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Drought-Tolerance Comparison of Aleppo Pine and Brutia Pine Seedlings

Mohammad S. Abido
Stephen F Austin State University

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DROUGHT-TOLERANCE COMPARISON OF ALEPPO PINE AND BRUTIA

PINE SEEDLINGS

APPROVED:

Lawrence C. Walker
(Thesis Director)

M. Victor Bilan

A. Jay Schultz

David L. Jeffrey
Dean of the Graduate School

DROUGHT-TOLERANCE COMPARISON OF ALEPPO PINE AND BRUTIA PINE SEEDLINGS

by

MOHAMMAD S. ABIDO, B.S.

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INTRODUCTION

Most of the forested area in Syria, once about 47% of the area of the country but now only 2.4%, is degraded and unproductive. Pinus brutia Ten. forests are naturally distributed on more than 40,000 hectares in northwestern Syria. Pinus halepensis Mill. also is a widespread species in Syria. The choice of species for particular sites is important in afforestation operations in Syria, particularly because of variation in drought and rainfall.

Aleppo pine (Pinus halepensis Mill.) is a common species throughout the Mediterranean region, ranging from southern Europe to Asia Minor. It occurs in the eastern Mediterranean area in scattered stands mixed with several kinds of oaks, such as Quercus calliprinos. Also it grows mixed with Pistacia lentiscus, Arbutus andrachne, and many other species to form the upper story of these stands (Zohary 1962).

Aleppo pine occurs in unevenaged stands and, usually, on shallow limestone soils and those derived from sandstone. It is reported that Aleppo pine is resistant to soil salinity (Francois and Clark 1978), to drought (Goor and Barney 1976), and to a reasonable amount of frost.

Because of its ability to endure severe edaphic and climatic conditions, Aleppo pine has been used for reclaiming poor soils and for afforestation in most of the Mediterranean countries. The species also has been introduced into Australia.

Brutia pine (*Pinus brutia* Ten.), once recognized as a variety of *P. halepensis*, is at present considered a different species (Mirov 1955, Nahall 1962).

P. brutia, as opposed to *P. halepensis*, is restricted to the eastern Mediterranean region. It grows from Greece to Iraq, and is concentrated principally in Turkey and Cyprus.

Brutia pine is usually distinguished from Aleppo pine by its straighter trunk, coarser and longer needles, and cones which are not deflexed. Also Aleppo pine is susceptible to the attacks of *Matscoccus josephi* infestation while brutia pine is not (Mirov 1955).

Papaioannou (1954) and Moulopulos (1951) reported that *P. brutia* is more resistant to injury from freezing than is *P. halepensis*. They also noted that brutia pine can withstand higher temperature and greater fluctuation in moisture. In general *P. brutia* grows at higher elevations. It is a faster-growing species than *P. halepensis*.

Although brutia pine grows on almost every soil, best growth can be obtained in soils with pH 5.8 to 7.2 (Giulimondi 1972). According to Urgenc (1971), *P. brutia* is a fast-growing species in its early stages. Satcioglu and Pamay (1962) reported that *P. brutia* is an important species in afforestation, control of erosion, and sand-dune fixation in arid and semi-arid regions.

OBJECTIVE

This study was undertaken to find out:

1. Whether Aleppo pine or brutia pine is the more tolerant to drought or water stress.
2. To determine the critical needle-moisture content (NMC) for both species.
3. To evaluate some morphological characteristics for both species during the first half of their first growing season.

LITERATURE REVIEW

Plant development is limited to some degree to the available amount of water. In dry areas, the efficient use of water by plants is increasingly necessary and a goal of all dry land systems in order to maximize the use of the land. Morphological and physiological characteristics of plants play an important role in determining the ability for vegetation to survive and grow in habitats of various moisture regimes.

Plant-Water Relationships

Water has an essential role in controlling survival and distribution of plant communities. Water is important because it is

1. a prime constituent of physiologically active tissue in plants,
2. a reagent (raw material) for most metabolic processes,
3. a solvent for salts, sugars, and gases, and
4. essential for maintaining plant turgidity, which is necessary for cell enlargement and growth (Kramer 1969).

Transpiration is defined as the loss of water from plants in vapor form through evaporation and diffusion processes. Absorption is the process of water uptake from the soil by plant roots, either by active or passive means (Kramer and Kozlowski 1979).

Both transpiration and absorption play an important role in controlling water status in plants. The rate of transpiration is controlled by several factors: leaf area and structure, extent of stomatal opening, temperature, and vapor-pressure gradient between leaves and the surrounding atmosphere (Kramer and Kozlowski 1979).

The rate of water absorption is controlled by transpiration (water loss), extent and efficiency of the roots, and also by some edaphic factors such as soil temperature, soil aeration, soil moisture, and the concentration of soil solution. Because so many factors affect the rate of transpiration and water absorption, water status in plants changes daily and seasonally. Water deficits can develop either by excessive loss of water, by insufficient absorption, or by a combination of these two measures (Kramer 1963).

Effect of Water Deficits

Shortage of water, or water deficit, not only reduces the amount of growth, but it also changes the pattern of growth. Vegetative growth is sensitive to moisture stress because growth is related to cell turgidity; loss of that turgidity stops cell enlargement and results in smaller plants (Hsiao 1973). Root-shoot ratio is increased by water deficit. Leaf area usually is reduced, but leaf thickness is increased. Under drought conditions, an extensive and dense network of veins and ribs is formed, and the epidermal and stomatal cells decrease in size. Also the amount of lignification and cutinization is increased. Hence, water deficits result in xeromorphic characteristics in plants.

Moisture stress is beneficial in reducing water loss from plants; but on the other hand, it has an indirect effect on photosynthetic processes by reducing leaf area, which, in turn, interferes with gas exchange. A direct effect of water stress on photosynthesis is dehydration of protoplasm, thus lowering its capacity for photosynthesis.

Water deficit has a variable effect on respiration. Brix (1962), found a general decrease in respiration of loblolly pine, followed by an increase and then a decrease as the moisture stress increased. Scheneider and Childers (1941), on the other hand, stated that respiration of apple tree leaves was increased with decreasing soil moisture.

Water stress can modify physiological and biochemical processes in plants. A decrease in starch content (depletion of food) is common. Disturbance of nitrogen metabolism (hydrolysis of protein) and destruction of ribonucleic acid are increased (Henckel 1950). Slatyer (1967) pointed out that accumulation and demand for nutrients are reduced during the period of water stress.

Drought Resistance

Drought resistance in plants can be defined, according to Meyer and Anderson (1952), as the "capacity of plants to survive periods of drought with little or no injury." The lack of water caused by drought is usually associated with high tissue temperatures. Plants which live in arid and semi-arid regions are continuously exposed to the impact of harsh external conditions; therefore these plants have some kind of adaptation to water scarcity and extremely high temperatures. Plants which are adapted to these xeric conditions are called "xerophytes".

Henckel (1950) defined drought-resistant plants as those which "in the process of ontogenesis are able to adapt to the effect of drought and which can normally grow, develop and reproduce under drought conditions because of a number of properties acquired in the process of evolution under the influence of environmental conditions and natural selection." The following table shows the classification of plants which are adapted to dry climate (Table 1).

Causes of Drought Resistance

Stress can be defined as any environmental factor potentially unfavorable to living organisms (Levitt 1972) while stress resistance is the ability of plants to survive unfavorable conditions. A plant's capacity to survive drought periods depends on morphological, physiological, and phenological factors. Some plants are considered drought-avoiding because they can escape periods of drought by means of completing their life cycle before drought is initiated. Some plants are considered drought postponing, thus able to store large amounts of water (cacti spp.), possess heavily cutinized leaves (carob), have good stomatal control, which lead to low rate of transpiration (Aleppo pine), or by having a deep root system (acacia) (Oppenheimer 1968). Other plants are considered desiccation-tolerant, the protoplasm of these being able to tolerate severe dehydration without irreversible injury (Levitt 1972).

Vaadia (1961) suggested that drought resistance depends on the ability of plants to bind water to proteins. Henckel (1950) suggested that drought resistance is associated with protoplasmic elasticity.

Table 1

Classification of plants adapted to dry climates

Adaptability to dry climates

Xerophytism

- Ability to stay alive
  Drought resistance
  - Ability to prevent reduction in water content.
    Drought avoidance
    - Ability to complete life cycle before extreme drought
      Ephemerals
      (Drought escaping)
    - Ability to obtain large amount of water during drought
      Water spenders
      (Drought evading)
    - Ability to reduce water loss to a minimum
      Water savers
      (Drought enduring)
  - Ability to survive reduction in water content.
    Drought tolerance
    (Drought hardiness, dehydration or desiccation resistance)
- Ability to grow and develop (no name):
  1. Ability to germinate
  2. Suitable optimum temperature for growth
  3. Suitable photoperiodic response
  4. Suitable thermoperiodic response

Source: Levitt *et al*. 1960

Aleppo pine and brutia pine are drought-resistant species. They can withstand hot climates and long periods of drought (Goor and Barney 1976). According to Waisel (1959), Aleppo pine can show 100% survival for up to nine days beyond the permanent wilting point of sunflower plants, while brutia pine is able to endure (with one hundred percent survival) for up to four days beyond the permanent wilting point of sunflower plants.

The mechanism by which these two species survive long periods of drought is unknown. Leshem (1965, 1974) attributed that mechanism to root activity. He stated that when the soil becomes dry, root extension ceases and the layer of cells under the root cap becomes suberized. This suberized tissue forms a continuous layer with the endodermis. When soil conditions improve, root apices penetrate the suberized layer, enabling root elongation to resume. Also he stated that the mucigel (gelatinous material at the surface of roots grown in normal soils) may retard desiccation of apical meristems and young tissue before suberized lamellae develop.

Plants, of course, do recover from moisture stress up to a degree. The capability of plants to recover after being exposed to moisture stress is considered a good indicator of the ability of these plants to survive periods of drought.

Needle-moisture content can be related to the degree of moisture stress in the soil (Stransky 1963). Brix (1960) established a lethal threshold for loblolly pine seedlings at 110% NMC. Stransky (1963) established a range of lethal needle moisture content at 65 to 105% NMC for loblolly and shortleaf pine seedlings.

METHODS

Seedlings of Aleppo pine and brutia pine were grown from seed in forty 7.5-inch plastic pots, three seedlings per pot. Each pot contained approximately 1500 grams of sandy loam soil from the Stephen F. Austin Experimental Forest. The soil pH was adjusted from 5.5 to 6.8 with ground lime. Temperature in the green house averaged 27^{o}C in the daytime and 12^{o}C at night. Relative humidity averaged 45% and 85% in day and night respectively. Photoperiod was not altered from the normal.

At six-months, 10 pots of each species were chosen randomly from the forty pots to be used as controls. The other ten pots of each species were used in the moisture-stress treatment. All seedlings had only primary needles.

Foliage Characteristics

Some morphological features for both species were evaluated. These were needle length, area of cross-section, perimeter of cross-section, surface area, volume, cuticle thickness, and number of stomates per mm^2. A needle sample was taken randomly from the middle of the shoot of each plant in the pot from the five randomly chosen pots of each species.

Needle lengths were measured. It was impossible to count stomates per row or per needle because the stomates do not always occur in complete rows. Stomates per mm^2 were counted at a distance of 0.5 cm from the tip and 0.5 cm from the base of both sides of the needles, then averaged. Counts of stomates were made with a binocular microscope (X10), using reflected light.

To measure the area of cross-section and the cuticle thickness, the same needles were cut into one-half centimeter segments. All needle segments pertaining to the same pot were stored in a vial containing 5% formaline for 24 hours, washed with distilled water, put in Carbowax (polyethylene glycol, mol. wt. 1000), and maintained in an oven at 45^{o}C for two days, during which time needle dehydration occurred as the needles were infiltrated with the Carbowax. Needle segments were then poured into chilled molds. The segment position was arranged before the Carbowax was hardened, using a warm needle, and the molded blocks placed in a refrigerator at 0^{o}C until hardened.

Needle segments were cut into hundreds of 12 micron cross-sections with a rotary microtome. Selected cross-sections were mounted on slides using Haupt's adhesive. Black and white photographs of the cross-sections were made using a photomicroscope.

The cross-sections were stained with Sudan IV to identify lipids and mounted in glycerin-gelatin (Jensen 1962). Cuticle thickness was measured at four different places and then averaged for each of thirty cross-sections of both species. Long and small diagonal cross-sections of the rhombus-shaped needles were measured. Cross-sectional area, perimeter, surface area, and volume of the needles were calculated using the basic data of the characteristics of each seedlings. Formulae appear in Appendix Table I.

Root-Shoot Characteristics

Five control plants of each species were removed from the soil and washed in water. Shoot heights were recorded. Lengths of main and first-order roots were measured. First-order roots were counted. Root volumes were measured using the water displacement method. Removed seedlings were photographed.

Moisture Relations

Prior to the moisture stress period, all pots were thoroughly watered to insure that the soil was at field capacity. Moisture stress seedlings were subjected to water stress by withholding water, while control plants continued to be watered as needed.

The experiment consisted of withholding irrigation from individual pots until the needle moisture content for each seedling reached a certain assigned level. The range of the assigned NMC level was determined by trial and error procedure by rewatering the individual pots at successively lower NMC. (At the beginning of the experiment, when soil moisture was at field capacity, the average needle-moisture content was 240 percent). When needle moisture content of the seedlings in a given pot was within the desired range, the pot was rewatered and the seedlings kept under observation for two weeks in order to determine if any recover. Seedlings were considered recovered if they regained their green color and regained needle-moisture content higher than 180 percent.

Needle moisture content was determined using the gravimetric method. Needles were sampled from the middle of the shoot every third day and then, at the end of the dry-down period, every day. Needles were weighed on a Mettler balance, placed in the oven at 85°C for twenty hours, and weighed again. Needle-moisture content percent was calculated from the formula:

$$\text{NMC\%} = \frac{\text{Fresh Weight - Dry Weight}}{\text{Dry Weight}} \times 100$$

The ability to survive drought was determined by monitoring needle-moisture content for each species in each pot. The species which would endure the lower needle moisture content would be considered the more drought-hardy of the two pines.

The _t_ test was applied to all measured data in order to determine statistical significance between the species at the 1% and 5% levels.

RESULTS AND DISCUSSION

Foliage Characteristics

Secondary needles for both species are semicircle-shaped in cross-section and are found in pairs. Cross-sections of primary needles approximated a rhombic shape (Figure 1). Basic data and mean values for morphological features for primary needles are given in Appendix Tables II-V.

Under uniform environmental conditions, and at the same age, drought-hardy plants should have some modifications which enable them to survive harsh climatic conditions. Table 2 shows that the leaf cross-section areas, perimeter of cross-sections, needle surface areas, volumes of the needles, and cuticle thicknesses are all significantly greater (t-test) for the primary needles of Aleppo pine than for brutia pine. These characteristics, except for cuticle thickness, lead to a higher rate of transpiration during drought. The cuticle serves as a moisture barrier; thereby, the greater its thickness, the greater the ability for plants to conserve water. Hence, moisture loss is reduced. However, in this case, the apparently greater cuticle thickness for Aleppo pine needles could be due to size of needles sampled. Needles for this species were longer than those of brutia pine at the time of collection. There was statistically no difference between species in respect to number of stomates per mm^2 or number of stomates per needle.

Figure 1. Cross-section of primary needles of Aleppo pine (top) and Brutia pine (bottom) (10X).

Table 2. Mean values and t-test values for morphological features of primary needles of six-month-old Aleppo and brutia pine seedlings.

	Aleppo pine	Brutia pine	t value	D.F.
Needle dimensions				
Length, cm	2.38	2.14	1.95	28
Dimensions of sections				
Length of long diagonal, mm	.932	.808	4.12**	28
Length of small diagonal, mm	.546	.493	2.47*	28
Area of cross-sections, mm^2	.256	.199	4.41**	28
Perimeter of cross-sections, mm	2.15	1.90	4.31**	28
Surface area, mm^2	51.50	40.75	3.39**	28
Volume of the needle, mm^3	6.11	4.29	3.98**	28
Cuticle thickness, u	2.86	2.38	2.92**	28
Number of stomates/mm^2	91.0	100.7	1.39	8
Number of stomates per needle	4676.9	4119.4	1.11	8

* Significant at the 5% level

** Significant at the 1% level

Knauf and Bilan (1977) studied loblolly pine seedlings from two seed sources: mesic and xeric locales. In that study, cuticle thickness was significantly thicker in needles of plants from the xeric seed source than from the mesic seed source. This cuticle thickness relationship is in contrast to the results found with the Mediterranean species; for there, that which appeared most drought-hardy seems to have the thinner needle cuticle.

Root-Shoot Characteristics

The characteristics of roots and shoots play an important role in enabling plants to survive drought. Deep-growing roots have greater access to available soil moisture than those inhabiting shallower zones. Large numbers of roots also provide appreciable moisture-absorbing surfaces. Small shoots indicate less transpiring surfaces.

Average values and _t_ tests of root characteristics for each species based on data collected from 30 excavated six-month-old seedlings are presented in Table 3 (Figure 2 and Appendix Tables VI-IX). Mean values for the length of main roots are 18 cm for Aleppo pine and 15 cm for brutia pine. The differences are significant at the 1% level. Total root volumes and length and number of first-order roots are not significantly different.

Differences for total root lengths, 110 cm for Aleppo pine and 89 cm for brutia pine, are significant at the 5% level. Shoot heights, 15.9 cm for Aleppo pine and 9.4 cm for brutia pine, are significantly different at the 1% level (Figure 3). However, the fraction (linear length of all roots ÷ linear length of stem) of total root length to

Table 3. Mean values per seedlings and t tests for root and shoot characteristics of six-month-old Aleppo and brutia pine seedlings.

	Aleppo pine	Brutia pine	t values	D.F.
Roots				
Length of main root, cm	18.06	15.40	5.57**	28
Length of first order, cm	9.16	7.93	1.76	28
Number of first order roots	9.87	9.33	.90	28
Total root length, cm (a)	110.8	89.2	2.13*	28
Root volume, ml	.93	.83	.83	28
Shoot height, cm (b)	15.9	9.4	7.47**	28
Root/Shoot $\frac{(a)}{(b)}$	6.98	9.54	4.26**	28

* Significant at the 5% level

** Significant at the 1% level

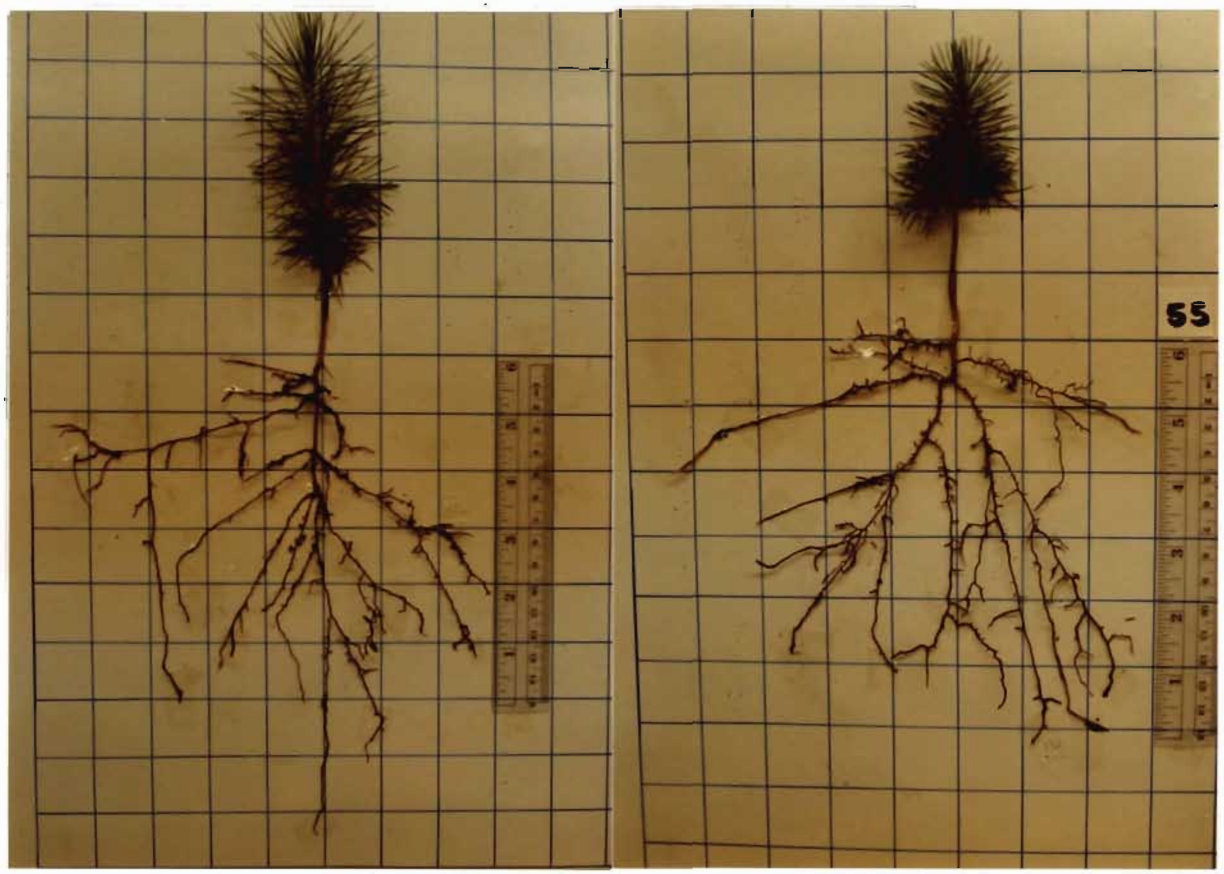

Figure 2. Root system for 6-month-old seedlings of Aleppo pine (left) and brutia pine (right).

shoot height is significant at the 1% level, favoring brutia pine. The ratio of total root lengths to shoot heights is 9.5 for brutia pine and 6.9 for Aleppo pine. This fraction means that every centimeter of shoot is supported by 6.9 cm of root for the latter species, while each centimeter of brutia pine stem is supported by 9.5 cm of root. Hence brutia pine seedlings have the greater absorbing system per unit of stem length.

Moisture Relations

Normally watered plants (Control treatment)

Needle-moisture content in watered plants ranged between 238% and 252% for Aleppo pine and 223% to 237% for brutia pine (Appendix Table X, XI). The variation of needle moisture within a species could be attributed to several factors. Decreasing needle-moisture during the first week might have been due to soil saturation, resulting in poor aeration. This could, in turn, have caused the slow-down in the rate of water absorption. The slight variation in needle-moisture content during the later part of the experiment could have been caused by the sampling of younger and more succulent needles of either species (Figure 4). Aleppo pine maintained a significantly higher needle-moisture content during most of the time of the experiment (Table 4).

Plants subjects to water stress (Moisture stress treatment)

Needle moisture for both species averaged 213% at the beginning of the experiment. Subsequently, needle moisture increased until it reached its maximum of 268% for Aleppo pine and 249% for brutia pine

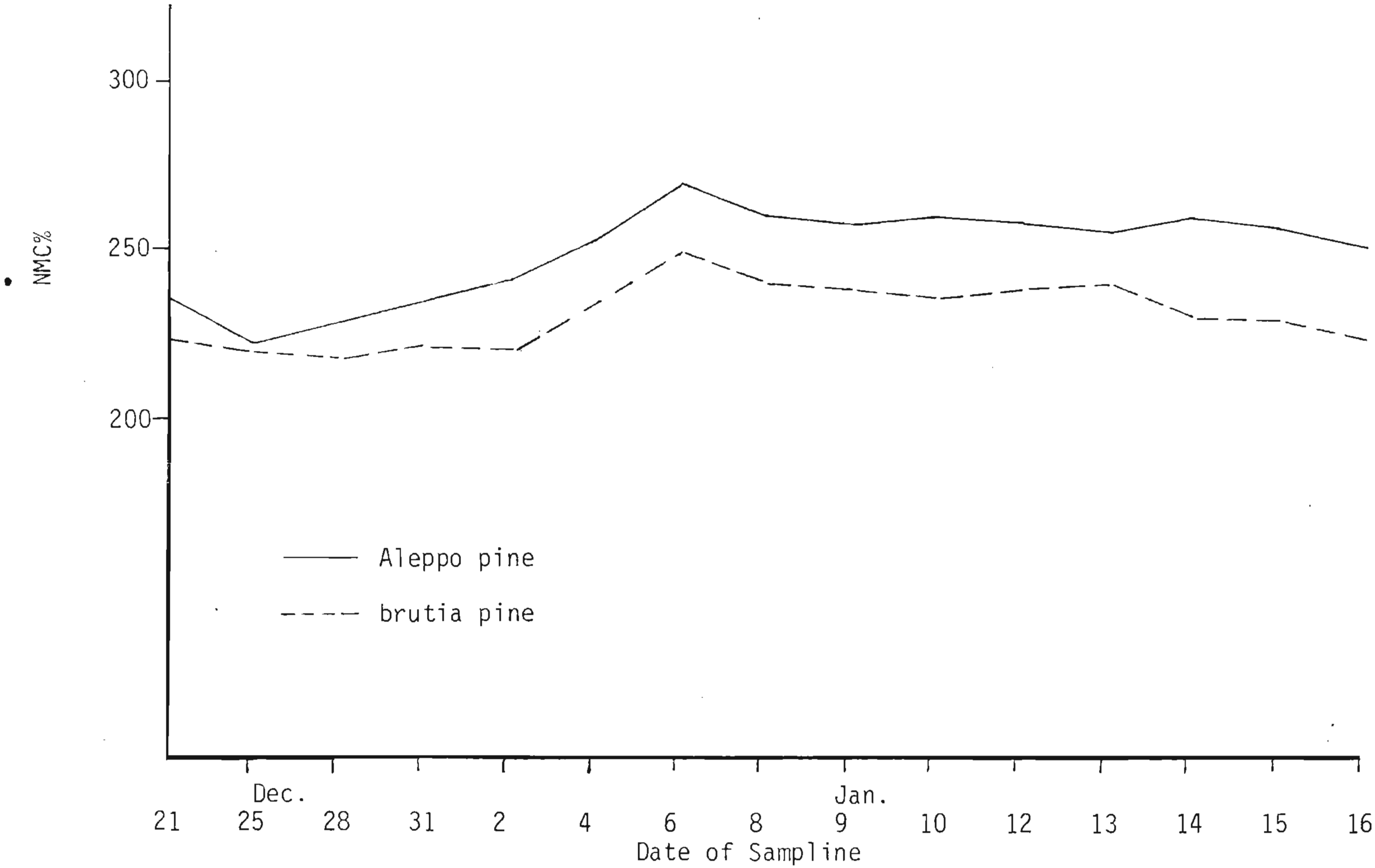

Figure 4. Average needle-moisture content for normally watered seedlings of both species.

about 14 days after the last watering (Figure 5). Needle-moisture content then declined gradually, reaching 200% about 22 days after the last watering. After this time, individual pots were rewatered at different needle-moisture levels, as shown in Appendix Tables XII and XIII.

Survival was ascertained two weeks after seedlings were rewatered. Table 5 and Figure 6 show that 12 Aleppo pine seedlings, in four pots, did not recover when watered at 155%, 159%, 152%, and 150% of needle-moisture content. The other 18 seedlings, in six pots, recovered when watered at 161%, 162%, 176%, 180%, and 199% of needle-moisture content. When Aleppo pine seedlings, which had needle-moisture content between 199% and 161%, were rewatered, none died. For those rewatered when below 160% NMC, none recovered.

For brutia pine, seedlings recovered when rewatered between 192% and 177% NMC. Those rewatered at needle-moisture content below 170% did not recover. Total survival was 18 seedlings (60%) and 15 seedlings (50%) for Aleppo and brutia pine, respectively.

It may be concluded from this part of the experiment that Aleppo pine survived lower needle-moisture content than did brutia pine by 10 percentiles. However it should be noted that this survival was based on a limited number of plants, confined root space, and one series of observations.

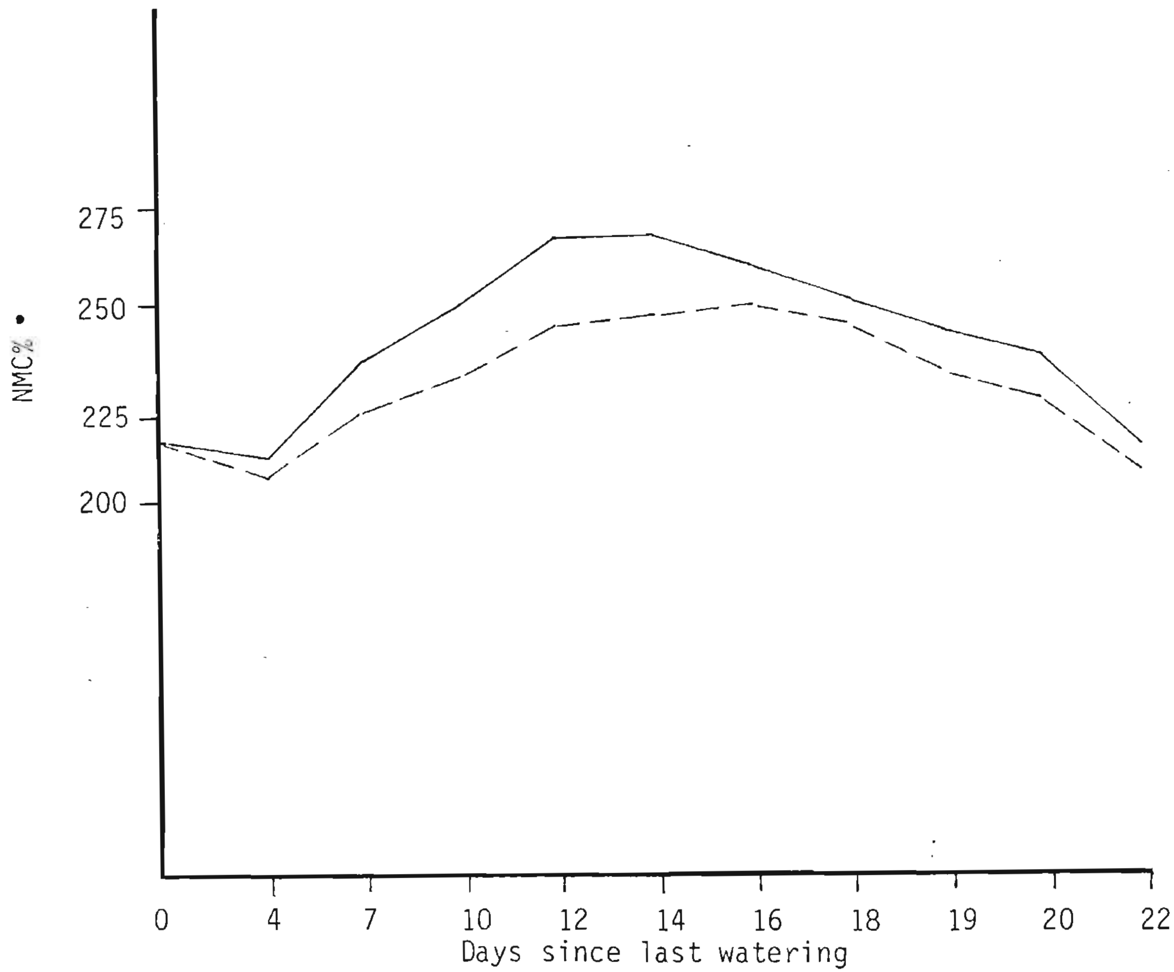

Figure 5. Average needle-moisture content during dry-down period.

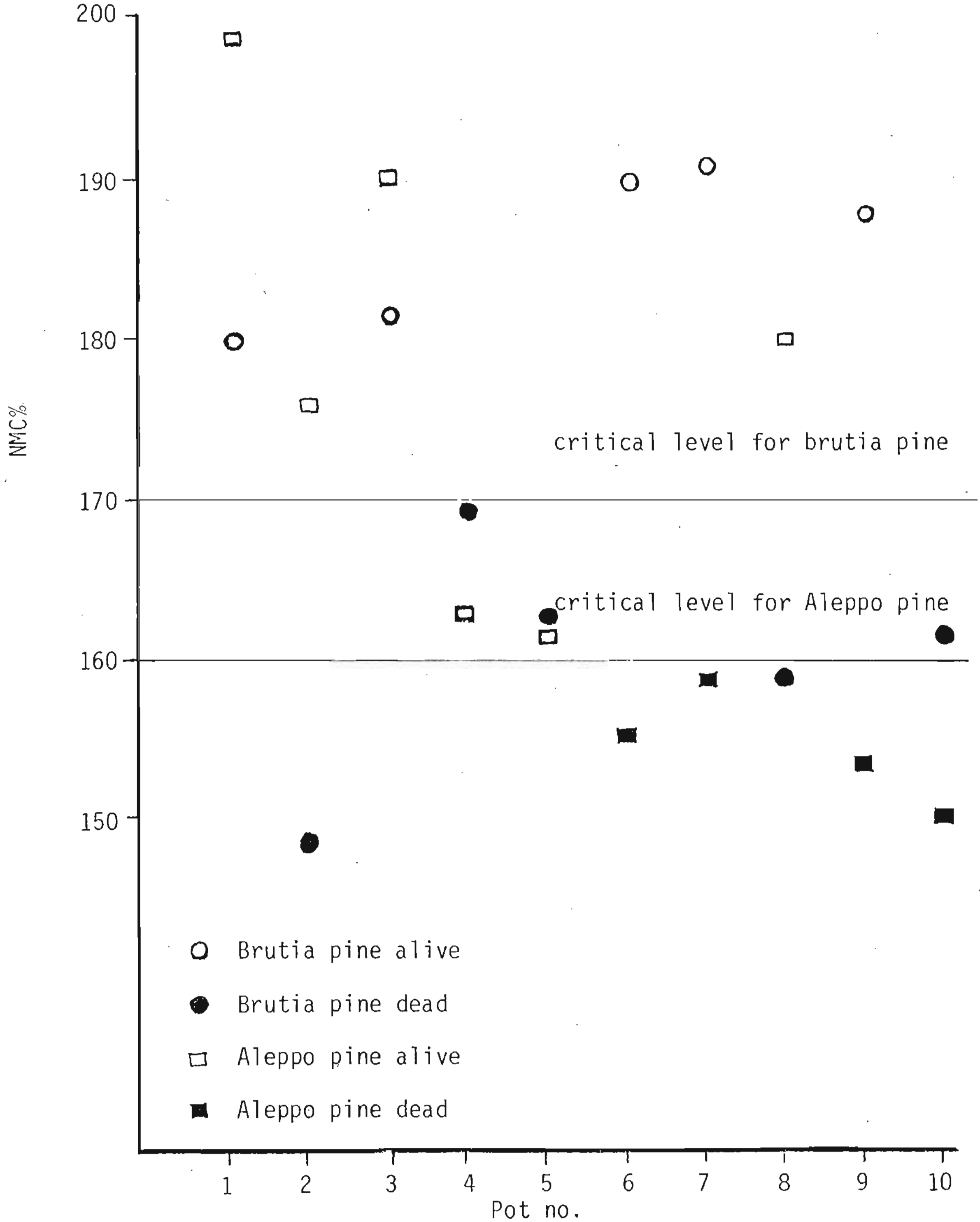

Figure 6. Needle-moisture content, and the apparent critical level, for six-month-old potted plants of Aleppo and brutia pine seedlings after moisture stress.

Table 4. Mean values and *t* tests for needle-moisture content of six-month-old regularly watered seedlings of Aleppo and brutia pine.

	Aleppo pine	Brutia pine		
Date	NMC%	NMC%	*t* value	D.F.
12/21/81	238.4	223.6	2.39*	32
12/25/81	230.5	222.9	1.11	32
12/28/81	233.7	218.1	2.46*	32
12/31/81	236.2	223.8	1.91	32
01/02/82	238.8	222.1	3.15**	32
01/04/82	252.1	230.9	3.75**	32
01/06/82	260.1	251.2	1.15	32
01/08/82	257.5	243.7	1.92	32
01/09/82	256.4	243.7	1.76	32
01/10/82	254.9	241.6	1.86	32
01/12/82	260.0	243.4	2.72*	32
01/13/82	256.6	245.8	2.18*	32
01/14/82	252.3	239.4	2.34*	32
01/15/82	257.8	239.2	3.23*	32
01/16/82	254.7	237.9	3.3**	32
01/17/82	252.4	236.0	3.44**	32
01/18/82	252.6	237.7	2.83**	32

** Significant at the 1-percent level

* Significant at the 5-percent level

Table 5. Recovery (R) and mortality (D) of Aleppo and brutia pine seedlings rewatered at various levels of needle-moisture content at the end of the dry-down period (percent of needle-moisture content).

Pot Number	Aleppo pine	Brutia pine
1	199.9 R	177.9 R
2	176.6 R	148.1 D
3	190.5 R	183.8 R
4	162.9 R	169.8 D
5	161.3 R	163.2 D
6	155.8 D	189.1 R
7	159.1 D	192.3 R
8	180.6 R	159.6 D
9	152.6 D	188.5 R
10	150.8 D	161.9 D
Total survived (no.)	6	5

CONCLUSION

On the basis of anatomical and morphological characteristics of Aleppo and brutia pines, some evidence indicates that the latter has an adaptation to endure drought. Brutia pine has smaller perimeter of needle cross-section, smaller surface area, smaller needle volume, and higher root-length to shoot-height ratio than for Aleppo pine. Hence, brutia pine appears to be able to absorb and conserve moisture more efficiently. On the other hand, Aleppo pine showed an ability to maintain higher, and survive with lower, needle-moisture content.

The evidence, based upon this study, which showed conflicting results, suggests that relatively dry soils in the Mid-East be afforested to brutia pine, although further studies in the region may suggest a preference for Aleppo pine. Further research with brutia and Aleppo pines could define anatomical distinctions for secondary needles, which may play a significant role in drought hardiness.

LITERATURE CITED

Brix, H. (1960). Determination of viability of loblolly pine seedlings after wilting. Bot. Gaz. 121:220-223.

Brix, H. (1962). The effect of water stress on the rate of photosynthesis and respiration in tomato plants and loblolly pine seedlings. Physiol. Plantarum 15:10-20.

Francois, L. E., and R. A. Clark (1978). Salt tolerance of ornamental shrubs, trees and iceplant. J. Am. Soc. Hort. Sci. 103:280-283.

Giulimondi, G. (1972). Influence of soil reaction on the nursery growth of Pinus Brutia and P. radiata. Agricolae Forestale. in Forestry Abstracts 34:414 (1973).

Goor, A. Y., and C. W. Barney (1976). Forest tree planting in arid zones. Ronald Press, New York.

Henckel, P. A. (1950). Physiology of plants under drought. in "Annual Review of Plant Physiology" 7:363-383.

Hsiao, T. C. (1973). Plant response to water stress. in Annual Review of Plant Physiology 24, 519-570.

Jensen, W. A. (1962). Botanical histochemistry. W. H. Freeman & Co., New York.

Knauf, T. A., and M. V. Bilan (1977). Cotyledon and primary needle variation in loblolly pine from mesic and xeric seed sources. For. Sci. 23:33-36.

Kramer, P. J. (1963). Water stress and plant growth. Agronomy Journal 55:31-35.

Kramer, P. J. (1969). Plant and soil water relationships: A modern synthesis. McGraw-Hill Book Co., New York.

Kramer, P. J., and T. T. Kozlowski (1979). Physiology of woody plants. Academic Press, New York.

Leshem, B. (1965). The annual activity of intermediary roots of Aleppo pine. For. Sci. 31:291-298.

Leshem, B. (1974). The relation of the collapse of the primary cortex to the suberization of the endodermis in roots of Pinus halepensis Mill. Bot. Gaz. 135:58-60.

Levitt, J., C. Y. Sullivan and E. Krull (1960). Some problems in drought resistance. Bull. Res. Counc. of Occupied Palestine 8D:173-174.

Levitt, J. (1972). Response of plants to environmental stresses. Academic Press, New York.

Meyer, B. S., and D. B. Anderson (1952). Plant physiology. D. Van Nostrand and Co., New York.

Mirov, N. T. (1955). Relationships between Pinus halepensis and other insignes pine of the Mediterranean region. Bull. Res. Counc. of Occupied Palestine 5D:65-71.

Moulopulos, C. H. (1951). Applied Silviculture. Un. of Thesaloniki, Thess., Greece.

Nahall, O. (1962). Le pin Dalep (Pinus halepensis Mill.) Etude taxonomique, phytogeographique ecologique et sylvicole. Anna. de Leco le Nat. des Eaux et Forests XIX(4):475-686.

Oppenheimer, H. R. (1968). Drought resistance of Monterey pine needles. Occupied Palestine J. Bot. 17:163-168.

Papaioannou, I. (1954). Hybridization of Mediterranean pines. To Dassos 25-28:104-116.

Satcioglu, F., and B. Pamay (1962). Adana bolgesinin Kizilcamini (Pinus brutia Ten.) Onemi ve Silvikulturu. Orman Fakultes Dergisi 12A(2):88-101.

Scheneider, G. W., and N. F. Childers (1941). Influence of moisture on photosynthesis, respiration, and transpiration of apple leaves. Plant Physiology 16:565-583.

Slatyer, R. O. (1967). Plant-water relationships. Academic Press, New York.

Stransky, J. J. (1963). Needle moisture as mortality index for southern pine seedlings. Bot. Gaz. 124:176-179.

Urgenc, S. (1971). Comparative results of long-term storage of Pinus brutia methods. Istanbul Universitei Orman Fakultesi Dergisi 21(2)82-93.

Vaadia, Y. (1961). Plant water deficits and physiological processes. Annual Review of Plant Physiology 12:265-87.

Waisel, Y. (1959). Endurance of drought period beyond wilting point. Bull. Res. Counc. of Occupied Palestine 7D:44-46.

Zohary, M. (1962). Plant life of Palestine: Palestine and Jordan. Ronald Press, New York.

APPENDIX TABLES

Appendix Table I. Computation for morphological features of primary needles.

Cross-section	$A = \frac{1}{2}ab$	where a is the long diagonal, and b is the short diagonal
Perimeter of cross-section	$B = 4\sqrt{\frac{1}{2}(a^2+b^2)}$	
Surface area of the needle	$S = BL$	where L is needle length
Volume of the needle	$V = AL$	
Stomates per needle	$K = SN$	where N is the number of stomates per mm^2

Appendix Table II. Basic data for morphological features of primary needles from six-month-old Aleppo pine seedlings (1 reading for each of 3 seedlings in each pot is given).

Feature	Pot				
	1	2	3	4	5
Needle dimensions					
Length, cm	2.7, 2.5 2.2	1.9, 2.9 1.9	2.3, 3 2.9	2.6, 1.8 2.2	1.7, 2.5 2.6
Dimensions of sections					
Length of long diagonal, mm	1.0, .96 .97	.98, .98 .89	.99, .89 .99	.78, .79 .69	.97, 1.1 1.0
Length of small diagonal, mm	.62, .56 .58	.54, .56 .54	.57, .54 .52	.52, .54 .49	.55, .57 .48
Area of cross-sections, mm^2	.31, .27 .29	.27, .28 .24	.29, .24 .26	.21, .22 .17	.27, .29 .24
Perimeter of cross-sections, mm	2.3, 2.2 2.3	2.2, 2.3 2.1	2.3, 2.1 2.3	1.9, 1.9 1.7	2.2, 2.4 2.2
Surface area, mm^2	62.6, 55.8 49.9	42.6, 65.5 39.5	52.9, 62.7 65.2	48.9, 34.4 37.5	37.2, 59.8 58.2
Volume of the needle, mm^3	8.4, 6.8 6.3	5.1, 8.1 4.6	6.6, 7.3 7.5	5.3, 3.8 3.8	4.5, 7.5 6.4
Cuticle thickness, u	2.8, 2.9 3.3	1.9, 3.4 2.2	3.1, 2.6 3.2	2.7, 3.3 3.1	2.8, 2.8 2.9

Appendix Table III. Basic data for morphological features of primary needles from six-month-old brutia pine seedlings (1 reading for each of 3 seedlings in each pot is given).

Feature	Pot				
	1	2	3	4	5
Needle dimensions					
Length, cm	2.4, 2 1.9	2.2, 2.3 1.9	1.9, 2.3 1.8	2.2, 2.5 2.4	1.9, 2.2 2.2
Dimensions of sections					
Length of long diagonal, mm	.83, .86 .83	.82, .67 .73	.79, .77 .82	.86, .79 .91	.82, .82 .79
Length of small diagonal, mm	.47, .46 .43	.59, .55 .42	.63, .53 .39	.56, .57 .48	.47, .48 .38
Area of cross-sections, mm^2	.20, .20 .18	.26, .18 .16	.25, .21 .16	.24, .26 .22	.20, .20 .15
Perimeter of cross-sections, mm	1.9, 2.0 1.9	2.0, 1.7 1.7	2.0, 1.8 1.8	2.1, 1.9 2.1	1.9, 1.9 1.8
Surface area, mm^2	45.8, 39.2 35.5	44.6, 40.0 31.9	38.6, 42.8 32.7	45.1, 48.8 49.4	36.1, 41.8 38.7
Volume of the needle, mm^3	4.6, 4.1 3.4	5.4, 4.3 2.9	4.8, 4.6 2.9	5.3, 5.6 5.3	3.4, 4.3 3.3
Cuticle thickness, u	1.9, 2.1 3.1	2.9, 2.1 1.8	1.7, 1.9 3.0	2.8, 2.1 2.3	2.9, 2.8 2.4

Appendix Table IV. Mean values per needle for morphological features of primary needles from five six-month-old Aleppo pine seedlings

Feature	Pot				
	1	2	3	4	5
Needle dimensions					
Length, cm	2.5	2.2	2.7	2.2	2.3
Dimensions of sections					
Length of long diagonal, mm	.98	.95	.96	.76	1.0
Length of small diagonal, mm	.59	.55	.55	.52	.53
Area of cross-sections, mm^2	.29	.26	.27	.20	.27
Perimeter of cross-sections, mm	2.3	2.2	2.2	1.8	2.3
Surface area, mm^2	56.3	48.8	60.4	40.3	51.8
Volume of the needle, mm^3	7.2	5.8	7.2	4.3	6.1
Cuticle thickness, u	3.0	2.5	2.9	3.0	2.8
Number of stomates/mm^2	78.2	96.7	85.5	85.5	109.1
Number of stomates per needle	4403.4	4721.9	5167.2	3445.09	5647.0

Appendix Table V. Mean values for morphological features of primary needles from five six-month-old brutia pine seedlings.

Feature	Pot				
	1	2	3	4	5
Needle dimensions					
Length, cm	2.1	2.1	2.0	2.4	2.1
Dimensions of sections					
Length of long diagonal, mm	.84	.74	.79	.85	.81
Length of small diagonal, mm	.46	.52	.52	.54	.44
Area of cross-sections, mm^2	.19	.20	.21	.23	.18
Perimeter of cross-sections, mm	1.9	1.8	1.9	2.0	1.9
Surface area, mm^2	40.2	38.6	38.2	47.9	38.9
Volume of the needle, mm^3	4.1	4.1	4.1	5.5	3.6
Cuticle thickness, u	2.4	2.3	2.2	2.4	2.7
Number of stomates/mm^2	95.9	88.1	108.5	112.2	98.8
Number of stomates per needle	3846.5	3396.3	4144.7	5371.0	3838.4

Appendix Table VI. Basic data for root and shoot characteristics of six-month-old seedlings of brutia pine (1 reading for each of 3 seedlings in each pot is given).

Feature	Pot				
	1	2	3	4	5
Roots					
Length of main root, cm	11, 20 17	18, 15 14	17, 15 13	13, 11 15	16, 20 16
Length of first order, cm	10.7, 6.8 8.3	7.2, 5.1 8.2	8.4, 5.8 5.8	7.4, 9.1 9.3	9.4, 8.9 8.4
Number of first order roots	9, 6 12	11, 10 11	10, 9 11	8, 8 9	10, 9 7
Total root length, cm	107, 61 117	97, 66 104	101, 68 77	72, 84 99	110, 100 75
Root volume, ml	.8, 1.2 .9	1.1, .6 .7	1.3, 1.5 .6	.8, .6 .7	.5, .7 .4
Shoot height, cm	10, 12 11	9. 7 11	12, 11 6	12, 7 8	9, 8 8

Appendix Table VII. Basic data for root and shoot characteristics of six-month-old seedlings of Aleppo pine (1 reading for each of 3 seedlings in each pot is given).

Feature	Pot 1	2	3	4	5
Roots					
Length of main root, cm	20, 13 16	10, 20 14	20, 22 23	20, 25 16	15, 25 22
Length of first order, cm	10.9, 9.4 8.8	6.8, 4.0 6.4	11.7, 9.0 12.6	9.0, 9.6 11.4	8.7, 8.9 10.2
Number of first order roots	9, 8 8	9, 8 10	11, 12 13	8, 10 12	12, 10 9
Total root length, cm	118, 88 86	71, 52 78	149, 130 187	92, 111 153	120, 114 114
Root volume, ml	.8, .4 1.3	1.1, 1.4 .7	.9, 1.2 1.5	1.1, .8 .9	.8, .7 .3
Shoot height, cm	16, 12 19	14, 19 18	16, 18 20	18, 15 12	12, 16 14

Appendix Table VIII. Mean values for root and shoot characteristics of five six-month-old seedlings of Aleppo pine.

Feature	Pot				
	1	2	3	4	5
Roots					
Length of main root, cm	16.3	14.7	21.6	17	20.6
Length of first order, cm	9.7	5.7	11.1	10.0	9.3
Number of first order roots	8.3	9.0	12	9.7	10.3
Total root length, cm (a)	97	67	155	119	116
Root volume, ml	.8	1.1	1.2	.9	.6
Shoot height, cm (b)	16	17	18	15	14
Root/Shoot $\frac{(a)}{(b)}$	6.2	3.9	8.6	7.9	8.3

Appendix Table IX. Mean values for root and shoot characteristics of five six-month-old seedlings of brutia pine.

Feature	Pot 1	2	3	4	5
Roots					
Length of main root, cm	16.0	15.7	15.0	13.0	17.3
Length of first order, cm	8.6	6.9	6.7	8.6	8.9
Number of first order roots	9.0	10.7	10.0	8.3	8.7
Total root length, cm (a)	95	89	82	85	95
Root volume, ml	1.0	.8	1.1	.7	.5
Shoot height, cm (b)	11	9	10	9	8
Root/Shoot $\frac{(a)}{(b)}$	8.6	9.9	8.3	9.4	11.5

Appendix Table X. Needle-moisture content (%) for normally-watered Aleppo pine seedlings (control group).

	Pot					
	1	2	3	4	5	6
Date						
12/21/81	229.1	248.7	204.6	228.5	223.3	267.7
12/25/81	234.0	235.9	217.9	235.3	216.3	255.6
12/28/81	256.3	250.0	217.2	212.9	237.0	271.1
12/31/81	252.2	242.9	210.2	234.2	245.6	264.9
01/02/82	245.6	246.9	238.7	221.5	253.2	263.2
01/04/82	256.2	254.7	231.3	245.5	252.2	274.5
01/06/82	266.8	255.6	264.5	241.2	261.9	278.8
01/08/82	247.1	269.1	249.2	231.3	255.4	277.0
01/09/82	231.2	261.0	255.1	239.1	263.2	288.8
01/10/82	225.1	249.2	261.3	245.2	259.9	289.2
01/12/82	239.2	251.2	271.2	256.1	253.7	279.9
01/13/82	250.0	243.1	251.2	253.1	249.5	259.6
01/14/82	241.1	249.1	239.9	254.1	245.2	261.5
01/15/82	258.2	255.1	245.5	250.0	249.1	265.6
01/16/82	255.1	243.1	248.2	246.6	253.7	264.8
01/17/82	251.9	241.2	251.2	239.9	251.3	259.6
01/18/82	256.6	240.1	250.0	241.4	249.5	254.4

Appendix Table X. (continued)

	Pot				
	7	8	9	10	Mean
Date					
12/21/81	265.7	228.2	235.4	252.4	238.4
12/25/81	227.6	225.6	216.6	245.4	230.5
12/28/81	231.5	216.7	209.2	235.4	233.7
12/31/81	240.7	218.7	221.5	231.1	236.2
01/02/82	263.7	220.2	211.7	250.4	238.8
01/04/82	251.0	232.7	241.7	280.9	252.1
01/06/82	264.7	245.7	251.0	270.1	260.1
01/08/82	258.9	239.2	249.2	298.8	257.5
01/09/82	249.9	235.2	252.6	287.8	256.4
01/10/82	255.5	241.1	241.2	281.2	254.9
01/12/82	260.5	251.6	251.0	285.5	260.0
01/13/82	271.2	247.7	252.1	288.8	256.6
01/14/82	259.2	252.2	245.5	275.1	252.3
01/15/82	261.2	256.1	261.6	275.5	257.8
01/16/82	261.1	245.1	257.2	272.1	254.7
01/17/82	261.9	246.1	250.8	269.9	252.4
01/18/82	251.9	249.5	252.6	280.0	252.6

Appendix Table XI. Needle-moisture content (%) for normally-watered brutia pine seedlings (control group).

	Pot					
	1	2	3	4	5	6
Date						
12/21/81	251.3	222.7	216.2	202.1	217.4	214.1
12/25/81	244.1	210.2	200.7	199.5	237.0	201.9
12/28/81	235.9	225.8	204.1	203.8	227.2	199.9
12/31/81	237.4	235.4	198.7	199.9	238.9	207.9
01/02/82	223.3	221.6	213.4	205.9	225.1	212.9
01/04/82	232.4	217.6	231.4	219.4	241.7	213.7
01/06/82	274.6	252.4	235.2	227.3	241.4	225.2
01/08/82	256.7	243.1	220.4	211.7	238.5	236.1
01/09/82	249.9	241.3	216.4	209.1	235.1	249.2
01/10/82	251.9	253.3	209.2	210.9	231.1	231.3
01/12/82	259.6	249.2	221.9	213.2	227.3	227.7
01/13/82	248.2	251.1	231.1	213.6	225.8	237.3
01/14/82	239.5	239.1	225.9	208.1	216.2	229.9
01/15/82	235.3	235.5	233.1	206.8	220.1	219.1
01/16/82	240.1	241.1	229.2	210.0	217.2	222.2
01/17/82	235.9	238.3	230.9	212.9	215.5	221.9
01/18/82	245.7	237.5	227.2	215.5	215.8	217.9

Appendix Table XI. (continued)

	Pot				
	7	8	9	10	Mean
Date					
12/21/81	211.4	242.9	216.9	240.9	223.6
12/25/81	243.2	264.6	212.4	254.9	222.9
12/28/81	200.0	242.6	210.2	231.3	218.1
12/31/81	201.4	256.6	218.5	242.7	223.8
01/02/82	211.1	241.1	215.1	251.9	222.1
01/04/82	223.7	242.7	220.1	258.3	230.9
01/06/82	232.8	290.8	256.7	271.5	251.2
01/08/82	241.6	280.4	241.9	266.5	243.7
01/09/82	239.5	288.4	252.2	256.6	243.7
01/10/82	235.1	281.3	257.2	255.5	241.6
01/12/82	245.9	279.3	249.9	259.9	243.4
01/13/82	250.0	260.6	245.1	265.3	245.8
01/14/82	247.8	273.1	253.2	261.1	239.4
01/15/82	243.1	279.2	261.1	259.1	239.2
01/16/82	236.9	265.8	258.0	259.1	237.9
01/17/82	231.1	259.6	261.9	252.2	236.0
01/18/82	234.2	261.9	260.9	260.0	237.7

Appendix Table XII. Needle-moisture content (%) for Aleppo pine during dry-down period.

	Pot					
	1	2	3	4	5	6
Date						
12/21/81	214.9	202.3	231.1	236.2	209.1	222.0
12/25/81	216.0	200.2	225.8	223.8	218.8	207.9
12/28/81	246.9	216.6	256.2	264.9	241.9	235.7
12/31/81	271.9	230.5	266.4	276.8	246.0	243.8
01/02/82	285.8	250.6	281.1	285.4	276.9	267.2
01/04/82	280.9	264.7	286.4	283.3	264.3	279.6
01/06/82	261.5	246.7	277.4	278.9	261.6	261.4
01/08/82	250.1	239.8	272.9	266.5	249.4	245.0
01/09/82	250.8	229.2	261.2	264.9	241.1	239.1
01/10/82	227.2	225.6	259.2	238.5	229.3	224.8
01/12/82	199.9	219.2	244.1	208.9	189.4	209.9
01/13/82	235.2	212.9	235.1	200.9	175.6	175.0
01/14/82	242.7	210.5	228.7	195.6	161.3	155.8
01/15/82	252.5	198.9	214.0	177.7	185.0	113.9
01/16/82	245.5	176.6	190.5	162.9	217.6	______
01/17/82	266.7	254.5	246.8	231.7	238.9	______
01.18.82	259.6	249.7	245.9	261.2	251.1	______

______ NMC% at rewatering day

Appendix Table XII. (continued)

	Pot				
	7	8	9	10	Mean
Date					
12/21/81	208.8	200.8	202.4	208.5	213.6
12/25/81	205.6	210.1	209.3	199.1	211.7
12/28/81	220.1	229.1	235.3	211.1	235.8
12/31/81	250.1	249.9	227.2	224.7	248.7
01/02/82	275.1	275.1	235.3	237.9	267.6
01/04/82	259.1	260.7	250.7	258.5	268.8
01/06/82	248.8	248.2	249.4	248.9	259.3
01/08/82	237.1	239.4	242.0	231.2	249.7
01/09/82	227.2	235.1	235.6	225.1	241.7
01/10/82	220.1	231.1	225.1	215.1	232.9
01/12/82	209.6	220.6	207.3	199.1	210.8
01/13/82	195.1	210.0	195.9	191.6	_____
01/14/82	191.6	201.2	180.6	188.9	_____
01/15/82	174.2	189.1	152.6	164.7	_____
01/16/82	159.1	180.9	135.1	150.7	_____
01/17/82	133.1	227.4	_____	140.0	_____
01/18/82	_____	235.1	_____	132.2	_____

_____ NMC% at rewatering day

Appendix Table XIII. Needle-moisture content (%) for brutia pine seedlings during dry-down period.

	Pot					
	1	2	3	4	5	6
Date						
12/21/81	211.7	202.9	217.7	211.6	213.9	204.9
12/25/81	211.6	201.2	215.1	214.1	202.9	203.5
12/28/81	216.5	215.1	220.9	221.1	200.8	222.1
12/31/81	217.6	218.6	233.1	233.1	222.2	234.9
01/01/82	219.8	220.9	245.7	245.7	235.6	244.9
01/04/82	227.9	222.1	249.8	246.3	240.5	250.2
01/06/82	238.5	237.8	245.8	232.8	236.6	273.7
01/08/82	230.2	233.1	228.3	221.9	236.1	264.9
01/09/82	229.7	231.1	219.9	210.1	228.1	259.5
01/10/82	219.9	219.9	214.8	205.1	215.7	245.8
01/12/82	210.1	214.6	206.5	190.8	212.3	230.7
01/13/82	207.8	209.8	216.6	185.9	201.8	227.5
01/14/82	200.3	204.5	226.4	<u>169.7</u>	197.2	223.6
01/15/82	<u>177.9</u>	176.3	231.9	133.8	177.2	221.6
01/16/82	209.6	<u>148.1</u>	209.1	119.9	<u>163.2</u>	<u>189.1</u>
01/17/82	201.4	135.4	<u>183.8</u>	100.1	142.1	204.6
01/18/82	219.3	122.6	235.0	______	______	214.6

______ NMC% at rewatering day

Appendix Table XIII. (continued)

	Pot				
	7	8	9	10	Mean
Date					
12/21/81	215.4	214.6	215.1	224.1	213.2
12/25/81	215.3	202.6	211.7	222.2	209.6
12/28/81	228.5	204.6	243.9	243.2	221.7
12/31/81	238.8	215.8	267.7	251.2	233.3
01/02/82	250.3	220.1	271.9	268.6	242.4
01/04/82	264.6	245.4	281.9	250.1	247.9
01/06/82	278.3	243.3	272.1	238.4	249.7
01/08/82	275.2	243.6	259.4	228.6	242.7
01/09/82	259.8	219.9	255.5	218.1	233.2
01/10/82	244.5	220.8	250.8	209.2	224.7
01/12/82	233.3	205.9	240.0	203.6	216.8
01/13/82	231.3	195.1	231.8	199.0	204.0
01/14/82	229.1	189.2	209.4	197.7	204.7
01/15/82	223.1	178.5	202.9	189.5	197.7
01/16/82	224.0	159.6	188.5	174.9	185.0
01/17/82	192.3	133.95	233.6	161.9	______
01/18/82	225.8	______	231.3	141.6	______

______ NMC% at rewatering day

DROUGHT-TOLERANCE COMPARISON OF ALEPPO PINE AND BRUTIA PINE SEEDLINGS

APPROVED:

(Thesis Director)

Dean of the Graduate School

DROUGHT-TOLERANCE COMPARISON OF ALEPPO PINE AND BRUTIA PINE SEEDLINGS

by

MOHAMMAD S. ABIDO, B.S.

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VITA

Mohammad Abido was born in Quneitra, Syria, on February 2, 1955, the son of Solieman and Salema Abido. In 1967, he and his family were forced to leave their home town after the Zionist occupation of the Golan Heights. He holds a B.S. in Agriculture from the University of Damascus College of Agriculture. After graduating, he served as an instructor at that University. In September, 1980, he entered the Graduate School of Stephen F. Austin State University at Nacogdoches, Texas. He is married to Wahebeia Abido and they have two daughters, May and Suzan.

Permanent Address: Damascus University
College of Agriculture
Damascus, Syria

This thesis was typed by Shelley Hamblen.

ABSTRACT

Seedlings of Pinus halepensis and P. brutia were grown from seeds in a greenhouse. When 6 months old, randomly sampled seedlings were subjected to water stress by withholding irrigation. During this period, foliage and root characteristics of seedlings not under moisture stress were recorded. Pinus halepensis showed the greater ability to endure moisture stress and to maintain a higher level of needle-moisture content during the dry-down period. Meanwhile, P. brutia showed important anatomical and morphological adaptations which enable the species to conserve moisture.