

**Determining Adequate Rooting Space for Trees in Planters  
or in the Ground**

by

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**ABSTRACT**

Placing a tree in a container, or in-ground in a location where the potential for root expansion is severely limited, results in a reduction in the growth rate of above ground portions of the tree. Containers are also limited in their ability to entrap and store water. Transpirational water losses can easily exceed stored water in a container, resulting in water stress. A formula is presented for calculating the minimally adequate container volume for a given cultivar and size of tree.

When a tree is grown out in the open, its roots opportunistically grow into any areas in which oxygen and water are not limiting. But whenever a tree is placed in a container, factors limiting root growth will also limit the extent of shoot growth or caliper expansion, even under well watered conditions. This phenomenon is also seen when trees are planted in in-ground sites in which subways, utility lines, or cellar vaults prevent the free movement of tree roots.

The direct relationship between container volume and plant growth has been shown by a number of researchers, working with both woody and non-woody plants (Table 1). In each case, an increase in container volume resulted in an

increase in plant dry weight, although the relation of root dry weight to container volume (Column 5) generally declined.

Table 1  
Trends with Increasing Container Volume

<u>Citation</u>	<u>Spp</u>	<u>Vol (l)</u>	<u>Plant Dry Wt</u>	<u>Root dry wt: Container vol.</u>
Biran & Eliassaf	<u>Ficus</u>	5		30.7
		21	increase	21.7
	<u>Pistacia</u>	1		37.7
		2.5	increase	21.6
		1		31.7
		2.5	increase	28.9
		10	increase	19.4
Carmi & Shalhevet	<u>Gossypium</u>	2		12.5
		5	increase	12
		10	increase	12.5
		25	increase	5.6
Carlson & Endean	<u>Picea</u>	.01		2.63
		.033	increase	1.57
		.066	increase	1.18
		.131	increase	0.77
		.262	increase	0.44
		.524	increase	0.21
Krizek et al.	<u>Glycine</u>	.14		
		1.25	increase	
Ruff et al.	<u>Lycopersicon</u>	.45		8.44
		13.0	increase	0.69
Rakow et al.	<u>Acer</u>	15.4		8.47
		21.9	increase	4.28
		30.7	increase	4.96
		42.6	increase	3.62

A follow-up study by Biran and Eliassaf is particularly relevant to the growing of trees in landscape containers. They compared the growth of a shallow rooting species (Ficus retusa) to that of a deep rooting species (Pistacia lentiscus) when both were grown in two container types of the same total volume: a) shallow and wide; b) deep and narrow.

These researchers found that, for both species, growth tends to be stimulated when there is a mutual matching between the natural growth pattern of

the roots and the shape of the container. Thus, not only container volume but also container configuration play important roles in determining the rates and extent of woody plant growth.

In addition to affecting the growth rates of trees grown in them, containers also offer a limited capacity for holding water, either from rainfall or irrigation. This can easily lead to water deficits for the tree and therefore water stress.

Especially in urban areas, summer transpirational water losses can be very high and frequently exceed the water held in the container's reservoir.

Deficits could be made up by irrigating, but a 1982 study by Kielbaso, Haston and Pawl revealed that an average of only three percent of municipal Department of Public Works budgets are available for irrigating.

So, given the likelihood of drought-inducing conditions in urban microclimates, free standing tree containers must be able to entrap and store adequate moisture to meet a tree's transpirational water needs if severe stress and premature tree death are to be avoided.

A study initiated in 1983 by the author, along with Drs. Nina L. Bassuk and Thomas H. Whitlow, has focused on the development of a formula for determining the minimally adequate container volume for a given type and size of tree.

Transpiration data used in developing this method were taken from a group of vegetatively propagated *Acer rubrum* 'October Glory' trees in 1985. Twenty-four trees were each standardized to a height of 1.7 m and potted into #5, #7, #10, and #15 nursery containers, six per size. The potting medium was a mixture of 65% sandy loam soil, 25% vermiculite, and 10% peat moss (by volume).

Transpiration was measured by means of a four pan electronic weighing lysimeter. Transpiration values were taken from all 24 trees over nine separate 24 hour cycles during the 1985 growing season.

In addition to water loss from the trees, factors involved in development of the formula were: tree leaf area, soil water holding capacity, seasonal rainfall, and seasonal evaporation potential of the air.

Before these factors could be introduced, we needed to establish an operative length of growing season. We considered this to be May 14, the approximate date of full leaf out, until September 30, the date of maximum fall coloration.

The key parameter in the formula is the Accumulated Atmospheric Demand, or AAD. Using data for an evaporation pan from a nearby weather station, AAD is a measure of the accumulated season-long precipitational input into the pan minus the accumulated losses due to evaporation.

By treating the tree as analogous to the evaporation pan - with the foliage equated to the evaporative surface and the soil water equated to the water in the pan - we could use the weather station data to parameterize the water budget of the containerized tree over the growing season.

Figure 1 is taken from a 26 year record of evaporation pan data. The graph shows the year with the greatest AAD, the least severe AAD, and the average. For any single calendar date, the most extreme mean AAD level was 21.82 cm. This value corresponds to the 75 percent frequency, i.e., three-quarters of all AAD values were equal to or less severe than 21.82 cm.

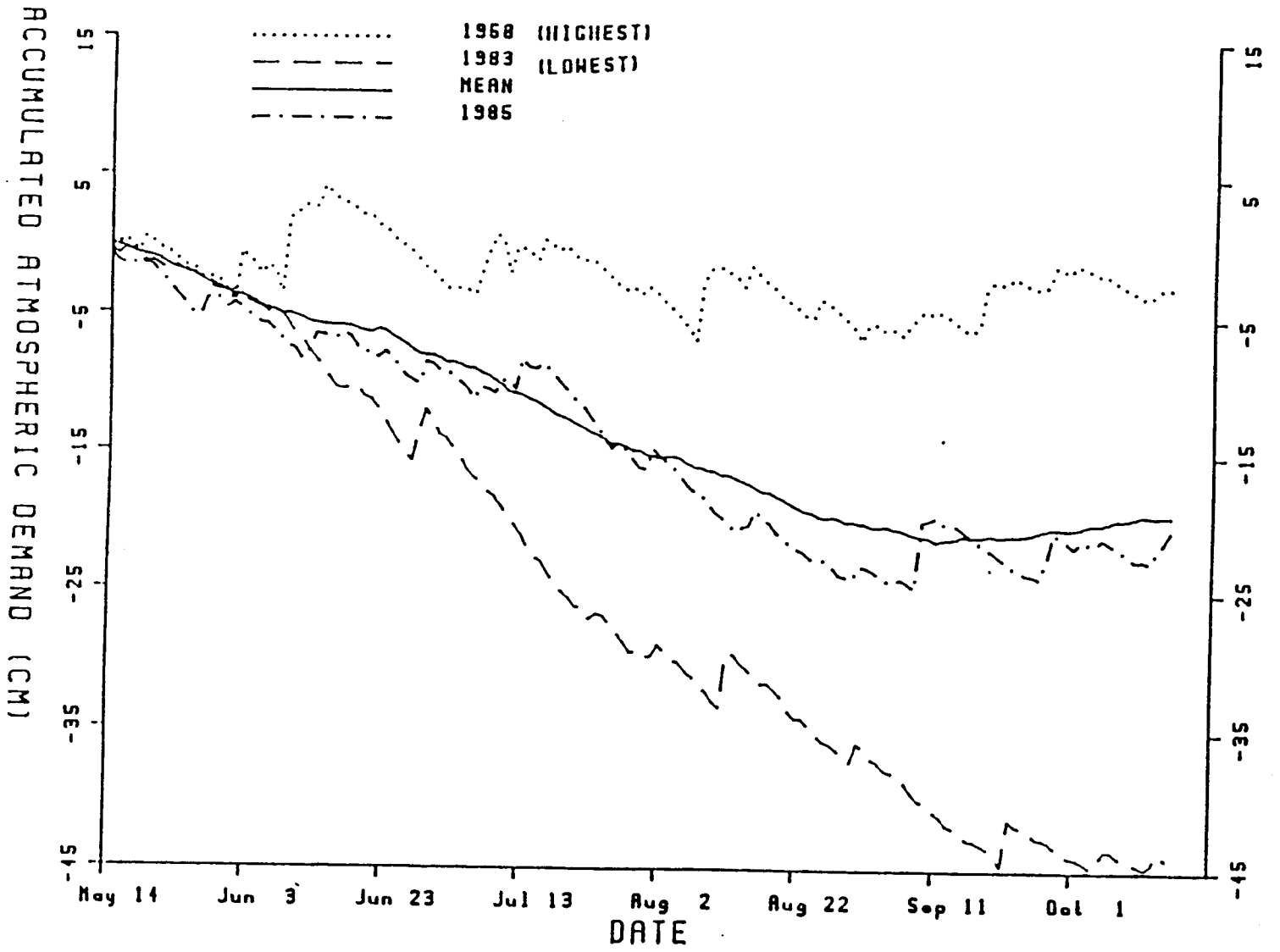


Fig. 1 - Accumulated Atmospheric Demand, 1958 - 1985

In order to more accurately relate the surface area of the evaporation pan to that of the tree, the next step involved measuring the leaf areas of the trees.

At the end of the growing season, we stripped all of the leaves from each of the trees and ran them through a leaf area meter (LI-COR Model 3100). For all 24 trees, the average leaf area per tree was 3586.13 cm.

The chosen AAD value of 21.83 cm actually represents a deficit of 21.82 cm<sup>3</sup>/cm<sup>2</sup> of evaporative surface area. By multiplying 21.82 cm by the average leaf area, we arrive at a non-adjusted evaporative demand for the trees of 78,249.42 cm<sup>3</sup>.

Due to their system of internal resistances, trees obviously do not transpire at the same rate per unit surface area as evaporation pans lose water. To factor this in, we related the average tree transpiration per cm<sup>2</sup> to the average pan evaporation per cm<sup>2</sup> on a series of nine dates. The average of the ratio values is .306. Next, we multiplied the non-adjusted evaporative demand by .306 to calculate a true transpiration demand of 23,944.32 cm<sup>3</sup>.

A laboratory analysis of the chosen soil mix was conducted to determine the percent of total soil volume that could be held as available water. We calculated that between -0.001 MPa and -1.5 MPa, the soil could hold a maximum of 38.58 percent of its volume as water available for uptake.

The adjusted evaporative demand of approximately 24,000 cm<sup>3</sup> of water was then divided by the percent water holding capacity to calculate the total soil volume needed to meet the seasonal water deficit per tree.

This value for total soil volume is 62,064.08 cm<sup>3</sup>. 62.06 l is the equivalent of 16.3 gallons. Thus, a 1.7 m tall *A. rubrum* 'October Glory' with a leaf area of approximately 3586 cm<sup>2</sup>, if initially fully saturated, can be

supported through an average growing season in Ithaca, NY in a 16.3 gallon container.

Table 2 is a development of this formula, step by step.

**Table 2**  
**Calculations for Sizing a Container for A rubrum**  
**'October Glory' - Accumulated Atmospheric Demand Method**

**STEP 1:**

Determine length of growing season (leaf-out to fall coloration):

$$\underline{\text{May 14- September 30} = 140 \text{ Days}}$$

**STEP 2:**

Determine most extreme mean AAD level for established growing season:

$$\underline{21.83 \text{ cm}^3 \text{ cm}^{-2}}$$

**STEP 3:**

Set leaf area of tree:

$$\text{Mean for all trees} - \underline{3586.13 \text{ cm}^2}$$

**STEP 4:**

Calculate non-adjusted evaporative demand for tree based on pan evaporation rates and leaf area:

$$\underline{21.82 \text{ cm}^3 \text{ cm}^{-2} \times 3586.13 \text{ cm}^2 = 78,249.42 \text{ cm}^3}$$

**STEP 5:**

Adjust evaporative demand to transpiration demand:

$$\underline{78,249.42 \text{ cm}^3 \times .306 = 23,944.32 \text{ cm}^3}$$

**STEP 6:**

Calculate soil volume needed to meet seasonal water deficit/tree:

$$\underline{23,944.32 \text{ cm}^3 \div .3858 = 62,064.08 \text{ cm}^3}$$

**STEP 7:**

Equivalent volume in gallons:

$$\underline{62.06 \text{ l} = 16.3 \text{ gallons}}$$

Current research focuses on applying this formula to a much wider range of tree cultivars and size classes. The eventual goal is the development of a matrix that municipal arborists, landscape architects, and other practitioners can use to match tree type and expected mature size to container volume.

#### LITERATURE CITED

- Biran, I. and A. Eliassaf. 1980. The effect of container shape on the development of roots and canopy of woody plants. *Scientia Hort.* 12:183-193.
- Biran, I. and A. Eliassaf. 1980. The effect of container size and aeration conditions on growth of roots and canopy of woody plants. *Scientia Hort.* 12:385-394.
- Carmi, A. and J. Shalhevet. 1983. Root effects on cotton growth and yield. *Crop Sci.* Sept.-Oct. 1983.
- Carlson, L.W. and F. Endean. 1976. The effect of rooting volume and container configuration on the early growth of white spruce seedlings. *Can. J. For. Res.* 6:221-224.
- Kielbaso, J., G. Haston, and D. Pawl. 1982. Municipal tree management in the U.S. - 1980. *J. of Arbor.* 8(10):253-257.
- Krizek, D.J., A. Carmi, R.M. Mirecki, F.W. Snyder, and J.A. Bunce. 1985. Comparative effects of soil moisture stress and restricted root zone volume on morphogenetic and physiological responses in soybean. *J. Exper. Bot.* 36(162):25-38.
- Ruff, M.S., D.J. Krizek, R.M. Mirecki, and D.W. Imouye. 1987. Restricted root zone volume: Influence on growth and development of tomato. *J. Amer. Soc. Hort. Sci.* 112(5):763-769.
- Rakow, D.A., T.H. Whitlow, and N.L. Bassuk. 1988. Effects of container size on growth and whole tree water relations in October Glory red maple (*Acer rubrum* L. 'October Glory'). In press.
- Whitlow, T.H. and N.L. Bassuk. 1987. Trees in difficult sites. *J. of Arbor.* 13(1):10-17.