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Assessing Soil Water Resource Space

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Trees require high quality resources in the correct proportions to perform best. Water, and the soil volume which holds water, are critical to great tree growth. In trees, 80% of growth variability is due to water availability differences, and 85% of tree demand for water is related to the tree's evaporative environment and crown volume. To better assess soil water resource space needed for trees, a set of calculations can be completed. Two of these calculation methods will be used here -- the Coder Tree Soil Water Resources Assessment and the Coder Days Until Dry Containerized Soil Water Assessment. Specific calculations use measurable values to determine soil volumes required, which are based primarily upon water availability and tree needs. Do not guess at tree water needs – calculate!

The Coder Tree Soil Water Resources Assessment method used here can be completed in six (6) steps. Each step builds on previous steps to assure a reasonable amount of space and water can be provided for a tree. Figure 1.

Step #1 is used to determine crown volume of a tree. The larger the crown volume, the greater number of leaves, buds, and twigs, and the greater potential for water loss. The average crown diameter in feet squared is multiplied by crown height in feet. This value gives the volume of a square cross-section shaped crown. Trees are not ideally square shaped, so a reduction in the volume is made by picking a shape factor for a tree crown from Figure 2. The shape factor multiplied by crown volume provides the actual crown volume of a tree in cubic feet. Table 1.

Crown Shape Factor – To accurately determine tree crown volumes, the size and shape of the living crown must be measured. Tree crown volumes are used to calculate daily water use. Standard linear dimensions of tree crowns, like height and diameter, are easily determined. Tree crown shape is another easily estimated value which can assist in more accurately calculating tree crown volumes. Calculations of tree crown volumes here consolidate variations within tree crowns by using calculations for solid geometric objects, helping simplify calculations.

Table 1 provides names and formulae for a variety of different idealized crown shapes. Note that within the various formulae for crown shape, the only portion which changes is a single decimal multiplier value, referred to as a "tree crown shape factor" or a "shape factor multiplier." These formulae represent a calculated volume for an idealized round cross-sectional shape. All shapes are found along a calculation gradient from a multiplier of 0.785, to a multiplier of 0.098. Figure 2 helps graphically define idealized tree crown shapes which have the same diameter and height.

Step #2 is used to determine the effective crown surface area of the tree. The crown volume in cubic feet determined in Step #1 is divided by crown height in feet. The result is multiplied by an average leaf area index, here with a value of four (4). A leaf area index is an approximation ratio of how many square feet of leaves are above each square foot of soil below. This value depends upon tree age, species, and stress levels. Here a value of four for an average community tree is used. The result of the Step#2 calculation is the effective crown surface area of a tree in square feet.

Step #3 is used to determine the daily water use of a tree. The effective crown surface area in square feet is multiplied by three atmospheric factors which impact tree water use: daily evaporation in feet per day (Figure 3); an evaporative pan factor (Figure 4); and, a heat load multiplier (Figure 5 & Table 2). The result of this calculation is the daily water use of a tree in cubic feet (ft^3/day). For comparisons, one cubic foot of water is approximately 7.5 gallons ($1ft^3 = \sim7.5$ gallons).

Step #4 is used to determine how much water a tree needs over time. The daily water use of a tree is multiplied by a value representing the average number of days in the growing season between normal rain events which can be daily rain in some places (multiplier = 1) up to once every 21 days (multiplier = 21). Here, for community trees on average sites, the multiplier value of 14 will be used (14 days between significant growing season rain events). This calculation generates a two week tree water needs amount in cubic feet of water.

Step #5 is used to determine total soil volume needed for supplying two weeks tree water needs amount over 14 days, from Step #4. Having plenty of water and no where to store it wastes water and trees. With no soil volume for storage, any water added will run-off and not be tree-usable. The two weeks tree water needs amount in cubic feet from Step #4 is divided by the tree available water in the soil as a decimal percent (Table 3 as modified by Figure 6). The result is the total soil volume needed for a tree in cubic feet over a 14 day water supply period.

Step #6 is used to determine diameter in feet of the required tree resource area on the ground surface centered upon a tree. The total soil volume needed for a tree in cubic feet value from Step #5 is divided by the effective soil depth in feet for storing tree-usable water. Figure 7. For most community trees the "compacted" values should be used. The result is multiplied by 0.785, with the answer taken to the 0.5th power (square root). The final number is the diameter of a resource area in feet which will supply a tree with water for 14 days.

One concern tied to the calculations above is with the use of percentages for soil water values. Actual inches of water per foot of soil represents real volumes while percentages are used in calculations. Figure 8 helps convert percent soil water into inches of water per foot of soil for use in irrigation and for measuring precipitation impacts on a site.

Contained Trees

Another soil water assessment helps determine how many days without precipitation or irrigation under current site conditions can pass before a tree with a limited soil area can no longer extract water. The time period before a soil has no tree-usable water remaining is critical in preventing major tree damage. The Coder "Days Until Dry" Containerized Soil Water Assessment is targeted at in-ground and above ground containers, and sites where tree rooting space and soil resources are physically limited. This is only a basic estimate because each container or site will have unique attributes impacting water availability, and can not be accounted for within this simple calculation.

The Coder Days Until Dry Containerized Soil Water Assessment method is shown in Figure 9. This assessment can be completed in five (5) steps, the first three steps from the previous Coder Tree Soil Water Resources Assessment (Figure 1). Please see the previous text regarding this assessment and figures and tables needed for determining daily tree water use. The fourth and fifth step are unique to this assessment and are used to determine soil water volume available to the tree and how many days will pass before the soil is dry. Figure 9.

Five Step Assessment

Step #1 is used to determine the crown volume of a tree. The larger the crown volume, the greater number of leaves, buds, and twigs, and the greater potential for water loss. The average crown diameter in feet squared is multiplied by crown height in feet. This value gives the volume of a square cross-sectional shaped crown. Trees are not ideally square shaped, so a reduction in the volume is made by picking a shape factor for a tree crown from Figure 2. The shape factor multiplied by crown volume provides the actual crown volume of a tree in cubic feet. Table 1.

Step #2 is used to determine the effective crown surface area of a tree. The crown volume in cubic feet determined in Step #1 is divided by crown height in feet. The result is multiplied by an average leaf area index, here with an example value of four (4). A leaf area index is an approximation ratio of how many square feet of leaves are above each square foot of soil below and depends upon tree age, species, and stress levels. Here a value of four for an average community tree is used. The result of the Step #2 calculation is the effective crown surface area of a tree in square feet.

Step #3 is used to determine daily water use of a tree. The effective crown surface area in square feet is multiplied by three atmospheric factors which impact tree water use: daily evaporation in feet per day (Figure 3); an evaporative pan factor (Figure 4); and, a heat load multiplier (Figure 5 & Table 2). The result of this calculation is the daily water use of a tree in cubic feet (ft^3/day). For comparisons, one cubic foot of water is approximately 7.5 gallons ($1ft^3 = \sim 7.5$ gallons). The daily water use of a tree determined here will be used in Step #5.

Step #4 determines the soil water volume present in cubic feet using values from Table 4. Because this assessment is designed for general container estimates, it is critical an accurate value for container soil volume be used. Container soil volume in cubic feet is divided by total soil water as a decimal percent (d%) for the soil texture used, as given in Table 4. This value is then multiplied by one minus the soil water limit (in soil with the same texture) as a decimal percent (d%), also given in Table 4. This limit is an approximation of the permanent wilting point for a soil.

Step #5 determines the number of days, under similar tree and site conditions, a soil volume can sustain water needs of a tree. Note there is no "grace" period of time included. If no irrigation or precipitation are added to soil water resources, a tree will be damaged or killed due to lack of water. Irrigation can be timed to always be applied before a soil is dry.

It is important tree health professionals better quantify soil volumes and surface areas when planning and installing hardscape surfaces and structures for a landscape which will contain trees. Trees must have adequate soil space and water for good performance.

Figure 1: The Coder Tree Soil Water Resources Assessment Method.

Step #1: Determine crown volume.

$$\left[\begin{matrix}\text{crown}\\ \text{diameter}\\ \text{(ft)}\end{matrix}\right]^2 \times \begin{matrix}\text{crown}\\ \text{height}\\ \text{(ft)}\end{matrix} \times \begin{matrix}\text{shape}\\ \text{factor}\\ \text{(value)}\\ \text{[FIGURE 2]}\end{matrix} = \begin{matrix}\text{crown}\\ \text{volume}\\ (\text{ft}^3)\end{matrix}$$

Step #2: Determine effective crown surface area.

$$\left[\begin{matrix}\text{crown}\\ \text{volume}\\ (\text{ft}^3)\end{matrix} \Big/ \begin{matrix}\text{crown}\\ \text{height}\\ \text{(ft)}\end{matrix}\right] \times \begin{matrix}4\\ \text{(LAI)}\\ \text{leaf area index}\end{matrix} = \begin{matrix}\text{effective crown}\\ \text{surface area } (\text{ft}^2)\end{matrix}$$

Step #3: Determine daily tree water use.

$$\begin{matrix}\text{effective crown}\\ \text{surface area } (\text{ft}^2)\end{matrix} \times \begin{matrix}\text{daily water}\\ \text{evaporation}\\ \text{(ft / day)}\\ \text{[FIGURE 3]}\end{matrix} \times \begin{matrix}\text{pan}\\ \text{factor}\\ \text{(value)}\\ \text{[FIGURE 4]}\end{matrix} \times \begin{matrix}\text{heat}\\ \text{load}\\ \text{(multiplier)}\\ \text{[FIGURE 5 \&}\\ \text{TABLE 2]}\end{matrix} =$$

$$\text{daily tree water use } (\text{ft}^3 \text{ / day})$$

NOTE: 1 ft^3 water = ~7.5 gallons

Step #4: Determine tree water needs over a period of time.

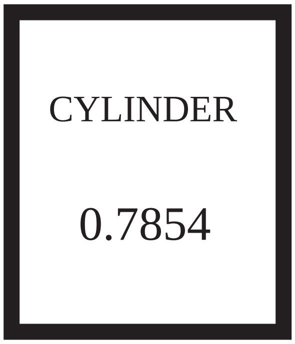
$$\begin{matrix}\text{daily tree}\\ \text{water use}\\ (\text{ft}^3 \text{ / day})\end{matrix} \times \begin{matrix}14\\ \text{(days)}\end{matrix} = \begin{matrix}\text{two week}\\ \text{tree water needs}\\ (\text{ft}^3 \text{ of water for 14 days})\end{matrix}$$

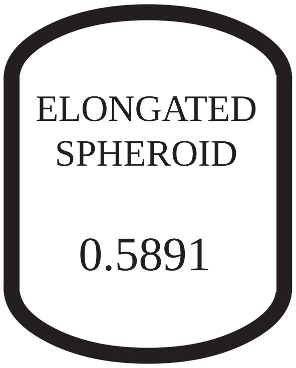
Step #5: Determine total soil volume needed for water storage.

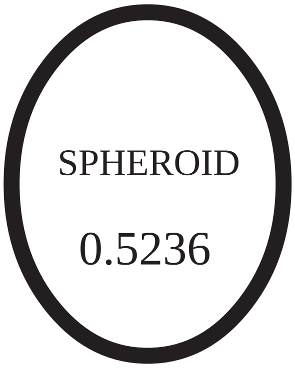
$$\begin{matrix}\text{two week}\\ \text{tree water needs}\\ (\text{ft}^3 \text{ of water for 14 days})\end{matrix} \Big/ \begin{matrix}\text{tree available}\\ \text{water in soil}\\ \text{(in decimal percent)}\\ \text{[TABLE 3]}\end{matrix} = \begin{matrix}\text{total soil}\\ \text{volume needed}\\ (\text{ft}^3)\end{matrix}$$

Step #6: Determine ground surface diameter of the tree resource area.

$$\sqrt{\left[\begin{matrix}\text{total soil}\\ \text{volume needed}\\ (\text{ft}^3)\end{matrix} \Big/ \begin{matrix}\text{effective}\\ \text{soil depth}\\ \text{(ft)}\\ \text{[FIGURE 7]}\end{matrix}\right] \Big/ 0.785} = \begin{matrix}\text{diameter of}\\ \text{resource area}\\ \text{(ft)}\end{matrix}$$







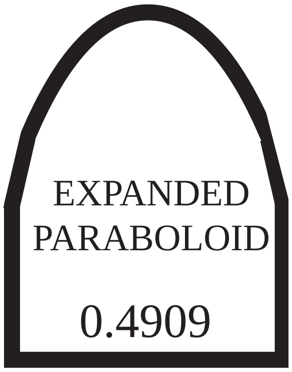
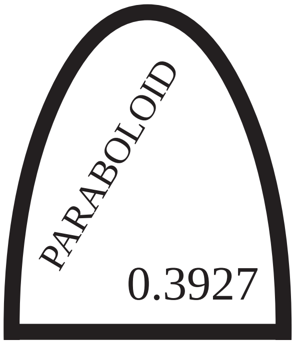
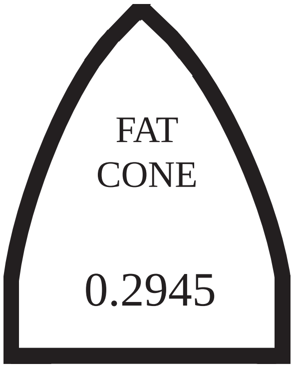


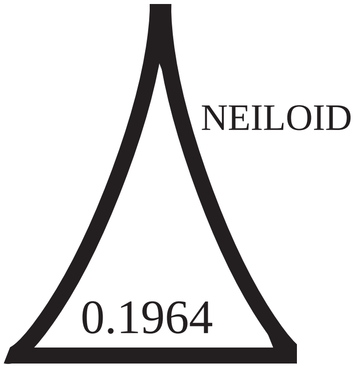
Figure 2:
An idealized side view of different tree crown shapes. All shapes have a circular cross-section or are round when viewed from above. The shape name and crown volume multiplier number are provided. See Table 1 for more details.

(crown diameter)^2 X
crown height X
crown shape factor =

CROWN VOLUME







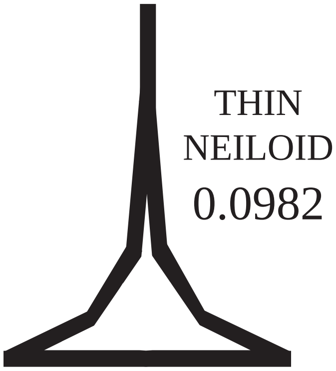
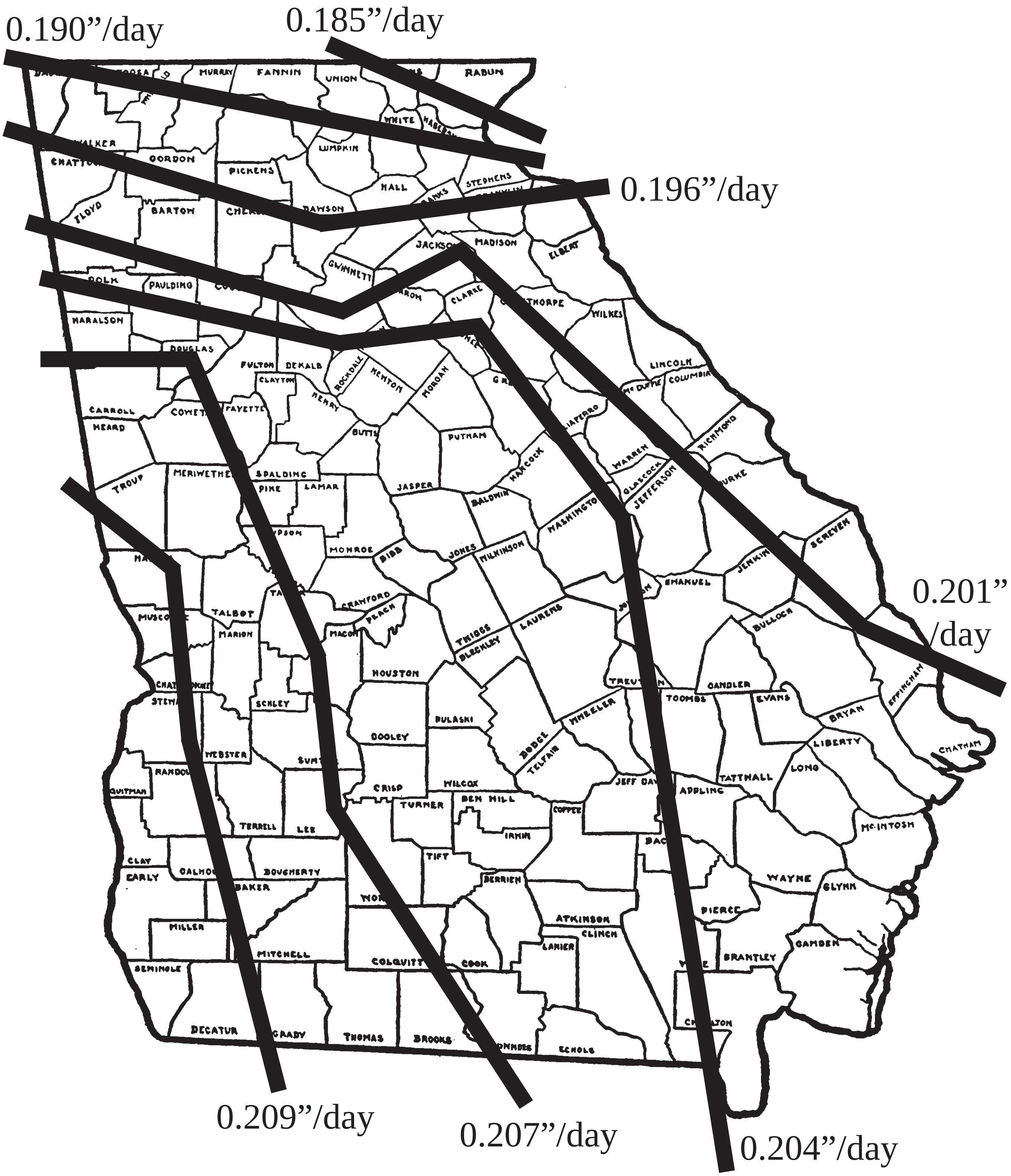


Table 1: Tree crown volume estimates for different crown shapes. Shape formula for these cylindrically based crown shape models range from a multiplier of 0.7854 for an ideal cylinder, to 0.0982 for a thin neiloid crown shape. Crown shape formula use crown diameter and crown height measures in feet to calculate crown volumes in cubic feet. The crown shape name is a descriptive approximation for visualizing idealized crown shapes based upon solid geometric figures. Figure 2 describes the shapes involved.

shape value	shape formula	shape name
8/8 (1.0)	(Crown Diameter)^2 x (Crown Height) x (0.7854)	CYLINDER
7/8 (0.875)	(Crown Diameter)^2 x (Crown Height) x (0.6872)	ROUNDED-EDGE CYLINDER
3/4 (0.75)	(Crown Diameter)^2 x (Crown Height) x (0.5891)	ELONGATED SPHEROID
2/3 (0.667)	(Crown Diameter)^2 x (Crown Height) x (0.5236)	SPHEROID
5/8 (0.625)	(Crown Diameter)^2 x (Crown Height) x (0.4909)	EXPANDED PARABOLOID
1/2 (0.5)	(Crown Diameter)^2 x (Crown Height) x (0.3927)	PARABOLOID
3/8 (0.375)	(Crown Diameter)^2 x (Crown Height) x (0.2945)	FAT CONE
1/3 (0.333)	(Crown Diameter)^2 x (Crown Height) x (0.2619)	CONE
1/4 (0.25)	(Crown Diameter)^2 x (Crown Height) x (0.1964)	NEILOID
1/8 (0.125)	(Crown Diameter)^2 x (Crown Height) x (0.0982)	THIN NEILOID

Note: Tree crown shape factors with multiplier values between 0.999 and 0.786 have a cylindrical appearing side view but would not have a circular cross-section. A multiplier value of 1.00 would be square in cross-section. Tree crown shape factors or multipliers greater than 0.785 are not shown here.

Figure 3: An example from the State of Georgia. These evaporation data are available for most places. This map shows historic average daily pan evaporation during the growing season (May through October) in inches per day based upon average annual pan evaporation. Divide by 12 to calculate feet per day.



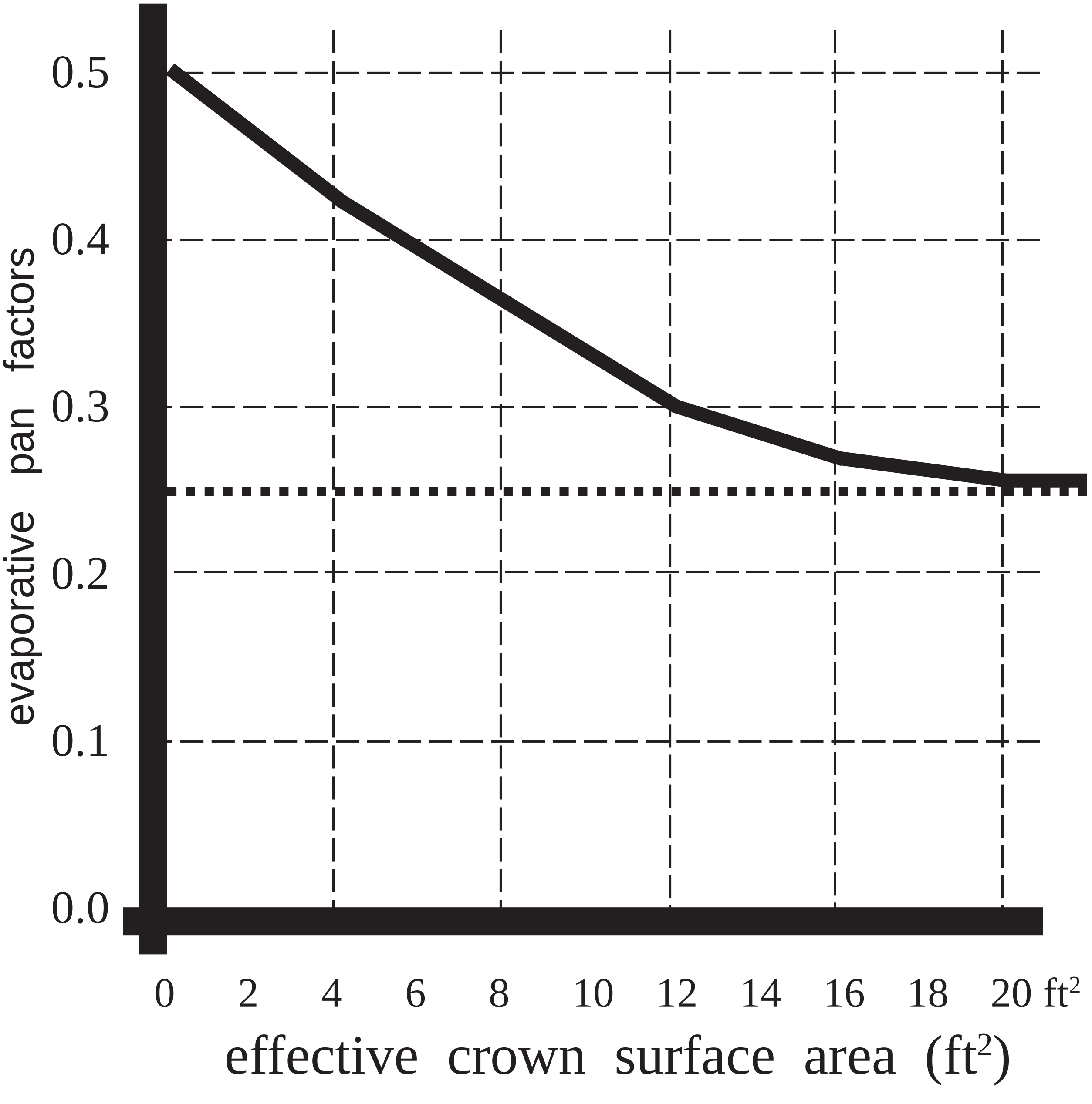


Figure 4: Ratio of tree transpiration to pan evaporation (pan factor or pan coefficient). Pan factors are not less than 0.25 for trees with larger than 20 ft^2 of effective crown surface area. (after Lindsey & Bassuk, 1992)

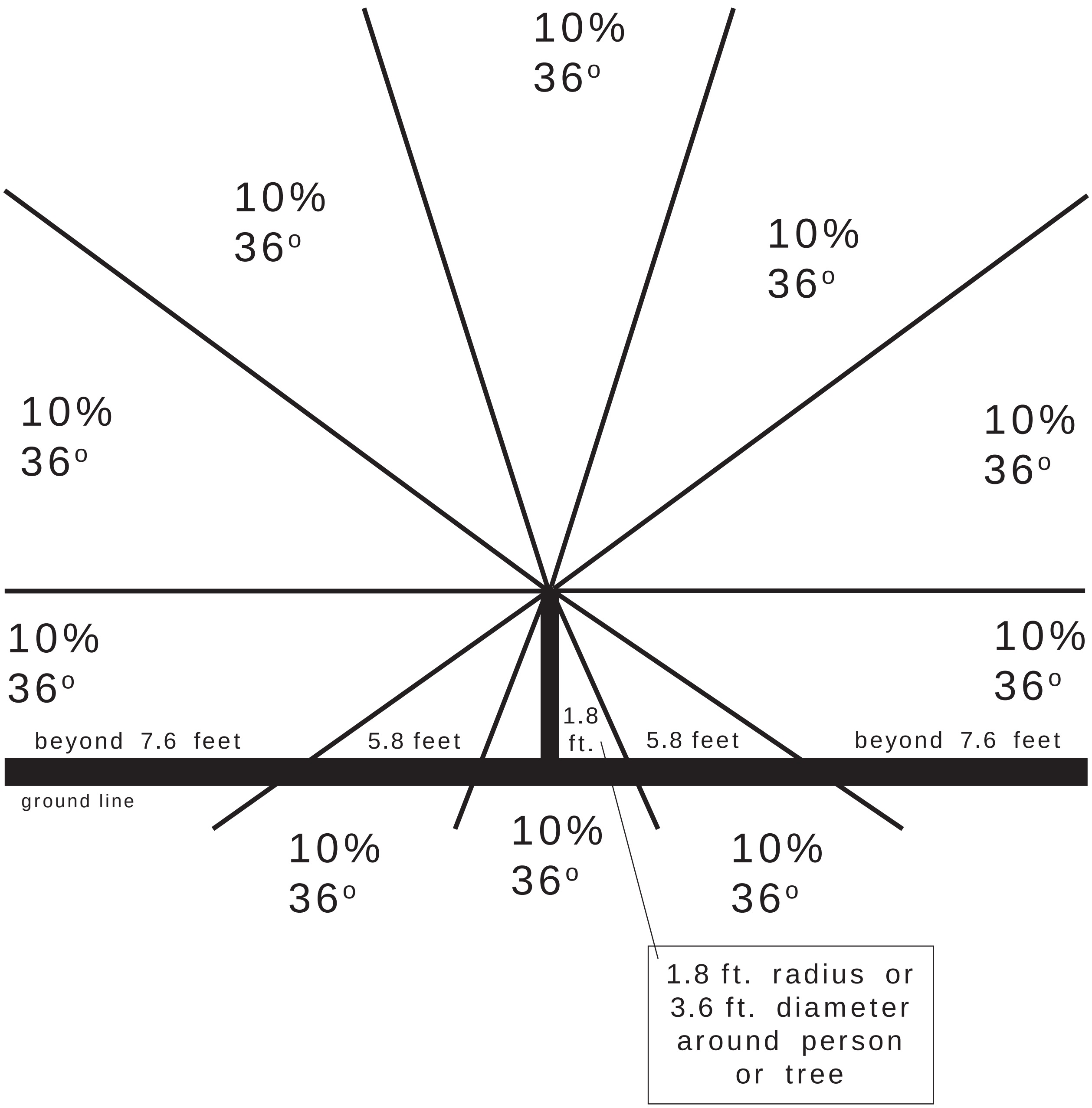


Figure 5: Diagram showing how heat loading can be estimated on a site using the Coder Heat Load View-Factor containing ten equal (36°) observation angles.

In each of ten angle segments, the dominant surface facing the tree or planting site is recorded. Surface types include sky & vegetation, or non-evaporative, dense surfaces (hardscape). The first estimate is made North/South and a second estimate is made East/West, with the two estimates averaged together to provide a single view-factor value (in 10% classes) which can then be used for determining a site heat load multiplier. Distances given above are based upon an observation height of 5.5 feet.

Table 2: Coder Heat Load View-Factor multiplier values for various non-evaporative, dense surface view-factors (nearest 10% class) for a site or tree.

view-factor percent of non-evaporative, dense surfaces facing the site	heat load multiplier**
100%	2.9
90%	2.6
80%	2.3
70%	2.1
60%	1.9
50%	1.7
40%	1.5
30%	1.3
20%	1.2
10%	1.1
0%	1.0

**Use heat load multiplier to increase water use values on trees under various heat loads.

Every 10% / 36^o of angle around a point, starting at the ground directly below and observing along a circular arc which passes through zenith, is determined to have either open sky / vegetation or non-evaporative, dense surfaces facing the measurement point. Each 10% angle segment is considered to be dominated by one or the other of these surfaces.

Table 3: Theoretical (T) and functional (F) tree available water values (in decimal percent) within soils of various textures under normal conditions and under compaction. Functional values should be used in assessments and were determined from Figure 6.

(after Cassel, 1983; Kays & Patterson, 1992; Craul, 1992 & 1999)

soil texture	tree available water (normal)		tree available water (compacted)	
	T	(F)	T	(F)
clay	.13	(.10)	.07	(.05)
clay loam	.17	(.13)	.08	(.06)
silt loam	.19	(.14)	.09	(.07)
loam	.18	(.14)	.09	(.07)
sandy loam	.11	(.08)	.06	(.05)
sand	.05	(.04)	.03	(.02)

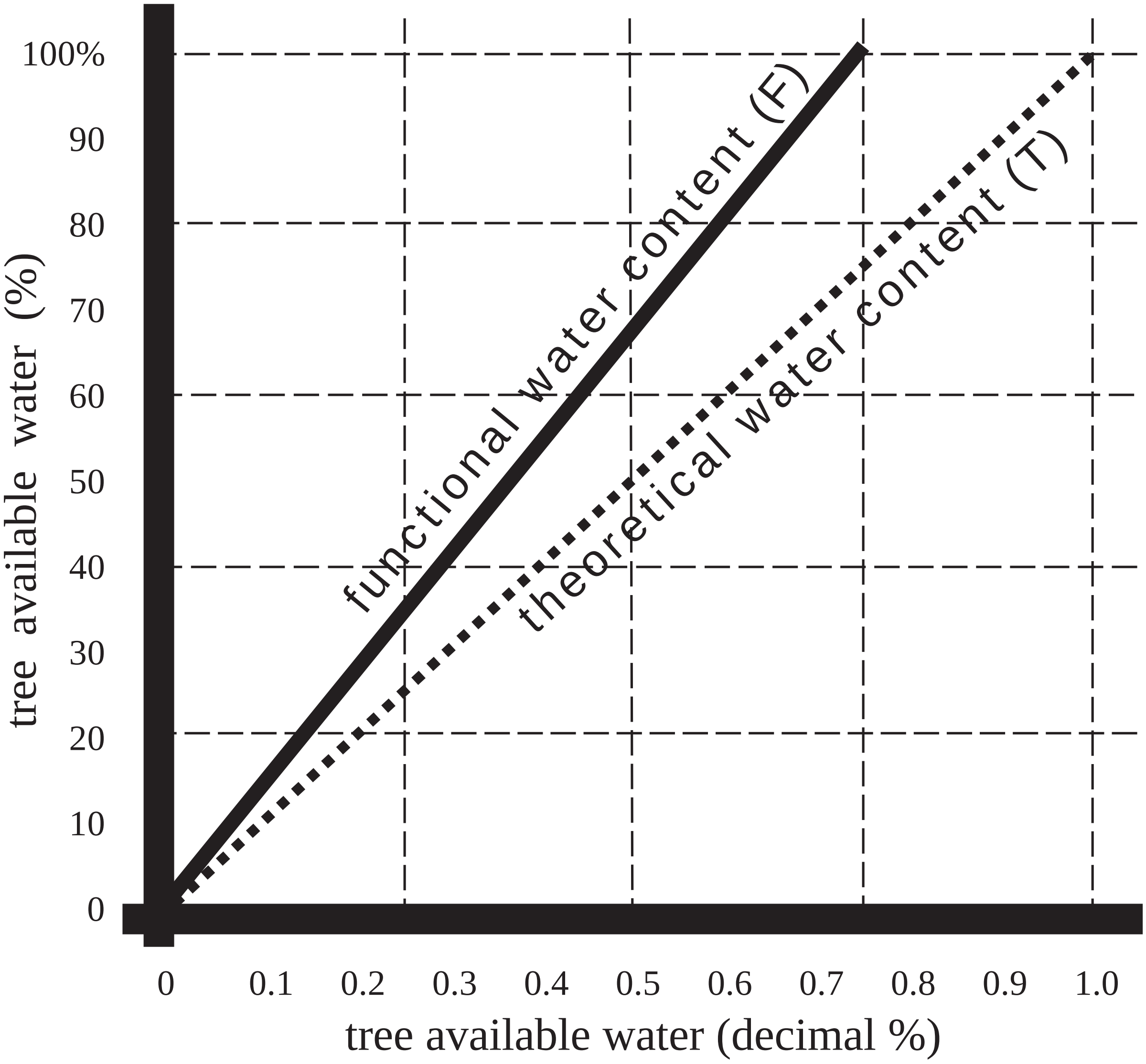


Figure 6: Estimate of functional tree available water in a soil compared with theoretical water availability. The functional water availability to a tree is less than the actual calculated amount of water in a soil. As soil dries, water is held progressively more tightly and the soil / root interface behaves as if there is less water in the soil. See Table 3. (after DeGaetano, 2000)

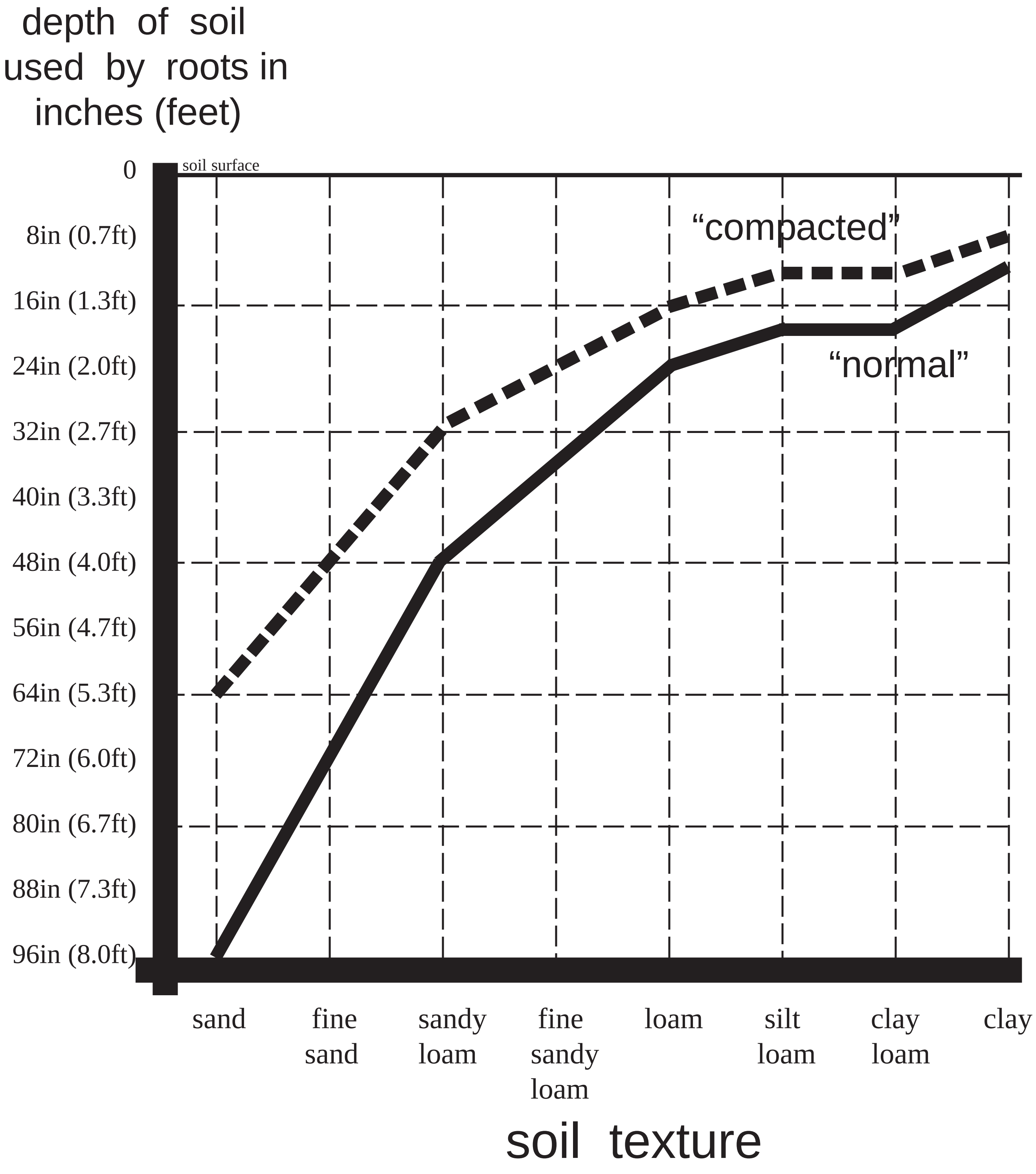


Figure 7: Effective soil depth used for defining biologically available resource depth in soils of various textures.

(solid line = normal; dotted line = moderate compaction)

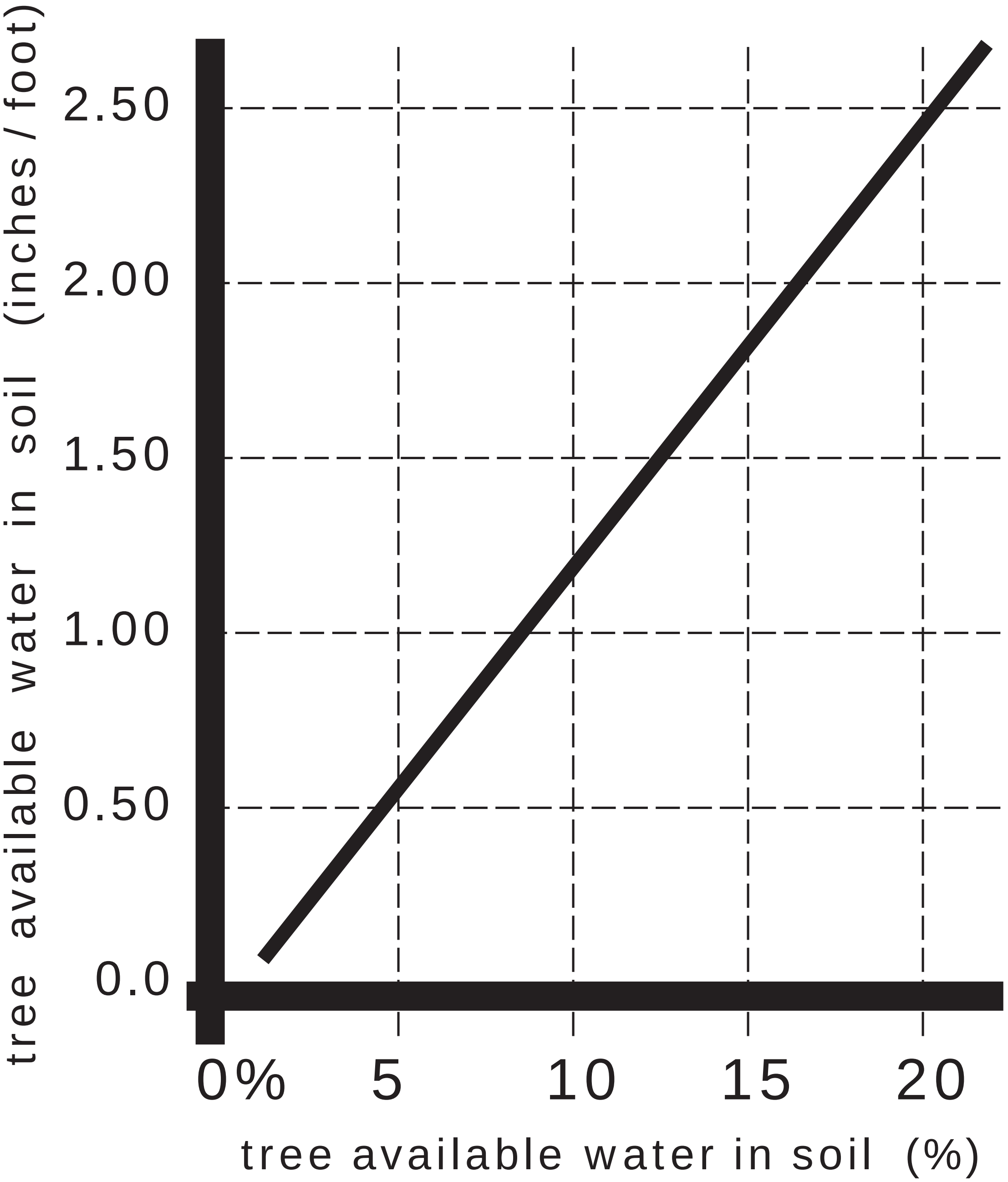


Figure 8: Estimated relationship between the percentage of tree available water in a soil and the number of inches of tree-available water per foot of soil.

Figure 9: The Coder "Days Until Dry" Containerized Soil Water Assessment Method.

Step #1: Determine crown volume.

$$\left[\begin{array}{c}\text{crown}\\ \text{diameter}\\ \text{(ft)}\end{array}\right]^{2} \times \begin{array}{c}\text{crown}\\ \text{height}\\ \text{(ft)}\end{array} \times \begin{array}{c}\text{shape}\\ \text{factor}\\ \text{(value)}\\ \text{[FIGURE 2]}\end{array} = \begin{array}{c}\text{crown}\\ \text{volume}\\ (\text{ft}^{3})\end{array}$$

Step #2: Determine effective crown surface area.

$$\left[\begin{array}{c}\text{crown}\\ \text{volume}\\ (\text{ft}^{3})\end{array} \Big/ \begin{array}{c}\text{crown}\\ \text{height}\\ \text{(ft)}\end{array}\right] \times \begin{array}{c}4\\ \text{(LAI)}\\ \text{leaf area index}\end{array} = \begin{array}{c}\text{effective crown}\\ \text{surface area } (\text{ft}^{2})\end{array}$$

Step #3: Determine daily tree water use.

$$\begin{array}{c}\text{effective crown}\\ \text{surface area } (\text{ft}^{2})\end{array} \times \begin{array}{c}\text{daily water}\\ \text{evaporation}\\ \text{(ft / day)}\\ \text{[FIGURE 3]}\end{array} \times \begin{array}{c}\text{pan}\\ \text{factor}\\ \text{(value)}\\ \text{[FIGURE 4]}\end{array} \times \begin{array}{c}\text{heat}\\ \text{load}\\ \text{(multiplier)}\\ \text{[FIGURE 5 \&}\\ \text{TABLE 2]}\end{array} =$$

$$\text{daily tree water use } (\text{ft}^{3}\text{ / day})$$

NOTE: 1 ft³ water = ~7.5 gallons

Step #4: Determine soil water volume.

$$\left[\begin{array}{c}\text{container}\\ \text{soil}\\ \text{volume}\\ (\text{ft}^{3})\end{array} \Big/ \begin{array}{c}\text{total}\\ \text{soil}\\ \text{water}\\ \text{(d\%)}\\ \text{[TABLE 4]}\end{array}\right] \times \left[1 - \begin{array}{c}\text{soil}\\ \text{water}\\ \text{limit}\\ \text{(d\%)}\\ \text{[TABLE 4]}\end{array}\right] = \begin{array}{c}\text{soil}\\ \text{water}\\ \text{volume}\\ (\text{ft}^{3})\end{array}$$

Step #5: Determine days until the soil resource area is dry.

$$\begin{array}{c}\text{soil}\\ \text{water}\\ \text{volume}\\ (\text{ft}^{3})\end{array} \Big/ \begin{array}{c}\text{daily tree}\\ \text{water use}\\ \text{from Step 3}\\ (\text{ft}^{3}\text{ / day})\end{array} = \begin{array}{c}\text{days}\\ \text{until}\\ \text{dry}\end{array}$$

Table 4: Total soil water and soil water limit (~ permanent wilting point) for various soil textures. Values given in decimal percents (d%).

soil texture	total soil water (d%)	soil water limit (d%)
clay	.39	.23
clay loam	.40	.20
silt loam	.39	.17
loam	.34	.14
sandy loam	.22	.09
sand	.10	.04