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SPECIFYING SOIL VOLUMES TO MEET THE WATER NEEDS OF MATURE URBAN STREET TREES AND TREES IN CONTAINERS

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Abstract. The small volume of soil in a typical street tree pit or container often is not capable of supplying adequate water as the tree needs it. As a result, trees can experience severe limitations upon healthy growth and development. Current soil volume estimations fail to address three problems: 1) how to predict whole tree water use, especially for a wide range of prevailing climatic conditions, 2) how to tie this prediction to some easily measured tree parameter, and 3) how to incorporate both of the above into some simple yet accurate means of estimating soil volume. A weatherbased methodology for adequately sizing soil volumes is presented to address these concerns. This incorporates the findings of a recent study indicating that whole tree water loss can be reasonably predicted with knowledge of evaporation from a U.S. Weather Bureau Class A pan. A soil volume of 220 ft^3 for a medium sized tree is then calculated. For use as a general estimate, 2ft^3 of soil per 1ft^2 of crown projection is recommended.

Inadequate soil rooting space can be one of the more important factors in the premature mortality of trees in urban areas (23). Clearly, there is a basic conflict between the biological needs of trees, whose roots systems are generally near the surface and spread laterally, and the small and confined areas they are relegated to in the design of streets in our urban areas. The typical street tree pit, which is inhospitably sandwiched in a narrow strip between the road and sidewalk, places severe limitations upon healthy tree growth and development. The small volumes of soil in these areas often do not hold water sufficient enough to meet transpirational demand, resulting in the tree experiencing periodic to prolonged water deficits.

While the soil serves many functions as a physical and biological medium of root growth, it is in its role as a reservoir for water that is of primary interest in soil volume calculations. Thus far, there has been no widely applicable method for determining the size of a tree pit or container that is based on a tree's water requirements. It is the intent of this article to provide a knowledgeable framework for both critically evaluating and effectively using the soil volume methodology presented here.

Current recommendations. Current recommendations detailing appropriate soil volumes for trees have been culled from a variety of sources in the literature and are presented for comparison in Table 1. Many of these estimates are quite high, up to 7000 ft^3 and would be next to impossible to achieve in most street tree plantings. Some of these recommendations are either simple rules of thumb, or are based on plant factors other than empirically determined water use rates. Further questions and considerations come readily to mind. Are changing regional climatic conditions accounted for in these estimates and is the amount and timing of rainfall integrated in some meaningful way? Are the changing water holding capacities of different soil types accomodated? Over what period of time will this soil volume support the tree and where will the water come from? Are these methods based on whole tree water use rates and do they account for species and canopy size differences? It would also be very useful if whole tree water loss estimations were standardized on one common plant parameter. Soil estimates could then be linked directly to this measurement. No one of these soil volume estimations really addresses all of these concerns

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together.

What governs whole tree water loss in urban areas? Water moves from the soil into the roots and up into the tree where almost 99% of it is evaporated as water vapor directly from the leaf surface in response to increasing sunlight, air temperature, wind speed and decreasing relative humidity (22). These factors regulate how rapidly water in the leaf is lost to the atmosphere through transpiration and together represent the sum total of atmospheric evaporative demand (38). It is this demand, external to the plant, which subsequently dictates the amount and rate of water that must be taken up by the roots to replenish these losses. However, water loss from tree leaves can be modified by various plant and soil factors. It can be generally stated that with plentiful soil moisture, whole tree water loss increases as atmospheric evaporative demand increases. Under conditions of low soil moisture and high atmospheric demand however, various plant responses are triggered. While stomatal closure is the primary response, leaf rolling or leaf inclinational change, and leaf wilting and drop may also occur, all of which serve to reduce whole tree water loss (4). The water status of the tree during these periods of high atmospheric demand is ultimately dependent on soil properties that influence water retention, such as soil texture, structure, and volume (19).

The city environment is a harsh montage of reflective and absorptive surfaces such as roads, buildings, sidewalks and cars. The subsequent release of stored heat from these surfaces leads to higher daytime and nighttime temperatures and lower relative humidities, hence the characterization of the city as a "heat island" (47, 8). These factors can greatly increase atmospheric evaporative demand thereby elevating a tree's need for water and aggravating the effects of already unfavorable growing conditions.

Where does the water for trees in urban areas come from? Water is added to the soil mainly through precipitation. For the global hydrological cycle, precipitation equals evaporation. However, for discrete areas this is not always true, as an examination of modified climatic diagrams created for a range of United States cities shows. For these cities, atmospheric evaporative demand almost always exceeds precipitation, especially during the period of greatest tree growth, May through October (Figure 1). Atmospheric evaporative demand rises steadily over the growing season, peaking mainly in July, less frequently in June. This only represents the potential evaporation both from the soil and transpiration from plants (evapotranspiration) that could occur given prevailing atmospheric conditions. Actual transpiration from plants can be much less.

Moreover, not all precipitation is particularly effective. While most of the moisture in the soil available to trees is obviously derived from precipitation, not all precipitation increases soil moisture. Significant amounts may be evaporated before reaching the ground, may be intercepted by the canopy foliage, lost by surface runoff, or percolated beyond the root zone (5, 34).

Therefore, the proportion of summer precipitation that actually becomes available for plant use is the result of complicated interplay between atmospheric evaporative demand, the duration and intensity of rainfall, tree canopy size and structure, and the waterholding and drainage capacities of the soil. As an alternative, summer soil water storage values could be calculated if a soil profile description and textural classification were known for the area of interest. This information is extremely difficult to obtain for disturbed, heterogeneous urban soils. We can therefore use precipitation rates only as a general estimate of the water available for tree uptake for any defined period of time.

Estimating whole tree water use with pan evaporation data

There are few studies that have quantified the water demands of trees. Kramer (21) estimated that a 35' height tree with an actual leaf surface area of 2000 ft^2 tree might lose up to 35 gallons of water a day. Vrecenak and Herrington (46) estimated 250 gallons a day for a 64' canopy diameter tree of average density. For comparison, a typical 4'x4'x3' (depth) tree pit with a loam textured soil having an available waterholding capacity of 12% and total volume of 48 ft^3 could hold approximately 45 gallons of water, which the larger tree would use in a little over two hours. Trees growing in these pits will fare poorly as they get larger and die, unless the roots are able to move out of this constraining volume of soil and "break out" into amenable soils nearby.

It is not always possible to directly measure water loss. More common are indirect methods using climatic data and these methods have largely been developed for agronomic crops. Currently, over thirty different mathematically derived weather-based formulas have been developed for the sole purpose of predicting evapotranspiration and calculating the subsequent irrigation needs of these crops (10, 31, 39). These formulas vary both in complexity and in the type and quantity of data required. Application of some of these formulas to modeling the water use of single trees has been attempted by a few studies but is still highly problematic (24, 42, 43, 45).

Alternatively, one simple and reasonably accurate approach to estimating crop water use has been through the use of an evaporation pan (6, 48, 41). Nine types of pans are in current usage, the most common and considered the standard however, is the U.S. Weather Bureau Class A pan (Figure 2). This metal pan is round with a diameter of 47½" (120.65 cm), 10" deep (25.4 cm), and is placed slightly above ground level (13, 31). It is filled with water and a micrometer gauge measures daily water level changes that are a result of free surface water evaporation from the pan. Typically, evaporation from a pan integrates the major environmental influences, sunlight, temperature, wind and humidity. Atmospheric evaporative demand can then be calculated.

Agronomic crop canopies are however, qualitatively different from an isolated tree canopy. When soil water is not limiting, and atmospheric conditions are primarily determining the rate and amount of whole tree water loss, can a proportional relationship be established between water evaporation from the surface of a pan

Table 1. Previous soil volume estimations

Arnold, 1980 (2)	224 ft^3 of soil total for tree 21 to 40 ft. in height (8' x 8' x 3½' depth pit).
Bakker, 1983 (3)	2½ ft^3 of soil for every 1 ft^2 of CP^A.
Vrecenak and Herrington, 1984 (46)	5543 ft^3 for a 64 ft. diameter tree.
Perry, 1985 (35, 36)	27 ft^3 of soil for every 1" of caliper, later refining this to come up with 600 ft^3 total for a 10" caliper tree (20' x 20' x 18" depth pit).
Kopinga, 1985 (20)	2500 ft^3 of soil total as the optimum volume for a large tree.
Cervelli, 1986 (7)	570 ft^3 of soil total (10' x 19' x 3' depth).
Helliwell, 1986 (17)	A rooting volume 1/10th of the canopy volume; a 65' tree with a 40' spread will need over 7000 ft^3 of soil.
Moll and Urban, 1989 (30)	1200 ft^3 of soil total (20' x 20' x 3' depth pit) for a tree expected to reach a caliper of over 25 inches.

[A]Crown projection (CP) is defined as the total ground area under the dripline of a canopy. It is easy to measure and frequently used as a way to quantitatively describe the canopy relative to some other measurement of plant growth or development.

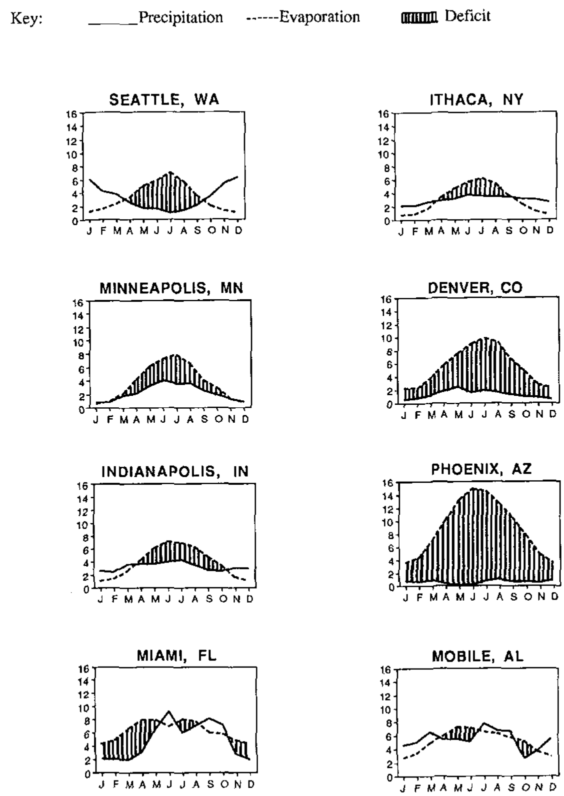


Figure 1. Climatic graphs of mean monthly precipitation and evaporation rates for eight major U.S. cities. The Y axis is in inches of precipitation and evaporation, the X axis is in months.

These graphs were derived from data in Farmsworth and Thompson (12); Farmsworth et al. (13) and NOAA (32). The data represents calculations of evapotranspiration and pan evaporation.

and transpiration from the surface of a leaf? Conveniently, evaporation from the pan is measured as inches of water lost per square inch of pan surface, which can be converted to milliliters of water per square centimeter of pan (ml/cm^2). Likewise, transpiration in plants can also be characterized as ml of water lost per cm^2 of leaf surface area.

It must be emphasized again that what the pan predicts is the potential transpiration that can occur from a plant under the prevailing atmospheric conditions, the actual amount will generally be lower. This is because of differing physical and aerodynamic properties between a pan and a leaf. Factors that increase evaporation from the pan compared to the plant are: water absorbs more heat than a leaf, heat may be transferred from the metal sides of the pan, heat may be stored and released it at night from the pan, and microclimatic conditions existing directly above the pan may be different than those above the plant (31). And too, as noted previously, soil and plant resistances can also significantly lower transpiration relative to pan evaporation.

In a previous study, the relationship between pan evaporation and gravimetrically determined water loss from tree canopies was derived for a variety of tree species over two growing seasons in Ithaca, N.Y. (27) These species, representing a range of leaf sizes were *Amelanchier* 'Robin Hill Pink', serviceberry; *Sophora japonica* 'Regent', Japanese pagoda tree; *Tilia americana* 'Redmond', basswood; and *Fraxinus americana* 'Autumn Purple, white ash. The results of this experiment yielded a significant regression equation, whereby 85% of the variability in whole tree water loss could be accounted for simply with knowledge of total tree canopy area (or leaf area) and pan evaporation. Pan evaporation, therefore, was a significant predictor of whole tree water loss on a daily basis for a range of atmospheric conditions. Knox (19) also found a strong correlation between pan evaporation and water use among five woody species growing in one gallon containers. However, instead of actual leaf area, a growth index was included with pan evaporation.

Also in our previous study we found that whole tree water loss relative to pan evaporation was not statistically different for the four species. On any given day, over comparable surface areas, water transpired from the trees generally averaged 30% of the water evaporated from the pan (Figure 2). In addition, though many studies discuss the possible effect of smaller leaf sizes on reduced water losses (26, 33, 40), in this study, leaf or leaflet size was not a good predictor of water loss. Transpiration increased only as overall canopy area increased, even though these four trees represent a gradient of leaf sizes from 5 to 46 cm^2. It would appear then that individual correlations between each species and pan evaporation may not have to be established to accurately describe whole tree water loss.

This 30% seems like a low value compared with the ones already derived for other trees, such as 25-50% for pecan (28), 40-135% for various fruit and nut trees (48), and 60-70% for apples in a semi-arid region (25). It must be remembered though that these other values included evaporation from the ground surface as well, which was eliminated in this study. Using small field grown liners, Ponder (37) found that replacing only 25% of net evaporation from a Class A pan produced plants that were not significantly smaller than plants grown with higher replacement rates. Our study also showed that the ratio of transpiration to pan evaporation decreased rapidly with increasing canopy size, dropping to about 20% in the larger trees (Figure 3). This is probably due to the effects of greater mutual leaf shading in these trees, which resulted in reduced water losses per cm^2 of leaf area. Therefore, while larger trees lose more water on a whole tree basis, they lose less per cm^2 of leaf area. This would indicate that as a tree canopy continues to mature, this ratio could in fact be much lower.

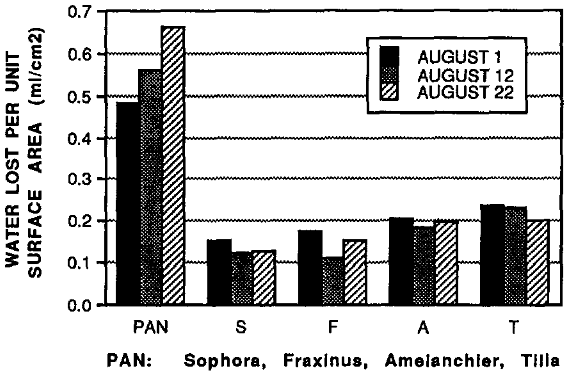


Figure 2. Evaporation from the pan compared with transpiration from the four tree species for a sampling of dates.

A Methodology to Determine Adequate Soil Volumes

Knowing now that there is strong relationship between pan evaporation and whole tree water loss and that a tree is expected to typically lose only 20% of what the pan loses, a methodology can be formulated. All of the calculations will be based on a hypothetical tree with a crown diameter (width) of 20', and an approximate height of 35'. This tree will be growing in Ithaca, N.Y. The intent of three steps that follow is to present the mathematical calculations of whole tree water loss, soil volume, and pit configuration in a logical order with informed discussion offered on the various decisions that must be made as one precedes through this methodology.

Step One: Determining Daily Whole Tree Water Use

1. *CALCULATE CROWN PROJECTION.* Crown projection (CP) is simply the area under the trees' dripline, which is just the area of circle, (radius)^2. We can adjust this formula to use diameter instead, so that crown projection equals (crown diameter)^2 x .7854. For a tree with a 20' crown diameter, **(20 ft)^2 x .7854 is 314 ft^2 of crown projection.**

2. *SELECT THE APPROXIMATE LEAF AREA INDEX (LAI) OF THE TREE.* This is simply the ratio of leaf surface area to crown projection or leaf density within the canopy. Deciduous trees commonly have LAI's of from 1 to 12, with the higher numbers indicating highly clumped leaves, and the lower numbers indicating little leaf overlap. **A LAI of 4 is selected,** which is a LAI commonly attributed to a deciduous tree of this size. This means that the tree has an actual leaf surface area that is *four times greater than the crown projection. Further* research is really needed to relate LAI to crown projection for a range of tree species, sizes and forms.

3. *DETERMINE THE EVAPORATION RATE.* Find the highest mean monthly pan evaporation rate. Pan evaporation values are obtainable from the National Oceanic and Atmospheric Administration, NOAA (12) or university research farms. The extreme mean monthly evaporation value for Ithaca (a compilation of 30 years of data record, most NOAA records represent about 15 years of data record) is highest in July, 6.21". This means that for every 1 square inch of surface water in the pan, **6.21 cubic inches is typically evaporated out over the month of July. This value is then divided by the number of days in the month (31) to come up with a mean daily evaporation rate of .20 in. This daily value, .20 in. is multplied by a conversion factor, 0.0833, to give 0.0167 ft. of water evaporated per day.**

4. *USE OF THE EVAPORATION RATIO AS A CONSTANT.* This represents the ratio of whole tree water use to pan. Up to this point, evaporation of water from the pan is assumed to be analogous to transpiration of water from the surface of a leaf. However, as previously established, evaporation from the pan represents the maximum possible evapotranspiration while actual transpiration will generally be far less. Based on previous research, **an adjustment factor of 20% (.20) is selected,** which assumes that a cm^2 of leaf transpires only about 1/5 as much as a cm^2 of pan surface.

All of the above are now multiplied together to derive cubic feet of water lost per day:

$$\underline{CP} \times \underline{LAI} \times \underline{\text{Evaporation Rate}} \times \underline{\text{Evaporation ratio}}$$
$$314\ ft \times 4 \times 0.0167\ ft \times .20$$
$$= 4.19\ ft^3\ (31\ \text{gallons of water})$$

STEP TWO: Determining an Adequate Soil Volume

The predicted daily water loss value of 4.19 ft^3 calculated above will be the value used here.

5. *SELECT AVAILABLE WATER HOLDING CAPACITY OF THE SOIL (AWHC).* Soils hold varying amounts of water depending on their texture and structure and only a certain amount of this water is actually available for tree uptake. Assuming one has the chance of specifying the soil type, a minimum of 10% of the water should be held as available water, with optimum values approaching 15-20%. Obviously, the higher the AWHC, the more water available per cubic ft. of soil and the longer a tree can go without additional water. As with the current soil estimations however, large soil volumes are hard to obtain in urban areas, especially if specifying *containers. The objective should be to keep the* volumes reasonably achievable and know what the limitations to that volume are, i.e. the tree can go for 10

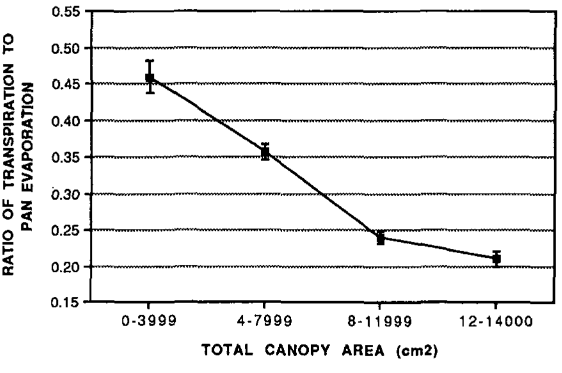


Figure 3. The change in the ratio of transpiration to pan evaporation as canopy size increases. All species are grouped. Standard errors as noted.

days without rain. For this example, **a silt loam is selected with an AWHC of 19%. So 4.19 ft^3 is divided by .19 to yield a total of 22 ft^3 of soil.** AWHC, and the percent sand, silt and clay in any soil can be determined in lab tests and can be specified for a project. Further *assumptions are that this soil has acceptable levels of* infiltration, permeability and adequate drainage.

6. DETERMINE THE RAINFALL FREQUENCY. Establish the average number of days between the critical rainfall events. A critical rainfall event is defined here as one that results in one tenth of an inch of rain or more. **For Ithaca, N.Y., 92% of all dry periods (less than 1/10" of rainfall) lasted 10 days or fewer.** Currently, the average length of this dry period between 1/10" of rainfall must be derived from daily precipitation rates published by NOAA for each city. The assumptions would be 1) that sufficient soil water storage occurs from November to April so that the soil is fully recharged in May and 2) the calculated soil volume would hold sufficient water to carry the tree through the interval chosen, after which recharge of soil water would occur through precipitation, the water table, lateral water movement, or perhaps irrigation. For containers, due to limited surface catchment area and canopy interception, it may never be assumed that precipitation will sufficiently recharge the soil for any period of time. Reliable recharge could occur only through irrigation. So a rainfree period of 10 days is selected for Ithaca, NY, a fairly humid region with substantial rainfall levels occurring on a regular basis. **The total of 22 ft^3 of soil is multiplied by 10 to yield 220 ft^3 of soil** needed to meet the water demands of a tree this size for a 10 day period.

Step Three: Calculating Possible Bed Dimensions
The depth should be no greater than 3 ft. The width and length of a bed that needs to hold 220 ft^3 of soil could be configured roughly then as an **8 ft x 9 ft x 3 ft or a 4 ft x 18 x 3 ft bed.**

Discussion

A summary of the steps involved and the data needed to compute these steps are given in Table 2. Several points need to be emphasized. The highest mean monthly pan evaporation value was used to calculate daily water use, and this represents the extreme condition. Generally, water use may be much lower on a dialy basis over the whole growing season. The highest water use typically occurs in July. This might be the month to target for supplemental irrigation, if at all. Also it will be at least 10-15 years before the tree used in the example reaches a size requiring the full use of all available water in this soil volume. The implication is that this volume is self-supporting for this number of years. When the maximum tree size used to make the calculations has been reached, the tree water supply needs should be assessed if one anticipates significantly more growth. At this point it should be determined if *summer soil water storage appears to be occurr*ing in sufficient amounts, or whether supplemental irrigation needs to be applied.

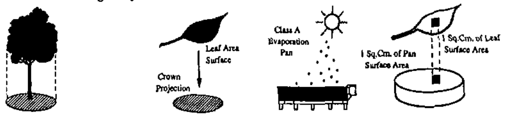
Importantly, this methodology also allows one to work from the other direction. If given an existing volume of soil in a tree pit, vault or container, one can decide what size tree this volume will reasonably support. Up to this point it has been assumed that the entire volume of soil provides usable rooting space. Obviously when planting directly into existing soils in urban areas, good soil structure may be lacking, i.e. roots may not be able to penetrate compacted soil. Appropriate soil remediative action must take place then before planting.

It should be emphasized strongly that for these volumes to work, tree pits, extended shared space, and containers all must be mulched. A coarse textured mulch, 3-4 inches deep, with a particle size roughly that of pea gravel, will conserve over 80% of the precipitation that accumulates in the soil (16). Groundcovers used under the tree canopy, especially turf, quite effectively compete for water with tree roots. Currently, it is hard to predict the amount of this additional water loss, and so these plantings should be avoided unless planted areas are irrigated.

TABLE 2

SOIL VOLUME METHODOLOGY EXAMPLE

STEP ONE: Determining daily whole tree water use:



1 Calculating Crown Projection CP = (crown diameter)^2 x .785		2 Leaf Area Index Leaf surface area to crown projection		3 Evaporation Rate Daily pan evaporation		4 Evaporation Ratio Ratio of whole tree water use to pan evaporation
(20)^2 x .785 = 314 ft^2	x	4	x	0.0167	x	.20

4.19 = CUBIC FEET OF WATER LOST PER DAY (31 gallons)

STEP TWO: Determining adequate soil volume:

Cubic feet of water lost per day		5 Available water holding capacity of the soil (%)		6 Rainfall Frequency (Critical number of days)
4.19	+	.19	x	10

220 = TOTAL CUBIC FEET OF SOIL VOLUME (~6 cubic meters)

STEP THREE: Calculating possible bed or container dimensions:

Assuming a depth of no more than 3 ft, calculate a surface area to accomodate 220 ft^3 of soil. This could be configured roughly in at least two ways, an 8 ft x 9 ft x 3 ft or a 4 ft x 18 ft x 3 ft bed.

The relationship of soil volume needed per unit area of crown projection has been computed for the six representative cities (Table 3). Omitting Phoenix, AZ (a city experiencing exceptionally high atmospheric evaporative demand coupled with low precipitation), rounding these values up yields a general estimate of 2 ft^3 of soil per 1 ft^2 of tree crown projection. This figure is in agreement with other related work. Re-interpretation of the estimation given by Vrecenak and Herrington (46), in an energy budget analysis of whole tree water loss, yields 1.6 ft^3 of soil per 1 ft^2 of crown projection. Bakker (3) deriving transpiration rates from annual forestry values using a multiplier, calculated 2½ ft^3 of soil per 1 ft^2 of crown projection.

If the total volumes derived from this methodology are hard to obtain at the desired planting site, then perhaps supplemental irrigation should be installed. Likewise, trees that are smaller at maturity and need less total soil could be planted. The best alternative is to modify adjoining soils under paved areas and then cover them with pervious paving. This paving will help ensure vital oxygen diffusion and water infiltration through the soil (11). Currently, aggregate-based tree pit soil mixes that can be compacted for use under these paved areas and yet still allow adequate root growth are being developed and tested on site (1, 44).

A final caveat concerns the reliability of using pan evaporation values that are not specifically tied to one urban site, where microclimatic conditions result in evaporation values that can be very different from weather station data (47, 18, 14). Most evaporation values are not obtained from airports or research stations, areas typically outside of the city proper. Predicting the size of any given site specific "urban effect" is highly problematic. The built environment is complicated and atmospheric demand conditions are still largely unquantified. This methodology though, is meant to offer just a general approximation of supportive soil volumes. More localized pan evaporation readings would be ideal but they are hard to obtain. Just as likely, informed and intuitive adjustments could be made in the field by the professional. If one suspects that a given planting site is subject to greater atmospheric demand than the pan evaporation values indicate, either larger evaporation values could be substituted, or a shorter rain/irrigation period could be specified.

Summary

Street trees live on average 7-10 years, with trees in containers living only 2-5 years (29). In Seattle, 80% of unirrigated newly planted street trees died within two years (9). Soil, overly wet or too dry, or even more simply, the lack of soil, can account for many tree survival problems. The challenge is to engineer a larger and more suitable soil environment, especially for the inner city street tree. Unfortunately, outdated installation details, planting specifications and procedures are often still being used. Successful urban planting must be properly informed by a new landscape technology based on the broadening body of scholarly urban tree research.

This soil volume methodology, and the subsequent recommendation of 2 ft^3 of soil for every ft^2 of crown projection, is an attempt to transfer a vital part of this burgeoning technology into the hands of interested professionals. Hopefully, the resulting applications of this soil volume methodology can enhance current attempts to "green" our cities, making them more aesthetically pleasing, livable, and ecologically sound environments.

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TABLE 3

CRITICAL SOIL VOLUMES

Estimated critical soil volumes are presented for a representative range of U.S. cities using the soil volume methodology. The tree used in this example has a crown diameter of 20' and is about 35' in height. Calculations were based on the tree having a crown projection of 314 ft^2 with an average leaf area index of 4. The growing site is Ithaca, N.Y.

CITY	EVAPORATION PAN RATE[1] Inches per month	ONE DAY SOIL VOLUME[2] (Ft^3)	RAINFALL FREQUENCY[3] (Days)	TOTAL SOIL VOLUME (Ft^3) if AWHC[4] of soil is either 15% or	19%	
Ithaca, NY	6.21" July	28	10	300	220	(.70 ft^3/ft^2 CP)[5]
Seattle, WA	7.00" July	30	20	600	480	(1.5 ft^3/ft^2 CP)
Mobile, AL	7.19" May	32	10	300	250	(.80 ft^3/ft^2 CP)
Indianapolis, IN	7.13" June	33	15	500	400	(1.2 ft^3/ft^2 CP)
Minneapolis, MN	7.88" July	35	10	350	275	(.87 ft^3/ft^2 CP)
Miami, FL	8.03" July	36	10	350	285	(.91 ft^3/ft^2 CP)
Denver, CO	9.80" July	45	15	700	525	(1.7 ft^3/ft^2 CP)
Phoenix, AZ	14.83" June	68	80	5400	4315	(14 ft^3/ft^2 CP)

[1]The highest mean monthly pan evaporation value for 20-30 years of data record for each city.
[2]Assumes a soil available water holding capacity of 15%.
[3]Defines the critical rainfall event. A minimum of 92% of all dry periods (less than 1/10" rainfall) lasted this number of days or fewer for each city. Derived from 10 years of data record for each city.
[4]AWHC-available water holding capacity of the soil. This represents the fraction of the total water, on a volume basis, that is actually available for root uptake. Two available water holding capacities are presented for comparison here, an average, 15% and a high, 19%. AWHC of any soil mix can be ascertained in a lab test, and specified for use a the tree pit.
[5]Derived cubic feet of soil per square foot of crown projection.

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Résumé. La faible volume de sol pour un arbre dans une fosse d'un trottoir ou dans un bac est souvent incapable de pourvoir adéquatement les besoins en eau comme l'arbre l'exige. Il en résulte que les arbres peuvent subir de sévères limitations au cours d'une croissance et d'un développement vigoureux. Les estimations courantes en volume de sol se montrent insuffisantes pour aborder trois problèmes: 1) comment prédire la consommation complète d'eau par l'arbre, surtout pour un large champ de conditions climatiques prédominantes, 2) comment rattacher cette prédiction à quelque paramètre facile à mesurer sur l'arbre et 3) comment incorporer l'un et l'autre des éléments ci-dessus dans quelque moyen simple néanmoins fidèle pour l'estimation du volume du sol. Une méthodologie basée sur les conditions atmosphériques, pour adéquatement évaluer les volumes de sol, est présentée pour aborder ces relations. Ceci incorpore les découvertes d'une récente étude indiquant que la perte entière d'eau par l'arbre peut être raisonnablement prédite avec la connaissance de l'évaporation d'un bassin Class A du U.S. Weather Bureau. Un volume de sol de 220 pi. cu. pour un arbre de dimension moyenne est par la suite calculé. Pour emploi comme estimation courante, 2 pi. cu. de sol est recommandé par pied carré de la projection de la couronne de l'arbre au sol.

Zusammenfassung: Das wenige Bodenvolumen in einer durchschnitt-lichen Baumgrube oder im Baumbehälter ist oft nicht fähig, genügend Wasser zu liefern. Infolgedessen können Bäume unter Beschränkungen auf den gesunden Wachstum und Entwicklung leiden. Den allgemeinen Schätzungen vom Bodenvolumen mißlingt es, drei Problemen anzusprechen: 1) wie man den ganzen Wasserverbrauch eines Baumes voraussagt, besonders für ein weites Spektrum von herrschendend Klimaverhältnissen, 2) wie man diese Voraussage mit irgendeinem einfach-gemessenem Baumparameter verbindet und 3) wie man die beiden obengenannten Aspekten in einen einfach aber genauen Art kombiniert um das Bodenvolumen zu schätzen. Eine Wetter-fundierte Methodologie, die das Bodenvolumen richtig schätzt wird dargestellt, um diese Gelegenheiten anzusprechen. Diese Methodologie beruht auf den Befund einer neuen Untersuchung, die zeigt, daß Wasserverlust des ganzen Baumes mit dem Wissen der Verdünstung von einem USA Wettebüro Klasse A Tiegel vorausgesagt kann. Ein Bodenvolumen von 220 ft^3 für einen mittleren Baum wird dann kalkuliert. Um als durchschnittliche Schätzung ist 2 ft^3 Boden für 1 ft^2 Gipfeldeckung empfohlen.

ABSTRACT

BALL, J. 1990. **Insights on on-site tree preservation**. Am. Nurseryman 172(4): 93-95, 98-111.

Trees have a tremendous ability to withstand sudden stress. They rarely show symptoms of injury during construction, but within a year or two, the trees begin to die back. This process of shedding branches continues until the trees are removed. To properly protect trees requires site work before, not after, construction. To determine which category a tree fits into, the designer-contractor must evaluate the tree's vitality. The advantage of vitality testing is it reduces some of the guesswork in predicting which trees have the best chance of adapting. Construction activities kill indirectly; most trees die due to change in the soil around them. Not all tree species are equally sensitive to soil-related construction injury. Bottomland species such as silver maple, green ash, American planetree, pin oak and black willow are good candidates for survival on construction sites. The most common way to protect trees is to define a construction envelope with temporary fencing. Fence placement is critical. If possible, the fencing should be placed no closer to the trunks than a distance equal to the average height of the trees.