*Senecio vulgaris* L. (common groundsel)	58.2	50.0

SEEDLING GROWTH PERFORMANCE IN THE FIELD (TLAXCALA, MEXICO)

SURVIVAL

Mean survival was low on this site (26.2%), and the ANOVA results indicated that there were no significant differences in seedling survival among watering regimes or species. Most of the survivors were not vigorous (Tables 13 and A16).

Approximately 5% of the pine seedlings were broken at the top, the damage was probably due to the presence of cattle in the area.

HEIGHT

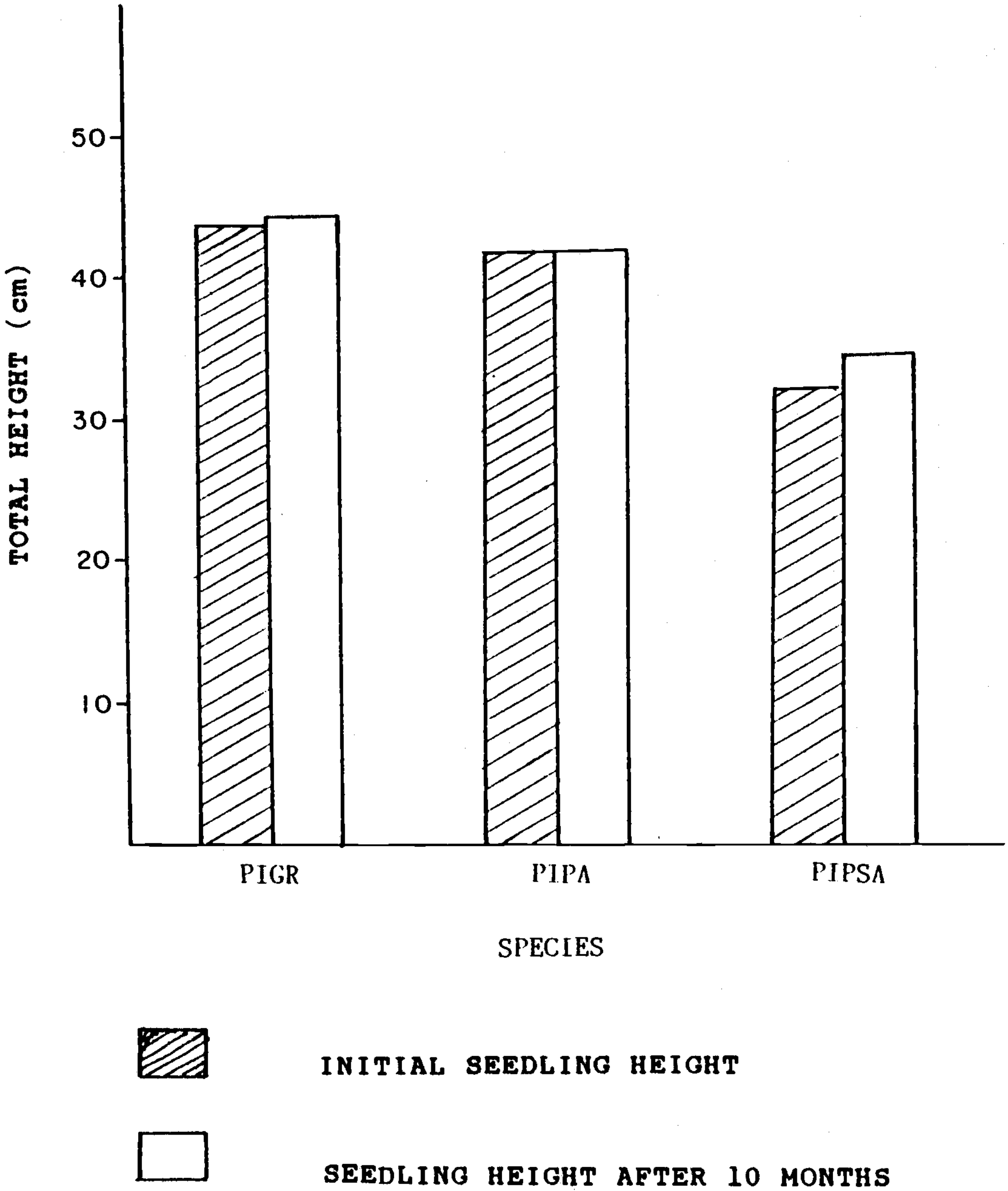
There were only significant differences (P = 0.044) in total height among means of species. PIGR was significantly taller than PIPSA, whereas PIPA showed no differences with respect to either of the species (Tables 12 and A17) (figure 5).

TABLE 12. MEAN HEIGHTS BY SPECIES OF THE SEEDLINGS OUTPLANTED IN TLAXCALA.

species		
PIGR	PIPA	PIPSA
height (cm)		
44.7^{a}	42.1^{ab}	34.7^{b}

$S\bar{y}B$ = 2.699 with 16 df
cv = 19.75%
Values not followed by the same letter are significantly different from each other (BLSD test, P = 0.05).

FIGURE 5. TOTAL HEIGHT OF SEEDLINGS OUTPLANTED IN TLAXCALA BY SPECIES



Mean differences among watering regimes treatments or mean differences among species for variables of diameter, shoot weight, lateral root weight and tap root weight were not significant. The results are summarized in tables 13, A18, A19, A20, and A21.

TABLE 13. MEANS OF SURVIVAL, DIAMETER, AND DRY WEIGHTS OF SHOOT, LATERAL ROOT, AND TAP ROOTS OF SEEDLINGS OUTPLANTED IN TLAXCALA.

	watering regimes			species		
	W	I	D	PIGR	PIPA	PIPSA
survival (%) cv = 53.0%	32.6	17.4	28.5	32.6	23.6	22.2
diameter (mm) cv = 10.4%	5.0	5.3	5.0	5.3	4.8	5.2
shoot (g) cv = 32.1%	6.6	6.0	5.1	7.1	4.9	5.7
lateral root (g) cv = 36.8%	2.2	2.4	2.2	2.2	2.5	2.1
Tap root (g) cv = 31.3%	1.0	1.2	1.0	1.1	1.1	1.1

Note: Means not significantly different at the 95% level.

SHOOT/ROOT RATIO

The ANOVA results indicated there were no significant differences between the watering regimes. However, there were significant differences among species ($P = 0.03$). PIGR showed a greater shoot/root ratio than PIPA, whereas PIPSA did not differ from the mean of PIGR or PIPA (Tables 14 and A22).

TABLE 14. MEAN SHOOT/ROOT RATIOS BY SPECIES OF THE SEEDLINGS OUTPLANTED IN TLAXCALA.

species shoot/root (ratio) PIGR	PIPA	PIPSA
2.3 a	1.3 b	1.8 ab

$S\bar{y}B$ = 0.226 with 16 df
cv = 36.9%
Values not followed by the same letter are significantly different from each other (BLSD test, P = 0.05).

VEGETATION ANALYSIS

The total cover vegetation was 36%, 47% and 52% for plot 1, 2 and 3 respectively. Major components were *Bromus anomalus* (plot 1 and 3), *Hilaria cenchroides* (plot 1), *Sporobolus indicus* (plot 2) and *Stippa sp*. (plot 3) (Table 15).

TABLE 15. TOTAL COVER AND HEIGHT SPECIES BY PLOT.

plot	species	height (cm)	cover (%)
1	*Bromus anomalus* Rupr.Ek.Four	30.5	15.0
1	*Hilaria cenchroides* HEM.	12.0	11.0
1	*Sida rhombifolia* L.	10.0	3.0
1	*Physalis chenopodifolia* Lam.	15.0	4.0
1	*Lepidium intermedium* Gray.	19.0	3.0
2	*Sporobolus indicus* (L) Br.	37.0	32.0
2	herbs (compositae)	14.0	1.5
3	*Stippa sp*. L.	26.0	20.0
3	*Bromus anomalus* Rupr.Ek.Four	36.0	25.0
3	*Brickellia veronicaefolia* (HBK)	27.5	7.0

PART 3. DROUGHT STUDY

SURVIVAL

There was highly significant interaction in survival between the drought level and previous watering regimes (P = 0.007). Survival was 100% in the low and moderate stress levels. In the high stress level, however, the differences among the watering regimes were significant from each other. The dry regime showed better survival than the wet, which was better than the intermediate regime (Tables 16a and A23).

TABLE 16a. MEAN SURVIVAL BY STRESS LEVELS AND PREVIOUS WATERING REGIMES.

drought stress	watering regimes			mean
	W	I	D	
	survival (%)			
low	100.0 a	100.0 a	100.0 a	100.0
moderate	100.0 a	100.0 a	100.0 a	100.0
high	61.4 c	50.0 d	70.7 b	60.5
mean	86.6	82.8	89.8	

$S_{\bar{y}AB}$ = 0.042 with 18 df

Values not followed by the same letter are significantly different from each other (BLSD test, P = 0.5).

Results of ANOVA also indicated that interaction between drought levels and species was highly significant (P = 0.0001). Under high stress, PIPA had lowest survival, about 50% less than PIGR, which had the highest survival. Survival rates of PIPSA and PIMO were intermediate (Tables 16b and A23).

TABLE 16b. MEAN SURVIVAL BY STRESS LEVELS AND SPECIES.

drought stress levels	species				mean
	PIGR	PIPA	PIPSA	PIMO	
	survival (%)				
low	100.0 a	100.0 a	100.0 a	100.0 a	100.0
moderate	100.0 a	100.0 a	100.0 a	100.0 a	100.0
high	83.3 b	33.3 e	69.4 c	56.9 d	60.5
mean	94.2	77.7	89.8	85.3	

$S\bar{y}AC$ = 0.071 with 81 df

Values not followed by the same letter are significantly different from each other (BLSD test, P = 0.05).

HEIGHT

The ANOVA results showed that interaction between drought levels and species were highly significant (P = 0.0001). Tallest seedlings, were produced by the low stress treatment, and shortest seedlings were at the high stress level (Figure 6).

Species responded differently to levels of stress. PIGR and PIPA did not differ significantly under the low stress. The rest of the species were significantly different from each other and among the different levels of stress.

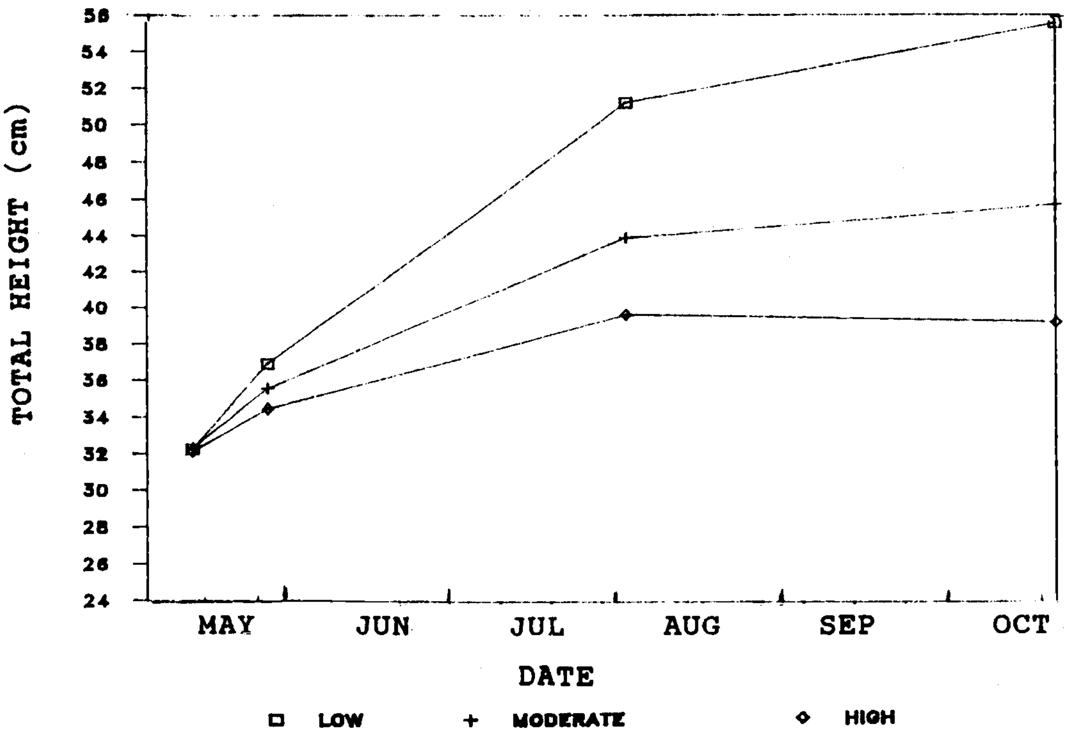
The same height pattern of the species as in the greenhose experiment was maintained; i.e., PIGR was the tallest, PIMO the shortest, while PIPA and PIPSA were intermediate (Tables 17 and A24).

TABLE 17. MEAN HEIGHTS BY STRESS LEVELS AND SPECIES.

drought stress	species				mean
levels	PIGR	PIPA	PIPSA	PIMO	
		height (cm)			
low	78.2 a	76.2 a	40.4 f	24.3 i	54.8
moderate	61.7 b	56.2 c	35.5 g	22.5 j	44.0
high	51.9 d	45.3 e	32.6 h	21.2 k	37.7
mean	63.9	59.2	36.2	22.6	

$S\bar{y}AC$ = 1.021 with 81 df
Values not followed by the same letter are significantly different from each other (BLSD test, P = 0.05).

FIGURE 6. SEEDLING HEIGHT GROWTH BY DROUGHT STRESS LEVELS



SHOOT WEIGHT

For all species, low stress resulted in the greatest shoot dry matter, and high stress resulted in the least.

Drought level and species interaction was highly significant (P = 0.0001). The BLSD test showed that under low stress, PIGR and PIPA were placed in one group (highest shoot weight), whereas PIPSA and PIMO were different from the other species and from each other.

All species were significantly different from each other in the moderate stress. Under high stress, however, PIGR had the highest shoot dry weight, but differences between the other species were not clearly delineated (Tables 18 and A25).

Table 18. MEAN SHOOT DRY WEIGHTS BY STRESS LEVELS AND SPECIES.

drought stress levels	species PIGR	PIPA	PIPSA	PIMO	mean
	shoot dry weight (g)				
low	19.4 a	18.7 a	13.7 b	12.9 c	16.0
moderate	13.5 b	12.1 c	10.6 d	8.7 f	11.2
high	9.1 e	6.5 gh	7.2 g	5.7 h	7.1
mean	14.0	12.4	10.5	8.9	

$S_{\bar{y}}AC$ = 0.396 with 81 df

Values not followed by the same letter are significantly different from each other (BLSD test, P = 0.05).

DIAMETER

Interaction between drought levels and species was significant (P = 0.0004). A trend of decreased diameter with increasing drought stress was consistent, but the magnitude and significance varied between species and drought levels. PIMO had the largest average diameter at each stress level (Tables 19 and A26).

TABLE 19. MEAN DIAMETER BY STRESS LEVELS AND SPECIES.

drought stress levels	species PIGR	PIPA	PIPSA	PIMO	mean
	diameter (mm)				
low	9.1 bc	8.7 c	8.2 d	11.4 a	9.4
moderate	7.1 ef	6.7 fg	6.6 g	9.4 b	7.4
high	5.8 h	5.1 i	5.6 h	7.4 e	6.0
mean	7.3	6.8	6.8	9.4	

$S_{\bar{y}}AC$ = 0.148 with 81 df

Values not followed by the same letter are significantly different from each other (BLSD test, P = 0.05).

TAP ROOT

Interaction between the drought levels and species was highly significant for dry weight of tap roots (P = 0.0001). For each species, dry weight of tap roots decreased significantly with increasing stress level. Differences in behavior among species within the drought stress levels were not clearly defined (Tables 20 and A27).

TABLE 20. MEAN TAP ROOT DRY WEIGHTS BY STRESS LEVELS AND SPECIES.

drought stress levels	species PIGR	PIPA	PIPSA	PIMO	mean
	tap root dry weight (g)				
low	1.5 a	1.3 b	1.1 c	0.8 de	1.2
moderate	0.8 d	0.7 e	0.8 de	0.6 f	0.7
high	0.5 fg	0.3 hi	0.4 gh	0.3 i	0.4
mean	0.9	0.8	0.8	0.5	

$S\bar{y}AC$ = 0.0453 with 81 df

Values not followed by the same letter are significantly different from each other (BLSD test, P = 0.05).

LATERAL ROOT

Overall, the greater the stress, the lower the dry matter production of lateral roots.

Interaction between drought levels and species were highly significant (P = 0.0001), however, The BLSD test showed that species responded differently from each other at the different stress levels. Under low stress, PIPA was the highest, PIMO the lowest, while PIGR and PIPSA were intermediate but different from each other. Under moderate and high stresses, PIPA, PIGR, and PIPSA responded similarly and PIMO was significantly the lowest. PIPA lost more weight of lateral roots than the other species (3.6 g) (Tables 21 and A28).

TABLE 21. MEAN LATERAL ROOT DRY WEIGHTS BY STRESS LEVELS AND SPECIES.

drought stress levels	species PIGR	PIPA	PIPSA	PIMO	mean
	lateral root dry weight (g)				
low	4.0 b	4.6 a	3.5 c	2.0 e	3.5
moderate	2.9 d	2.9 d	2.7 d	1.5 f	2.5
high	1.2 fg	1.0 g	1.2 fg	0.5 h	1.0
mean	2.7	2.8	2.4	1.3	

$S_{\bar{y}}AC$ = 0.128 with 81 df

Values not followed by the same letter are significantly different from each other (BLSD test, P = 0.05).

SHOOT/ROOT RATIO

There was a highly significant interaction between drought levels and species (P = 0.0004). There was an increase in shoot/root ratio under high stress. PIMO tended to have higher ratios than the other species, and the ratio tends to increase with increasing stress. However, the differences were small and not clearly delineated especially within species (Tables 22 and A29).

TABLE 22. MEAN SHOOT/ROOT RATIOS BY STRESS LEVELS AND SPECIES.

drought stress levels	species PIGR	PIPA	PIPSA	PIMO	mean
	shoot/root (ratio)				
low	3.4 b	3.1 b	2.9 b	5.3 ab	3.7
moderate	3.8 b	3.4 b	3.1 b	4.7 ab	3.7
high	5.1 ab	4.4 ab	4.3 ab	7.4 a	5.3
mean	4.1	3.6	3.4	5.8	

$S_{\bar{y}}AC$ = 0.231 with 81 df

Values not followed by the same letter are significantly different from each other (BLSD test, P = 0.05).

TRANSPIRATION

Transpiration rates are expressed in average micrograms of water lost, per square centimeter of foliage area per second. Interaction between drought levels and species was significant (P = 0.015).

The low and moderate stress levels were not significantly different from each other. However, the high stress showed differences in relation to other levels of stress for each species. All species under high stress decreased transpiration rates drastically. Overall, PIPSA transpired at the highest rate, PIMO the least, while PIGR and PIPA were intermediate (Tables 23 and A30) (Figures 7, 8, 9, and 10).

TABLE 23. MEAN TRANSPIRATION RATES BY STRESS LEVELS AND SPECIES.

drought stress levels	species PIGR	PIPA	PIPSA	PIMO	mean
	transpiration ($\mu g\ cm^{-2}\ s^{-1}$)				
low	3.086 ab	2.870 b	3.514 a	2.342 c	2.953
moderate	2.678 bc	2.856 b	3.518 a	2.260 c	2.828
high	0.545 d	0.377 d	0.543 d	0.273 d	0.435
mean	2.103	2.034	2.525	1.625	

$S\bar{y}AC$ = 0.146 with 81 df

Values not followed by the same letter are significantly different from each other (BLSD test, P = 0.05).

FIGURE 7. TRANSPIRATION RATE OF PIGR BY LEVELS OF DROUGHT STRESS

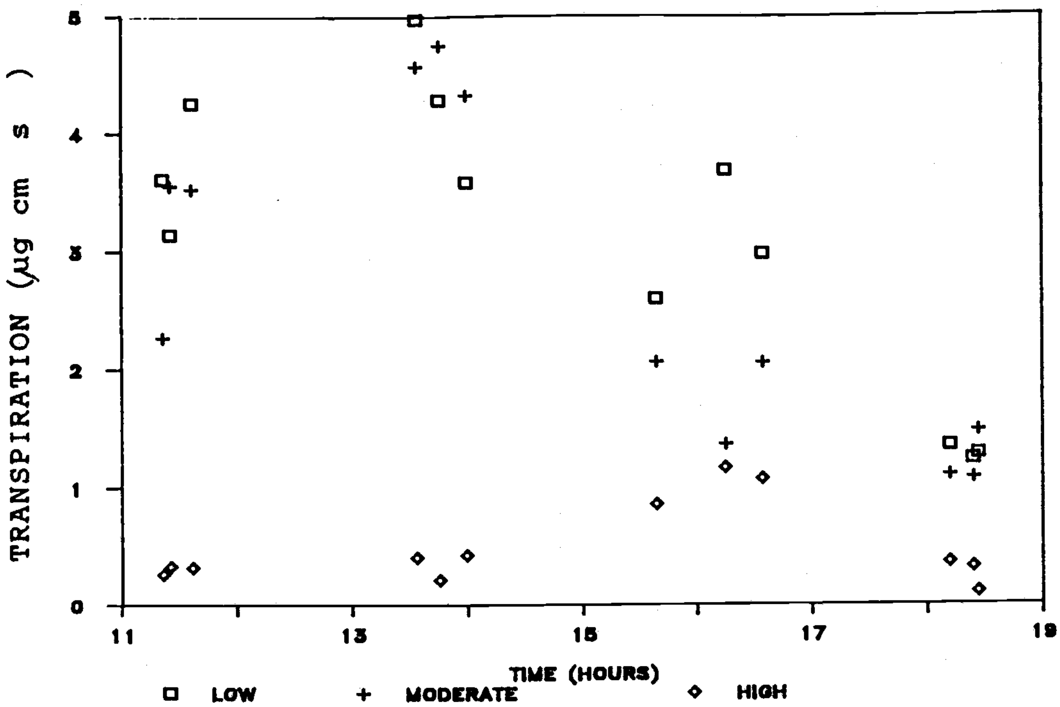


FIGURE 8. TRANSPIRATION RATE OF PIPA BY LEVELS OF DROUGHT STRESS

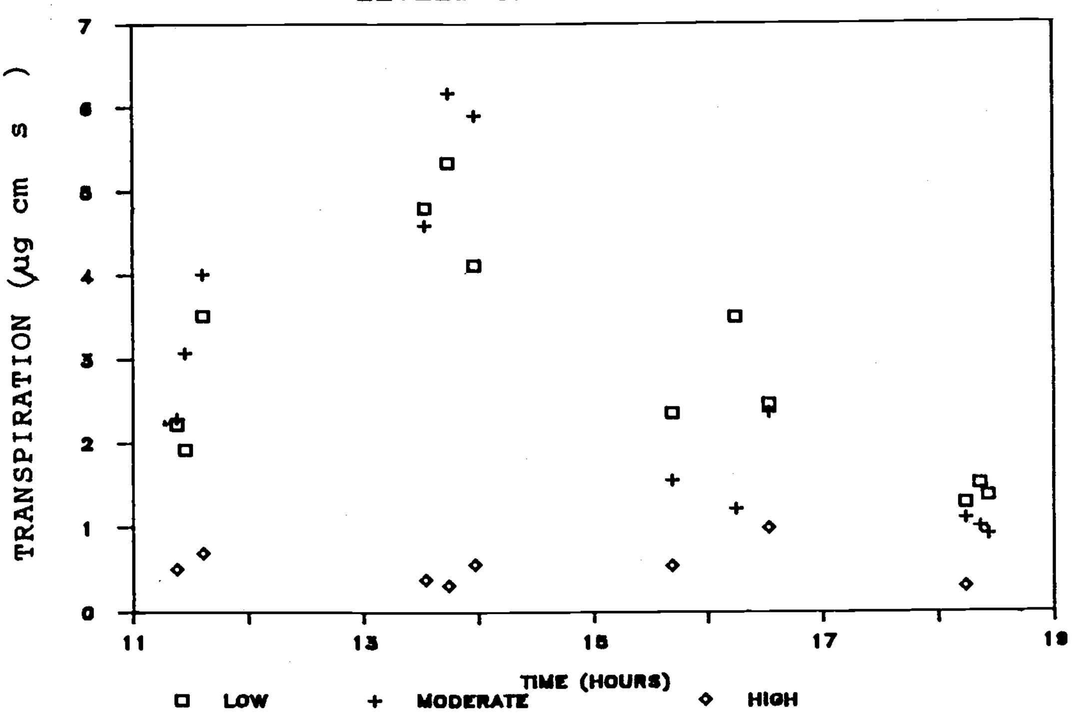


FIGURE 9. TRANSPIRATION RATE OF PIPSA BY LEVELS OF DROUGHT STRESS

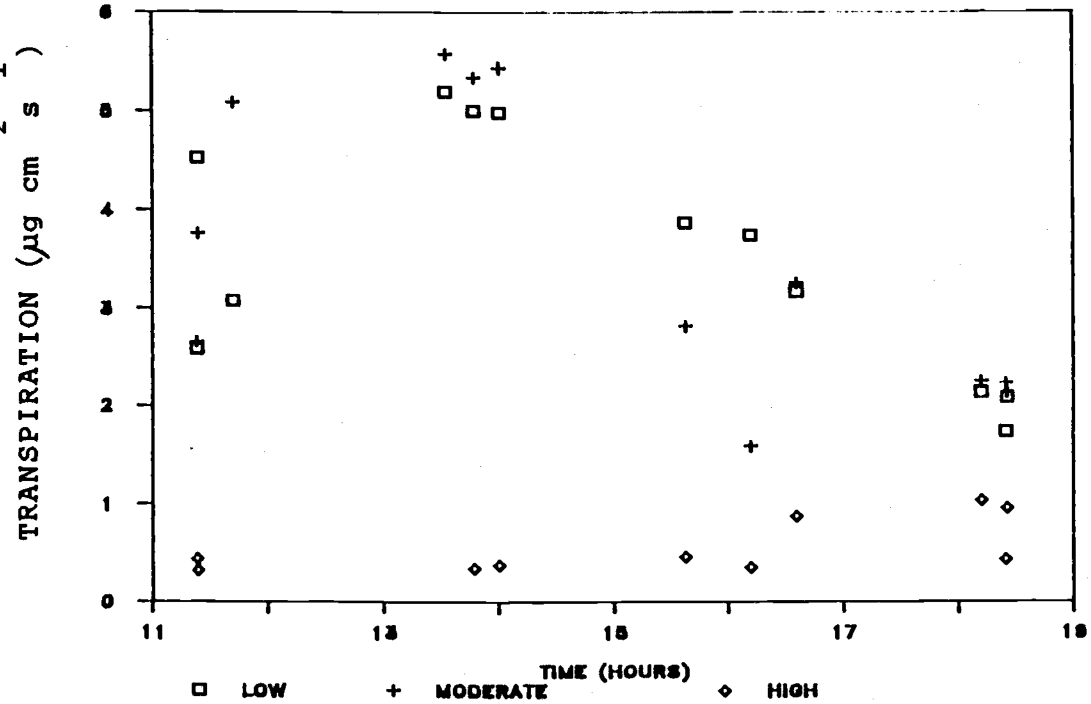
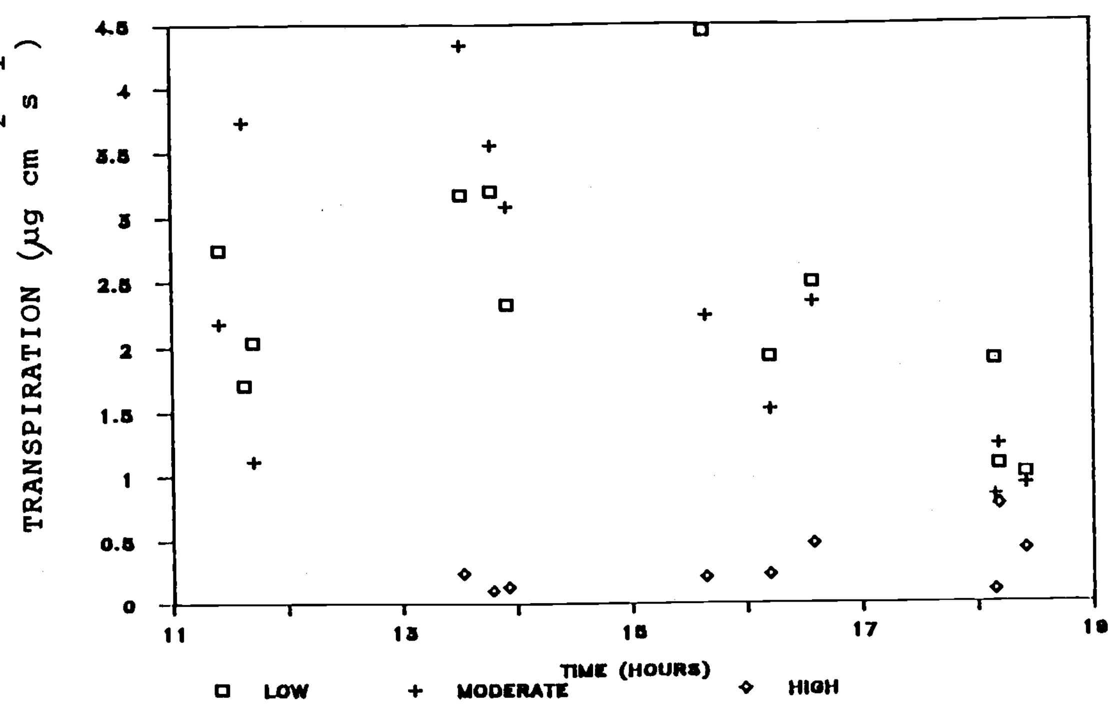


FIGURE 10. TRANSPIRATION RATE OF PIMO BY LEVELS OF DROUGHT STRESS



V. DISCUSSION

PART 1. GREENHOUSE STUDY

After the first 8 weeks of the experiment (June 19), the watering regime treatments did not have a well defined impact on the behavior of the seedlings. The effect of the treatments started to become noticeable after the 12th week (July 20) (Figure 2). By early September, the differences among the watering regimes varied by species (Table 1): Pinus montezumae the shortest, and Pinus pseudostrobus var. apulcensis as intermediate did not show any substantial change in top height among the watering regime treatments. On the other hand, Pinus greggii, the tallest, and Pinus patula as intermediate, had decreased height growth when subjected to the intermediate or dry treatment.

It seems evident that the moisture stress affected top height of the latter two species subjected to the intermediate and dry treatments by reducing the elongation rate of shoots.

After budbreak of the seedlings early in the second growing season, the gain in height between early January and mid-February of 1986 was increased 6.7 cm and 7.3 cm in the dry and the intermediate treatments, respectively, and 4.0 cm in the wet treatment. These height differences might be due to fewer seedlings of the dry and intermediate watering regime treatments having formed buds with cataphylls during the dormant season. Thus, seedlings of these treatments could resume height growth more quickly than those of the wet treatment, which had to go to a bud break period.

The differences in height could also be the result of the termination of the watering regime treatments in late August 1985. All seedlings were subjected to the same watering regime schedule after the treatments were suspended. Possibly, after seedling budbreak, the larger seedlings of the wet watering schedule came under more moisture stress because of their higher transpiration rates in relation to seedlings of the other two treatments. With more water available, seedlings of the intermediate and dry treatments began height growth sooner and at a higher rate than those in the wet treatment (Owston 1972b).

The height growth of the same species grown in a Mexican nursery in past years was slower than for the ones grown in the greenhouse experiment in Oregon. This difference is probably due to the effect of the fertilizer regime (supplemental fertilizing is not a common practice in México), greater control of the environmental conditions, and longer summer days in Oregon (Figures 1 and A1).

Greater shoot dry weight was expected for Pinus pseudostrobus var. apulcensis in the wet treatment (Table 4). The low value was probably due to having smaller trees to sample for this treatment after reserving samples of good seedlings for the two outplanting sites and the drought test. This effect did not occur for *Pinus patula* and *Pinus greggii*, because many more seedlings were available for sampling.

Root dry weight and shoot/root ratio only varied among species (Tables 5 and 6). These findings may be due to the size of the containers. These could have restricted the seedling root growth, especially after being grown for a full year in the greenhouse. As a result, the seedlings did not respond differently to watering regime as expected.

PART 2. OUTPLANTING TESTS

SEEDLING GROWTH PERFORMANCE IN THE FIELD (OREGON COAST RANGE)

The fact that seedlings from the dry watering regime had the greatest height increment and were no longer the shortest seedlings, indicates that the previous year of pre-conditioning did, somehow, improve field performance (Figure 3). This was probably not related to drought tolerance, because the coastal site did not came under serious moisture stress. More likely, the response was related to an unmeasured effect on the morphology or physiology of the shoot meristem. An added advantage of pre-conditioning seedlings under a dry regime is that is not necessary to water as frequently in the nursery to produce seedlings of good growth potential.

After one growing season, *Pinus greggii* was the tallest species and grew 17.3 cm in height on the outplanting site during that season. *Pinus patula*, as the intermediate species, had more increment in height growth than the first species (19.4 cm), but it was still shorter. *Pinus pseudostrobus* var. *apulcensis* was the shortest, and it gained only 8.8 cm in the field (Figure 4).

In general, the soils on this planting site corresponded to the great group of haplohumults with good physical properties (soil texture and soil moisture retention). Differences in tap root dry weight, and shoot/root ratio among species were basically due to their inherent growth response to the environmental and site factors and not to the effect of the previous watering regime treatments.

Based on the inventory of vegetation present on the site, species with moderate cover such as salal, salmonberry, and common groundsel might be a future problem for competing with the pine species. Salmonberry is a brush species that sprouts following disturbance. On relatively high site lands in the Coast Range, this species might be a serious competitor to conifers within one to two years after disturbance (Greaves et al., 1980).

SEEDLING GROWTH PERFORMANCE IN THE FIELD (TLAXCALA, MEXICO)

Contrasting with the excellent survival of the seedlings in Oregon Coast Range, survival was poor in Tlaxcala. This was probably due to poor soil characteristics combined with physiological stress during the trip from Corvallis to México City. The severity of the conditions may have masked any difference in drought tolerance due to treatments or species. The soils of the outplanting site are classified as hardpans (Cervantes, 1978). According to Flores, cited by Valdés (1970), hardpans showed low soil permeability, low organic matter, and low nutrient content. These soils were originated from volcanic ashes and, due to inadequate soil management, they were highly eroded. Few natural areas near the outplanting site remained with a few native species such as Juniperus deppeana, Agave sp, Opuntia sp, and Baccharis conferta (Cervantes 1978).

Lower than normal rainfall during the summer (Personal communication, Morales, 1987) undoubtedly added to the survival problem. The average annual precipitation of the experimental area recorded in past years was around 600 mm. mainly distributed during the summer (June through September).

Initial seedling heights after one growing season on the outplanting site in Tlaxcala followed a similar pattern as in the Oregon Coast site and in the greenhouse experiment. Pinus greggii was the tallest species, Pinus patula was intermediate, and Pinus pseudostrobus var. apulcensis, was the shortest. However, the seedlings had very little height growth between 1986 and 1987. Pinus pseudostrobus var. apulcensis had an increment of 2 cm, Pinus greggii had less than 1 cm, and Pinus patula did not show any increment at all (Figure 5). Thus, it is not surprising that the greenhouse pattern was maintained.

The significant differences in shoot/root ratio among species were due basically to their inherent growth characteristics in response to the same soil conditions.

There was a considerable difference in shoot/root ratios between those of the Oregon Coast Range and Tlaxcala sites. The differences are probably due to the poor seedling growth performance of the species on the droughty site of Tlaxcala.

PART 3. DROUGHT STUDY

The drought levels affected survival, growth, and physiological characteristics.

Seedlings of all species under high stress, and previously subjected to the dry treatment in the greenhouse, survived better than those subjected to the other watering regimes. This result is further indication that the previous dry watering regime was beneficial (other one being greater height growth in the Oregon Coast outplanting test).

As stated before for growth rates, the pre-conditioning must be related to unmeasured factors, because neither the morphological characteristics or transpiration measurements gave clues as to why it occurred. Other characteristics that could have perhaps better explained the pre-conditioning for drought tolerance are the ratios: leaf area/foliage dry weight or leaf dry weight/root dry weight.

In reference to the morphological measurements, most of the variables decreased between 10% to 50% under moderate and high stress. However, not all the variables measured were affected in the same magnitude by the different levels of stress. Shoot, tap root, and lateral root dry weights were the variables most affected by the high stress. Differences in shoot/root ratio were not significant at the 95% level among the drought levels. However, seedlings under high stress had the highest mean ratios, whereas seedlings under low stress had the lowest mean ratios. This indicates relatively more effect of the stress on roots (mainly on the lateral roots) than on tops. In regard to transpiration rates, the low and moderate stress levels were higher than those of the high stress. No difference was apparent between the low and moderate stress levels, probably because the date that the moderate level needed to be watered just prior to the measurements was the same as for the low level.

Irrespective of species and previous watering regimes, transpiration values were highest between 12:00 A.M. and 3:00 P.M. in the low and moderate levels, probably due to high evaporative demand (Figures 7, 8, 9, and 10).

Whereas, in the high stress treatment, transpiration rate decreased during the same time. This probably occurred because seedlings were more stressed under the high stress treatment than those under the low and moderate stress levels. This probably resulted in loss of leaf turgor and subsequent stomatal closure for the high stress seedlings.

Pinus pseudostrobus var. apulcensis, transpired more than the other species. According to Eguiluz (1978), the seed provenance of this species grows in natural habitats of low precipitation (600 mm to 750 mm of annual rainfall). It has characteristically thick leaves (needles) which help reduction of water loss during drought conditions. However, this species was intermediate for most growth measurements, as well as for seedling survival which showed a reduction of 31% (Table 16b). Apparently, there was not a direct relationship with the transpiration rates, seedling survival, and growth characteristics of this species.

Pinus greggii had the highest survival, height growth, shoot dry weight, tap root dry weight, and lateral root dry weight. This species was also the most capable of surviving under the high drought stress. The reduction in survival was only 17% (Table 16B). This study showed this species to be more drought tolerant than the others. The morphological characteristics as well as the transpiration rates were not modified drastically by the levels of stress.

According to Vargas (1985), Pinus greggii maintained higher plant water potential than Pinus patula and Pinus montezumae when they were under a soil water potential less than -1.5 MPa. He also pointed out that the number of lateral root tips as well as low ratios of foliage to roots are directly related to its high plant water potential under stress.

The stem diameters of Pinus patula were similar to those of Pinus greggii in the low stress treatment (Table 19). Contrary to Pinus greggii, Pinus patula had the least diameter under high stress. The transpiration rates of both species were intermediate. However, the survival of both species was quite different and did not seem to be related to the transpiration behavior of Pinus patula. Pinus patula, as well as Pinus greggii, had the greatest lateral root dry weight (Table 21). This characteristic apparently provided an efficient way for water absorption thorough roots. Thus, this variable did not provide an explanation for the high seedling mortality of Pinus patula under high stress (Table 16b).

Vela (1976), pointed out that Pinus patula is distributed in areas of high annual precipitation (1900 mm) and high relative humidity with the presence of fog. This species is also characterized by having thin needles. Probably, thin foliage and less efficient control of internal plant water potential leads to faster loss of water under high stress.

Pinus montezumae transpired less than the other species. In regard to its growth characteristics, the shoot, tap root, and lateral root dry weights were affected under high stress, and high shoot/root ratios resulted (Tables 18, 20 and 21).

This species is characterized by a grass stage during the first and second growing season in its natural habitat. In this current study, diameter remained as the highest of any of the species, It is likely that the large stem diameter was due to its grass stage.

According to Vargas (1985), the low transpiration values of this species seemed to be related to its high shoot/root ratio. This is a less efficient way for a plant to supply water for carrying out the transpiration per foliar area. He pointed out that this species was the most affected in its morphological and physiological characteristics when it was subjected to soil water potential less than -1.5 MPa for a 28 day period.

Probably, the needle thickness and the grass stage also contributed to the reduction of transpiration. These characteristics provide seedlings a way to adapt to severe conditions. For example, leaves growing upright during the grass stage probably result in decreased energy absorption and thus, decreased midday leaf temperature, which in turn, results in decreased water loss. However, an effect on seedling survival due to the former explanation has never been demonstrated (Kramer and Kozlowski, 1979). For this study, Pinus montezumae showed a reduction of 43% in seedling survival in the high stress (Table 16b).

Pinus montezumae a widespread species in Mexico, normally has a grass stage during the early growing seasons. The grass stage is an adaptation to an unfavorable environment due to a high frequency of fires. This species was expected to be more drought tolerant than Pinus greggii. However, seed provenance of Pinus montezumae used for this study was from Southern latitudes, where probably natural hybridization occurred with other species that do not have a grass stage (Nepamuceno and De la Garza, 1987). Thus, these seedlings did not show a true grass stage during the drought study.

In general, the previous watering regime treatments did not have differential effects among the drought stress levels for most of the growth and transpiration variables evaluated in this study. It is likely that the effect of the watering regimes decreased in time, probably due to the short time that seedlings received these treatments (3 months) (Figure A2). If these treatments had been continued for the five months that seedlings were hardened-off in the greenhouse, the effect of the watering regimes would probably have had more effect on the growth, transpiration, and drought tolerance of the seedlings.

VI. CONCLUSIONS AND RECOMMENDATIONS

Main conclusions drawn from the experiments are:

1. During the greenhouse production of four Mexican pine species, heavy irrigation resulted in taller seedlings than did watering regimes in which the potting mixture was allowed to dry somewhat between waterings.
2. _Pinus patula_ had less diameter growth and shoot dry weight under a dry watering regime than under intermediate or wet regimes during greenhouse production. Diameter and shoot dry weight of other species were generally not affected by watering regime.
3. _Pinus greggii_ was the tallest species, and _Pinus montezumae_ was the shortest after one growing season in a greenhouse.
4. On a low stress site, there was an indication that pre-conditioning the seedlings under a the dry watering regime improved seedling height growth.
5. On a high stress, the severity of the conditions masked any difference in drought tolerance of the pre-conditioned seedlings.
6. In a greenhouse drought test, seedlings pre-conditioned in a dry watering regime had higher survival (i.e., were more drought tolerant) than those pre-conditioned under intermediate or wet regimes.

7. Pinus greggii was the most drought tolerant species in these experiments. During a drought test in the greenhouse, it had the highest survival and best growth. It also had slightly higher mean survival on both outplanting sites than did Pinus patula or Pinus pseudostrobus var. apulcensis.

Based on the conclusions, I recommend that, in container nurseries, these pine species should be watered under a dry watering schedule; i.e., watering should be thorough but as infrequent as possible to sustain suitable growth. On droughty sites in Mexico, I recommend planting Pinus greggii over Pinus patula.

VII. LITERATURE CITED

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APPENDIX

FIGURE A1. SEEDLING HEIGHT GROWTH BY SPECIES IN A MEXICAN NURSERY

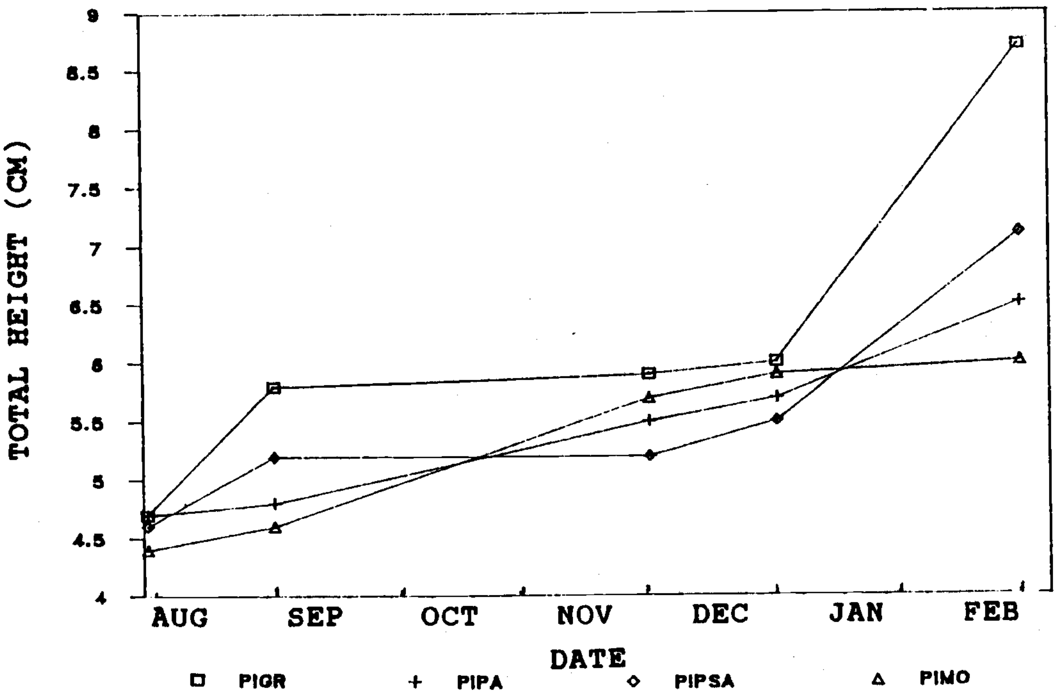

FIGURE A2. SEEDLING HEIGHT GROWTH BY PREVIOUS WATERING REGIMES DURING THE DROUGHT STUDY

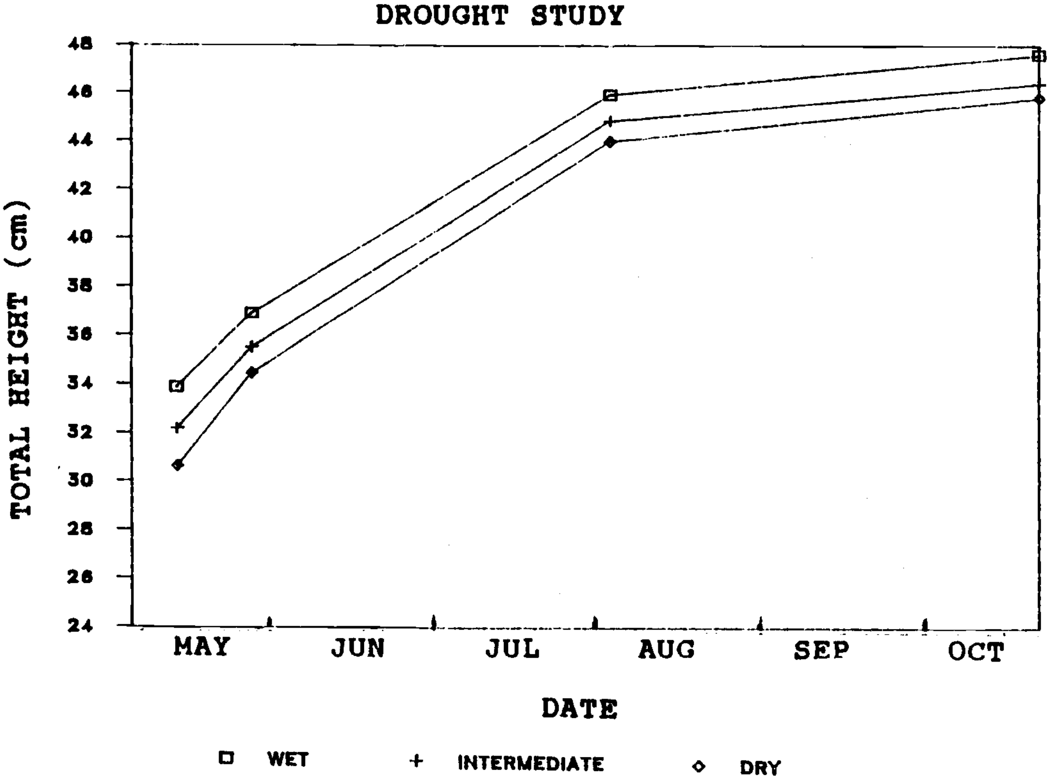

TABLE A1. ANALYSIS OF VARIANCE TABLE FOR HEIGHT MEASUREMENTS (GREENHOUSE STUDY) DATE: JUNE 19, 1985.

source	df	ss	ms	F	PR>F
model	20	125.4679	6.2733	5.01	0.0001
rep.	3	2.8739	0.9579	2.47ns	0.5233
w.r. (A)	2	0.8461	0.4233	1.09ns	0.3941
error (A)	6	2.3266	0.3877	0.31	0.9262
sp. (B)	3	114.4589	38.1529	30.49**	0.0001
(A)*(B)	6	4.9616	0.8269	0.66ns	0.6815
error (AB)	27	33.7868	1.2513		
total	47	159.2547			

TABLE A2. ANALYSIS OF VARIANCE TABLE FOR HEIGHT MEASUREMENTS (GREENHOUSE STUDY) DATE: JULY 20, 1985.

source	df	ss	ms	F	PR>F
model	20	925.8129	46.2906	12.85	0.0001
rep.	3	43.3750	14.4583	2.21ns	0.0175
w.r. (A)	2	160.0004	80.0002	12.25**	0.0076
error (A)	6	39.1862	6.5310	1.81	0.1341
sp.(B)	3	633.6733	211.2244	58.64**	0.0001
(A)*(B)	6	49.5779	8.2629	2.29ns	0.0643
error (AB)	27	97.2637	3.6023		
total	47	1023.0766			

TABLE A3. ANALYSIS OF VARIANCE TABLE FOR HEIGHT MEASUREMENTS (GREENHOUSE STUDY) DATE: SEPTEMBER 4, 1985.

source	df	ss	ms	F	PR>F
model	20	3177.4866	158.8743	19.28	0.0001
rep.	3	122.8341	40.9447	2.78ns	0.1325
w.r. (A)	2	372.8516	186.4258	12.67**	0.0070
error (A)	6	88.2683	14.7113	1.79	0.1399
sp. (B)	3	2459.1375	819.7125	99.47**	0.0001
(A)*(B)	6	134.3950	22.3991	2.72*	0.0339
error (AB)	27	222.4925	8.2404		
total	47	3399.9791			

TABLE A4. ANALYSIS OF VARIANCE TABLE FOR SEEDLING HEIGHT MEASUREMENTS AFTER BEING SUBJECTED TO THE WATERING REGIMES (GREENHOUSE STUDY).

source	df	ss	ms	F	PR>F
model	14	551.5333	39.3952	8.68	0.0003
rep.	2	13.0200	6.5100	3.45ns	0.1347
w.r. (A)	2	54.0866	27.0430	14.35*	0.0150
error (A)	4	7.5400	1.8850	0.42	0.7947
sp. (B)	2	408.0855	204.0170	44.93**	0.0001
(A)*(B)	4	68.8511	17.2120	3.79*	0.0323
error (AB)	12	54.4933	4.5411		
total	26	606.0266			

TABLE A5. ANALYSIS OF VARIANCE TABLE FOR SEEDLING DIAMETER MEASUREMENTS AFTER BEING SUBJECTED TO THE WATERING REGIMES (GREENHOUSE STUDY).

source	df	ss	ms	F	PR>F
model	14	1.1051	0.0789	4.31	0.0078
rep.	2	0.0318	0.0159	0.41ns	0.5557
w.r. (A)	2	0.1918	0.0959	2.48ns	0.1994
error (A)	4	0.1548	0.0387	2.11	0.1422
sp.(B)	2	0.4674	0.2337	12.75**	0.0011
(A)*(B)	4	0.2592	0.0648	3.54*	0.0397
error (AB)	12	0.2200	0.0183		
total	26	1.3251			

TABLE A6. ANALYSIS OF VARIANCE TABLE FOR SEEDLING SHOOT MEASUREMENTS AFTER BEING SUBJECTED TO THE WATERING REGIMES (GREENHOUSE STUDY).

source	df	ss	ms	F	PR>F
model	14	2.7108	0.1936	4.06	0.0099
rep.	2	0.3371	0.1685	1.70ns	0.2922
w.r. (A)	2	0.1244	0.0622	0.63ns	0.5792
error (A)	4	0.3962	0.0990	2.08	0.1468
sp. (B)	2	0.8577	0.4288	9.0**	0.0041
(A)*(B)	4	0.9952	0.2488	5.22*	0.0114
error (AB)	12	0.5718	0.0476		
total	26	3.2826			

TABLE A7. ANALYSIS OF VARIANCE TABLE FOR SEEDLING ROOT MEASUREMENTS AFTER BEING SUBJECTED TO THE WATERING REGIMES (GREENHOUSE STUDY).

source	df	ss	ms	F	PR>F
model	14	0.7618	0.0544	3.95	0.0111
rep.	2	0.0347	0.0173	0.278ns	0.7708
w.r. (A)	2	0.0160	0.0080	0.13ns	0.8827
error (A)	4	0.2489	0.0622	4.52	0.0185
sp. (B)	2	0.3935	0.1967	14.29**	0.0007
(A)*(B)	4	0.0686	0.0171	1.25ns	0.3430
error (AB)	12	0.1651	0.0137		
total	26	0.9270			

TABLE A8. ANALYSIS OF VARIANCE TABLE FOR SEEDLING SHOOT/ROOT RATIO CALCULATIONS AFTER BEING SUBJECTED TO THE WATERING REGIMES (GREENHOUSE STUDY).

source	df	ss	ms	F	PR>F
model	14	2.2005	0.1571	4.91	0.0044
rep.	2	0.0301	0.0150	0.57ns	0.6351
w.r. (A)	2	0.0233	0.0116	0.45ns	0.6679
error (A)	4	0.1042	0.0260	0.81	0.5401
sp. (B)	2	1.6562	0.8281	25.87**	0.0001
(A)*(B)	4	0.3865	0.0966	3.02ns	0.0615
error (AB)	12	0.3841	0.0320		
total	26	2.5846			

TABLE A9. ANALYSIS OF VARIANCE TABLE FOR SURVIVAL COUNTS (OUTPLANTING TEST, OREGON).

source	df	ss	ms	F	PR>F
model	11	0.1532	0.0139	0.65	0.7706
rep.	3	0.1012	0.0337	1.57ns	0.2224
w.r. (A)	2	0.0116	0.0058	0.27ns	0.7649
sp. (B)	2	0.0283	0.0141	0.66ns	0.5262
(A)*(B)	4	0.0119	0.0029	0.14ns	0.9660
error (AB)	24	0.5158	0.0214		
total	35	0.6691			

TABLE A10. ANALYSIS OF VARIANCE TABLE FOR HEIGHT MEASUREMENTS (OUTPLANTING TEST, OREGON).

source	df	ss	ms	F	PR>F
model	11	3217.2127	292.4738	26.40	0.0001
rep.	3	234.2877	78.0963	7.05**	0.0015
w.r. (A)	2	105.4950	52.7485	4.76*	0.0181
sp. (B)	2	2837.5216	1418.7615	28.07**	0.0001
(A)*(B)	4	39.9083	9.9767	0.90ns	0.4791
error (AB)	24	265.8772	11.0782		
total	35	3483.0900			

TABLE A11. ANALYSIS OF VARIANCE TABLE FOR DIAMETER MEASUREMENTS (OUTPLANTING TEST, OREGON).

source	df	ms	ss	F	PR>F
model	11	38.6969	3.5179	1.78	0.1143
rep.	3	26.8097	8.9365	4.53*	0.0118
w.r (A)	2	1.4705	0.7352	0.37ns	0.6928
sp. (B)	2	8.8738	4.4369	2.25ns	0.1273
(A)*(B)	4	1.5427	0.3856	0.20ns	0.9383
error (AB)	24	47.3527	1.9730		
total	35	86.0497			

TABLE A12. ANALYSIS OF VARIANCE TABLE FOR SHOOT MEASUREMENTS (OUTPLANTING TEST, OREGON).

source	df	ss	ms	F	PR>F
model	11	331.9630	30.1784	0.77	0.6672
rep.	3	260.6030	86.8676	2.21ns	0.1129
w.r. (A)	2	4.4716	2.2358	0.06ns	0.9448
sp. (B)	2	44.5550	22.2700	0.57ns	0.5747
(A)*(B)	4	22.3333	5.5833	0.14ns	0.9648
error (AB)	24	948.1644	39.2985		
total	35	1275.1275			

TABLE A13. ANALYSIS OF VARIANCE TABLE FOR LATERAL ROOT MEASUREMENTS (OUTPLANTING TEST, OREGON).

source	df	ss	ms	F	PR>F
model	11	18.3394	1.6672	1.10	0.4047
rep.	3	1.4688	0.4896	0.32ns	0.8094
w.r. (A)	2	3.5572	1.7786	1.17ns	0.3276
sp. (B)	2	9.3038	4.6519	3.06ns	0.0656
(A)*(B)	4	4.0094	1.0023	0.66ns	0.6263
error (AB)	24	36.4961	1.5206		
total	35	54.8355			

TABLE A14. ANALYSIS OF VARIANCE TABLE FOR TAP ROOT MEASUREMENTS (OUTPLANTING TEST, OREGON).

source	df	ss	ms	F	PR>F
model	11	2.8344	0.2576	1.74	0.1249
rep.	3	0.4888	0.1629	1.10ns	0.3691
w.r. (A)	2	0.1172	0.0586	0.40ns	0.6780
sp. (B)	2	1.8405	0.9202	6.20**	0.0067
(A)*(B)	4	0.3877	0.0969	0.65ns	0.6302
error (AB)	24	3.5611	0.1483		
total	35	6.3955			

TABLE A15. ANALYSIS OF VARIANCE TABLE FOR SHOOT/ROOT RATIO CALCULATIONS (OUTPLANTING TEST, OREGON).

source	df	ss	ms	F	PR>F
model	11	30.2539	2.7503	1.15	0.3691
rep.	3	6.8374	2.2791	0.95ns	0.4308
w.r. (A)	2	3.4212	1.7106	0.72ns	0.4991
sp. (B)	2	18.3366	9.1683	3.83*	0.0359
(A)*(B)	4	1.6586	0.4146	0.17ns	0.9499
error (AB)	24	57.3906	2.3912		
total	35	87.6446			

TABLE A16. ANALYSIS OF VARIANCE TABLE FOR SURVIVAL COUNTS (OUTPLANTING TEST, TLAXCALA).

source	df	ss	ms	F	PR>F
model	10	1.0298	0.1029	1.57	0.2043
rep.	2	0.5334	0.2667	4.06*	0.0376
w.r. (A)	2	0.3319	0.1659	2.52ns	0.1115
sp. (B)	2	0.0435	0.0217	0.33ns	0.7226
(A)*(B)	4	0.1208	0.0302	0.46ns	
error (AB)	16	1.0519	0.0657		
total	26	2.0817			

TABLE A17. ANALYSIS OF VARIANCE TABLE FOR HEIGHT MEASUREMENTS (OUTPLANTING TEST, TLAXCALA).

source	df	ss	ms	F	PR>F
model	10	862.2303	86.2230	1.34	0.2882
rep.	2	16.8674	8.4337	0.13ns	0.8777
w.r. (A)	2	235.6718	117.8359	1.84ns	0.1912
sp. (B)	2	488.6940	244.3470	3.81*	0.0443
(A)*(B)	4	120.9970	30.2492	0.47ns	0.7558
error (AB)	16	1025.9259	64.1203		
total	26	1888.1562			

TABLE A18. ANALYSIS OF VARIANCE TABLE FOR DIAMETER MEASUREMENTS (OUTPLANTING TEST, TLAXCALA).

souece	df	ss	ms	F	PR>F
model	10	2.8614	0.2861	0.99	0.4858
rep.	2	0.7118	0.3559	1.24ns	0.3164
w.r. (A)	2	0.6585	0.3292	1.14ns	0.3430
sp. (B)	2	1.0696	0.5348	1.86ns	0.1879
(A)*(B)	4	0.4214	0.1053	0.37ns	0.8290
error (AB)	16	4.6014	0.2875		
total	26	7.4629			

TABLE A19. ANALYSIS OF VARIANCE TABLE FOR SHOOT MEASUREMENTS (OUTPLANTING TEST, TLAXCALA).

source	df	ss	ms	F	PR>F
model	10	57.1837	5.7183	1.55	0.2079
rep.	2	19.6274	9.8137	2.67ns	0.1000
w.r. (A)	2	10.9118	5.4559	1.48ns	0.2564
sp. (B)	2	23.2274	11.6137	3.16ns	0.0698
(A)*(B)	4	3.4170	0.8542	0.23ns	0.9161
error (AB)	16	58.8392	3.6774		
total	26	116.0229			

TABLE A20. ANALYSIS OF VARIANCE TABLE FOR LATERAL ROOT MEASUREMENTS (OUTPLANTING TEST, TLAXCALA).

source	df	ss	ms	F	PR>F
model	10	5.6770	0.5677	0.79	0.6364
rep.	2	2.8118	1.4059	1.97ns	0.1724
w.r. (A)	2	0.0585	0.0292	0.04ns	0.9600
sp. (B)	2	0.7118	0.3559	0.50ns	0.6170
(A)*(B)	4	2.0948	0.5237	0.73ns	0.5831
error (AB)	16	11.4414	0.7150		
total	26	17.1185			

TABLE A21. ANALYSIS OF VARIANCE TABLE FOR TAP ROOT MEASUREMENTS (OUTPLANTING TEST, TLAXCALA).

source	df	ss	ms	F	PR>F
model	10	0.8570	0.0857	0.70	0.7115
rep.	2	0.4229	0.2114	1.73ns	0.2090
w.r. (A)	2	0.2318	0.1159	0.95ns	0.4083
sp. (B)	2	0.0007	0.0003	0.00ns	0.9970
(A)*(B)	4	0.2014	0.0503	0.41ns	0.7976
error (AB)	16	1.9570	0.1223		
total	26	2.8140			

TABLE A22. ANALYSIS OF VARIANCE TABLE FOR SHOOT/ROOT RATIO CALCULATIONS (OUTPLANTING TEST, TLAXCALA).

source	df	ss	ms	F	PR>F
model	10	7.8268	0.7826	1.69	0.1682
rep.	2	0.6508	0.3254	0.70ns	0.5097
w.r. (A)	2	1.6449	0.8224	1.78ns	0.2009
sp. (B)	2	4.2049	2.1024	4.54*	0.0274
(A)*(B)	4	1.3260	0.3315	0.72ns	0.5930
error (AB)	16	7.4046	0.4627		
total	26	15.2314			

TABLE A23. ANALYSIS OF VARIANCE TABLE FOR SURVIVAL COUNTS (DROUGHT STUDY).

source	df	ss	ms	F	PR>F
model	62	10.5235	0.2987	4.90	0.0001
rep.	3	0.2565	0.0855	1.0ns	0.4568
d.l. (A)	2	12.1551	6.0775	71.07**	0.0001
error (A)	6	0.5130	0.0855	1.40	0.2238
w.r. (B)	2	0.2865	0.1432	5.04*	0.0182
(A)*(B)	4	0.5730	0.1432	5.04**	0.0066
error (AB)	18	0.5111	0.0283	0.47	0.9654
sp. (C)	3	1.3341	0.4447	7.29**	0.0003
(A)*(C)	6	2.6682	0.4447	7.29**	0.0001
(B)*(C)	6	0.0752	0.0125	0.21ns	0.9741
(A)*(B)*(C)	12	0.1504	0.0125	0.21ns	0.9979
error (ABC)	81	4.9390	0.0609		
total	143	23.4626			

TABLE A24. ANALYSIS OF VARIANCE TABLE FOR HEIGHT MEASUREMENTS (DROUGHT STUDY).

source	df	ss	ms	F	PR>F
model	62	53326.0775	860.0980	68.63	0.0001
rep.	3	126.5902	42.1900	0.75ns	0.5609
d.l. (A)	2	7118.0654	3559.0300	63.32**	0.0001
error (A)	6	337.2351	56.2000	4.48	0.0006
w.r. (B)	2	87.4466	43.7233	0.79ns	0.4910
(A)*(B)	4	76.0404	19.0100	0.32ns	0.8596
error (AB)	18	1063.1445	59.0600	4.71	0.0001
sp. (C)	3	40935.1247	13645.0410	1088.76**	0.0001
(A)*(C)	6	3424.1423	570.6900	45.54**	0.0001
(B)*(C)	6	24.9694	4.1610	0.33ns	0.9182
(A)*(B)*(C)	12	133.3184	11.1000	0.89ns	0.5637
error (ABC)	81	1015.1400	12.5325		
total	143	54341.2175			

TABLE A25. ANALYSIS OF VARIANCE TABLE FOR SHOOT MEASUREMENTS (DROUGHT STUDY).

source	df	ss	ms	F	PR>F
model	62	2806.1072	45.2597	24.04	0.0001
rep.	3	5.1233	1.7077	0.17ns	0.913
d.l. (A)	2	1895.1926	947.5900	98.71**	0.0001
error (A)	6	57.5979	9.5996	5.10	0.0002
w.r. (B)	2	39.7834	19.8917	4.43*	0.0273
(A)*(B)	4	19.3761	4.8440	1.08ns	0.3964
error (AB)	18	80.8637	4.4924	2.39	0.0043
sp. (C)	3	541.6716	180.5570	95.92**	0.0001
(A)*(C)	6	144.8829	24.1470	12.83**	0.0001
(B)*(C)	6	11.6604	1.9430	1.03ns	0.4105
(A)*(B)*(C)	12	9.9550	0.8295	0.44ns	0.9419
error (ABC)	81	152.4750	1.8824		
total	143	2958.5822			

TABLE A26. ANALYSIS OF VARIANCE TABLE FOR DIAMETER MEASUREMENTS (DROUGHT STUDY).

source	df	ss	ms	F	PR>F
model	62	480.9822	7.7577	29.50	0.0001
rep.	3	0.4297	0.1432	0.11ns	0.9512
d.l. (A)	2	275.7005	137.8500	105.87**	0.0001
error (A)	6	7.8127	1.3021	4.95	0.0002
w.r. (B)	2	0.2834	0.1417	0.17ns	0.8466
(A)*(B)	4	6.0031	1.5007	1.78ns	0.1768
error (AB)	18	15.1750	0.8430	3.21	0.0002
sp. (C)	3	162.5513	54.1830	206.08**	0.0001
(A)*(C)	6	7.4627	1.2437	4.73**	0.0004
(B)*(C)	6	0.4298	0.0716	0.27ns	0.9483
(A)*(B)*(C)	12	5.1334	0.4277	1.63ns	0.1003
error (ABC)	81	21.2975	0.2629		
total	143	502.2797			

TABLE A27. ANALYSIS OF VARIANCE TABLE FOR TAP ROOT MEASUREMENTS (DROUGHT STUDY).

source	df	ss	ms	F	PR>F
model	62	22.6693	0.3656	14.78	0.0001
rep.	3	0.0275	0.0091	0.19ns	0.8994
d.l. (A)	2	16.3734	8.1867	173.11**	0.0001
error (A)	6	0.2837	0.0472	1.91	0.0888
w.r. (B)	2	0.1759	0.0879	1.29ns	0.2988
(A)*(B)	4	0.4473	0.1118	1.64ns	0.2069
error (AB)	18	1.2250	0.0680	2.75	0.0010
sp. (C)	3	2.8336	0.944	38.18**	0.0001
(A)*(C)	6	0.9926	0.1654	6.69**	0.0001
(B)*(C)	6	0.1568	0.0261	1.06ns	0.3956
(A)*(B)*(C)	12	0.1531	0.0127	0.52ns	0.8986
error (ABC)	81	2.0037	0.0247		
total	143	24.6730			

TABLE A28. ANALYSIS OF VARIANCE TABLE FOR LATERAL ROOT MEASUREMENTS (DROUGHT STUDY).

source	df	ss	ms	F	PR>F
model	62	257.6184	4.1551	21.03	0.0001
rep.	3	4.3702	1.4567	0.59ns	0.6437
d.l. (A)	2	155.8955	77.9470	32.01**	0.0006
error (A)	6	14.6088	2.4348	12.33	0.0001
w.r. (B)	2	1.7338	0.8669	2.46ns	0.1133
(A)*(B)	4	3.2015	0.8003	2.27ns	0.1013
error (AB)	18	6.3345	0.3519	1.78	0.0420
sp. (C)	3	52.9275	17.6420	89.31**	0.0001
(A)*(C)	6	14.3816	2.3960	12.13**	0.0001
(B)*(C)	6	2.2100	0.3683	1.86ns	0.0970
(A)*(B)*(C)	12	1.9545	0.1628	0.82ns	0.6249
error (ABC)	81	16.0012	0.1975		
total	143	273.6197			

TABLE A29. ANALYSIS OF VARIANCE TABLE FOR SHOOT/ROOT RATIO CALCULATIONS (DROUGHT STUDY).

source	df	ss	ms	F	PR>F
rep.	3	14.5763	4.8587	0.61ns	0.6313
d.l. (A)	2	97.7091	48.8545	6.15*	0.0351
error (A)	6	47.5871	7.9311		
w.r. (B)	2	2.2958	1.1479	0.38ns	0.6891
(A)*(B)	4	20.3794	5.0948	1.68ns	0.1967
error (AB)	18	54.3558	3.0197		
sp. (C)	3	88.8111	29.6037	46.19**	0.0001
(A)*(C)	6	17.5323	2.9220	4.55**	0.0004
(B)*(C)	6	2.8606	0.4767	0.74ns	0.1160
(A)*(B)*(C)	12	12.5642	1.0470	1.63ns	0.0985
error (ABC)	81	51.9183	0.6409		
total	143	2634.4762			

TABLE A30. ANALYSIS OF VARIANCE TABLE FOR TRANSPIRATION CALCULATIONS (DROUGHT STUDY).

source	df	ss	ms	F	PR>F
rep.	3	84.10618	28.03539	3.68ns	0.0815
d.l. (A)	2	193.36620	96.68310	12.75**	0.0070
error (A)	6	45.48178	7.58029		
w.r. (B)	2	1.59888	0.79944	1.28ns	0.3008
(A)*(B)	4	1.13933	0.28483	0.45ns	0.7711
error (AB)	18	11.20349	0.62241		
sp.(C)	3	14.66821	4.66940	18.96**	0.0001
(A)*(C)	6	4.39308	0.73218	2.83*	0.0149
(B)*(C)	6	2.01529	0.33588	1.30ns	0.2666
(A)*(B)*(C)	12	3.18594	0.26549	1.09ns	0.3797
error (ABC)	81	20.88262	0.25781		
total	143	382.041			