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Assessing Soil Water Resource Space: Tree Soil Water (TSWR) Method

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Trees require high quality resources in correct proportions to perform best. Water, and 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 called the Coder Tree Soil Water Resources assessment (TSWR). Specific calculations use measurable values to determine soil volumes required to support tree health and growth, which are based primarily upon water availability and tree needs. Calculate tree water needs!

Six Step Program

The Coder Tree Soil Water Resources assessment (TSWR) 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. 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 volume is made by picking a shape factor for tree crown from Figure 2. The shape factor multiplied by crown volume provides an estimate of crown volume for a tree in cubic feet. Figure 3.

To accurately determine tree crown volumes, size and shape of 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.

Note within 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.

Step #2 is used to determine effective crown surface area of a tree. 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 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. 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 4); an evaporative pan factor (Figure 5); and, a heat load multiplier (Figures 6 & 7). The result of this calculation is a daily water use for 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).

Step #4 is used to determine how much water a tree needs over time. Daily water use of a tree is multiplied by a value representing the average number of days in a growing season between normal rain events (which can be daily rain in some places with a 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 holding and supplying two weeks of tree water needs, 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 (Figure 8, as modified by Figure 9). 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 a required tree resource area on the ground surface centered upon a tree. Total soil volume needed for a tree in cubic feet value from Step #5 is divided by effective soil depth in feet for storing tree-useable water. Figure 10. 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 calculations above is with use of percentages for soil water values. Actual inches of water per foot of soil represent real volumes, while percentages are used in calculations. Figure 11 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.

Conclusions

A tree health care worker should understand water requirements of trees and know how much water is lost per day. In addition, understanding the ecological viable space (volume) available is critical to assuring water for tree health and growth.

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.

$$\begin{array}{c}\text{effective crown}\\ \text{surface area } (\text{ft}^{2})\end{array} \times \begin{array}{c}\text{daily water}\\ \text{evaporation}\\ \text{(ft / day)}\\ \text{[FIGURE 4]}\end{array} \times \begin{array}{c}\text{pan}\\ \text{factor}\\ \text{(value)}\\ \text{[FIGURE 5]}\end{array} \times \begin{array}{c}\text{heat}\\ \text{load}\\ \text{(multiplier)}\\ \text{[FIGURE 6 \& 7]}\end{array} =$$

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

NOTE: 1 ft^3 water = ~7.5 gallons

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

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

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

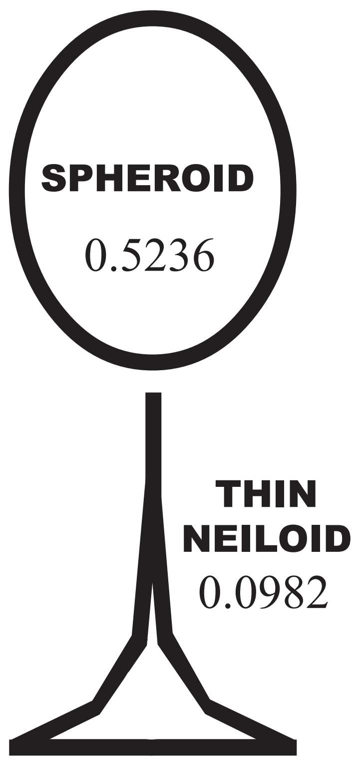
$$\begin{array}{c}\text{two week}\\ \text{tree water needs}\\ (\text{ft}^{3}\text{ of water for 14 days})\end{array} \Big/ \begin{array}{c}\text{tree available}\\ \text{water in soil}\\ \text{(in decimal percent)}\\ \text{[FIGURE 8]}\end{array} = \begin{array}{c}\text{total soil}\\ \text{volume needed}\\ (\text{ft}^{3})\end{array}$$

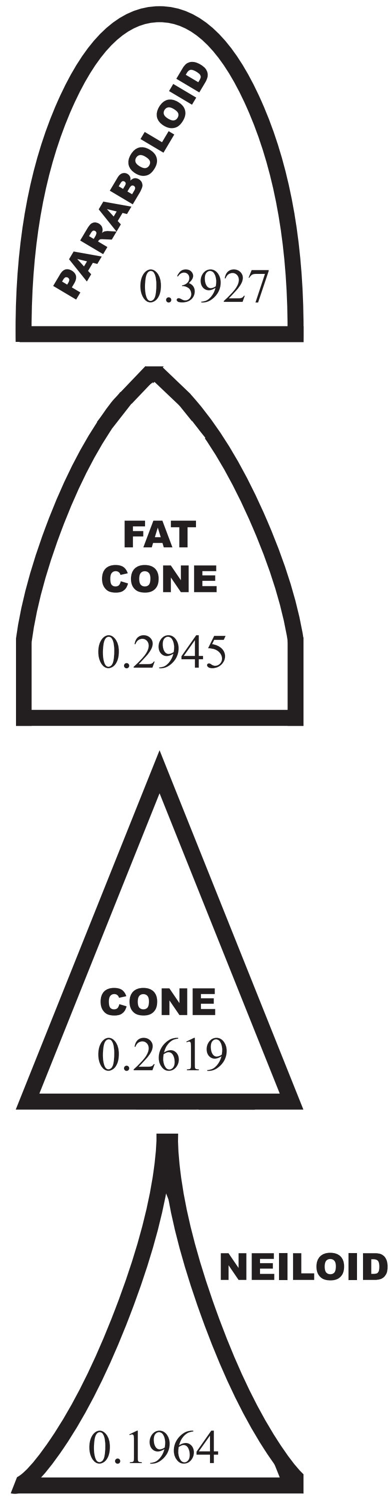
Step #6: Determine ground surface diameter of the tree resource area.

$$\sqrt{\left[\begin{array}{c}\text{total soil}\\ \text{volume needed}\\ (\text{ft}^{3})\end{array} \Big/ \begin{array}{c}\text{effective}\\ \text{soil depth}\\ \text{(ft)}\\ \text{[FIGURE 10]}\end{array}\right] \Big/ 0.785} = \begin{array}{c}\text{diameter of}\\ \text{resource area}\\ \text{(ft)}\end{array}$$

Figure 1: Coder Tree Soil Water Resources Assessment method (TSWR).

Figure 2:
Idealized side view of different tree crown shapes. All shapes have a circular cross-section or are round when viewed from above. Shape name and crown volume multiplier number are provided.





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

Figure 3: 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. Idealized crown shape names are visualized based upon solid geometric figures.

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.

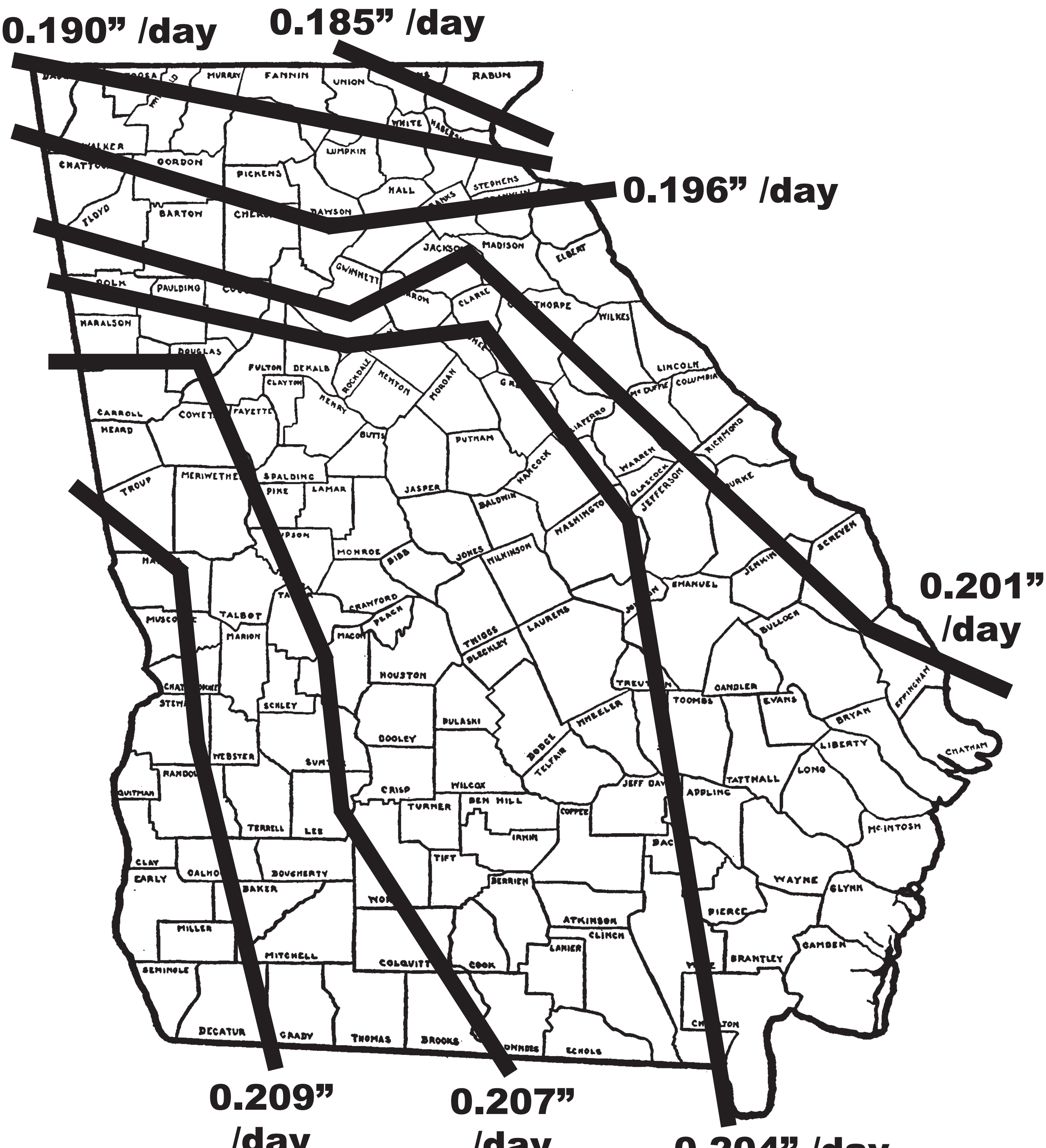


Figure 4: Example daily pan evaporation in Georgia.
This map shows historic average daily pan evaporation during the growing season (May through October) in inches per day.
Divide by 12 to calculate feet per day.

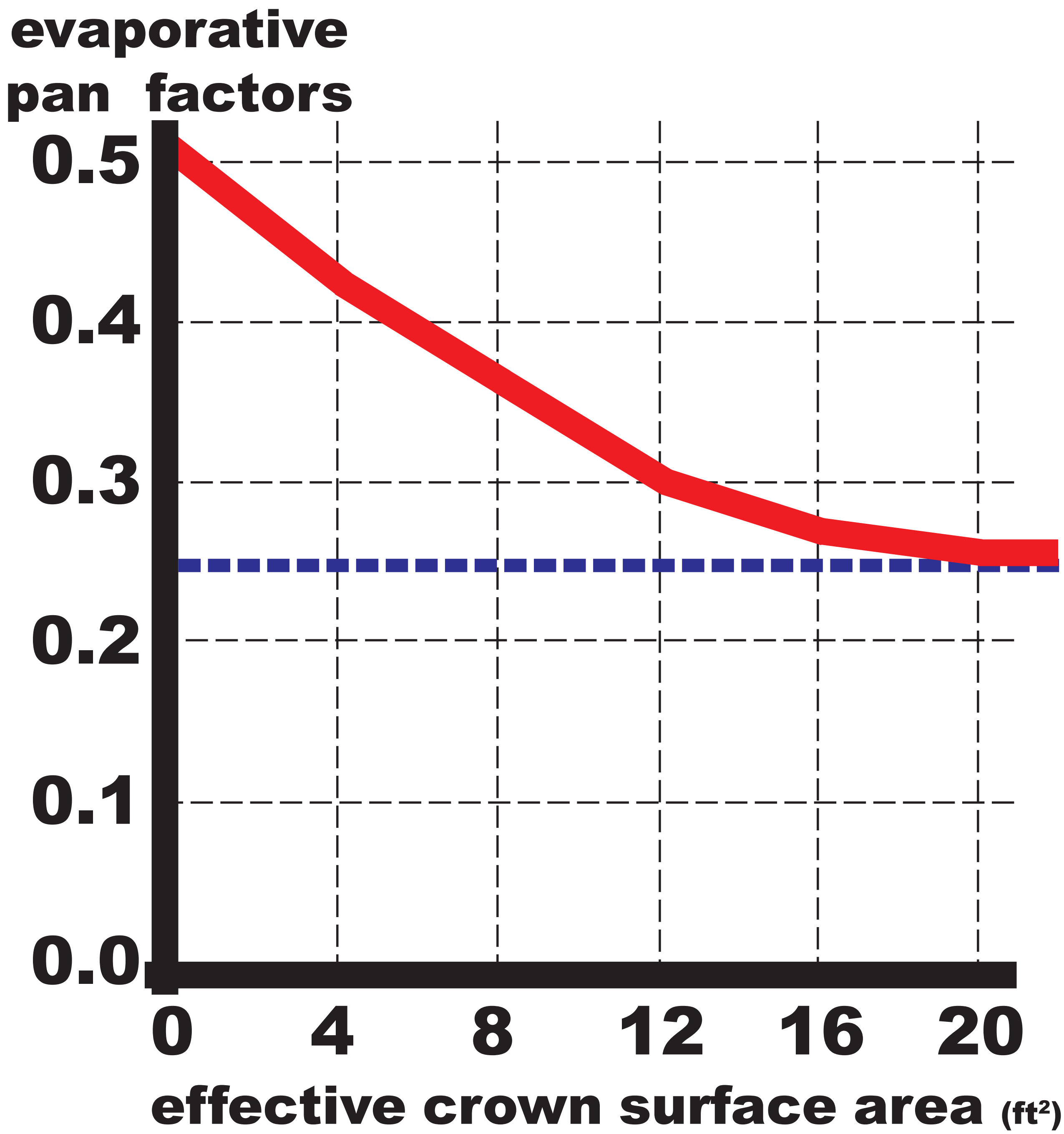


Figure 5: Ratio of tree transpiration to pan evaporation (pan factor or pan coefficient). Pan factors are not less than 0.25 for trees with larger than 20 ft^2 of effective crown surface area. (after Lindsey & Bassuk, 1992)

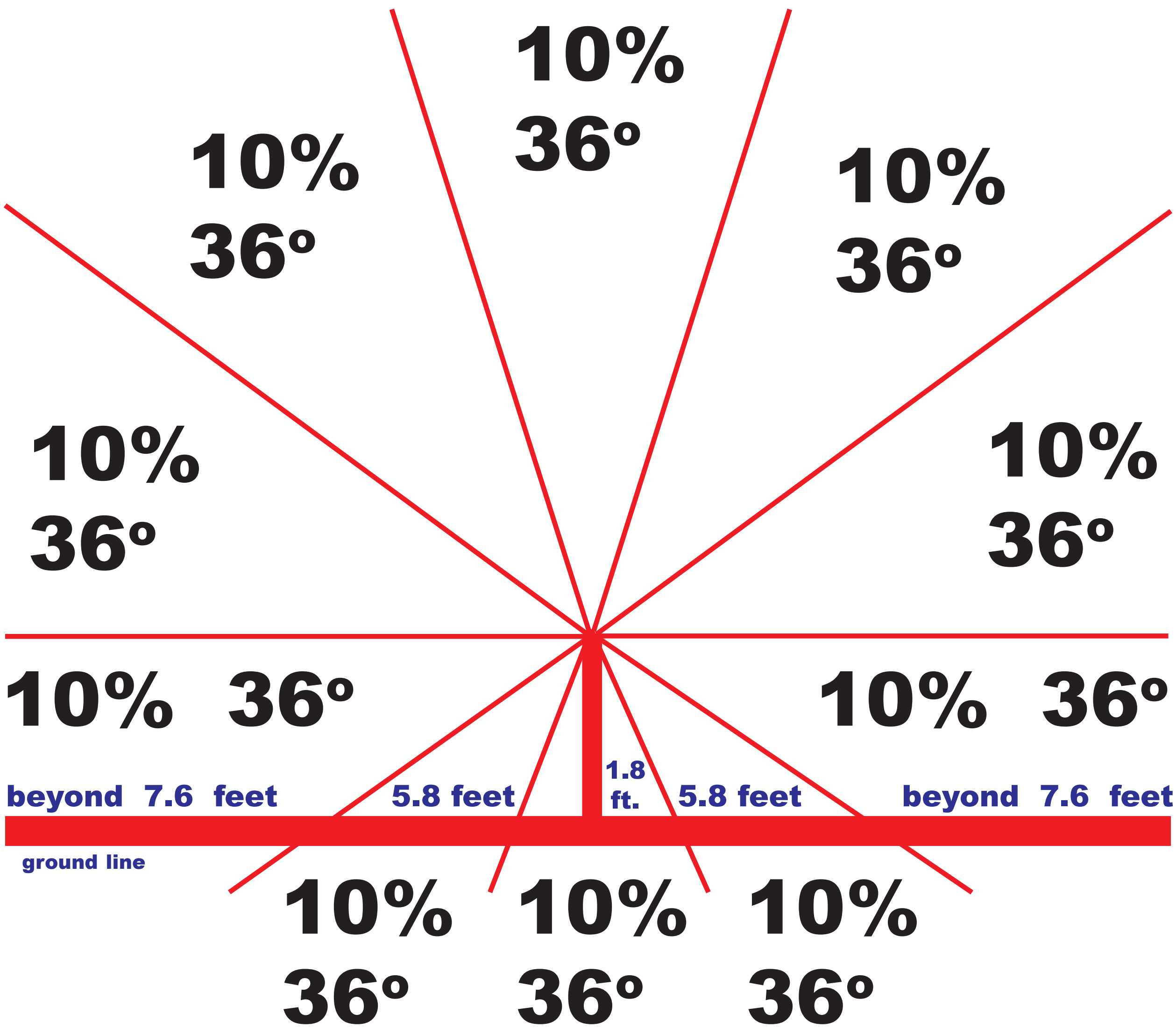


Figure 6: Diagram showing how heat loading can be estimated on a site using the Coder Heat Load Viewfactor containing ten equal (36°) observation angles.

viewfactor percent of non-evaporative, dense surfaces facing a site	heat load multiplier
100%	3.0
90%	2.7
80%	2.4
70%	2.1
60%	1.9
50%	1.7
40%	1.5
30%	1.3
20%	1.2
10%	1.1
0%	1.0

Figure 7: Coder Heat Load Viewfactor multiplier values for various non-evaporative, dense surface viewfactors (nearest 10% class) on a site. Use heat load multipliers to increase water use values for trees.

soil texture	tree available water (normal) T	tree available water (normal) (F)	tree available water (compacted) T	tree available water (compacted) (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 8: 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.
(after Cassel, 1983; Kays & Patterson, 1992; Craul, 1992 & 1999)

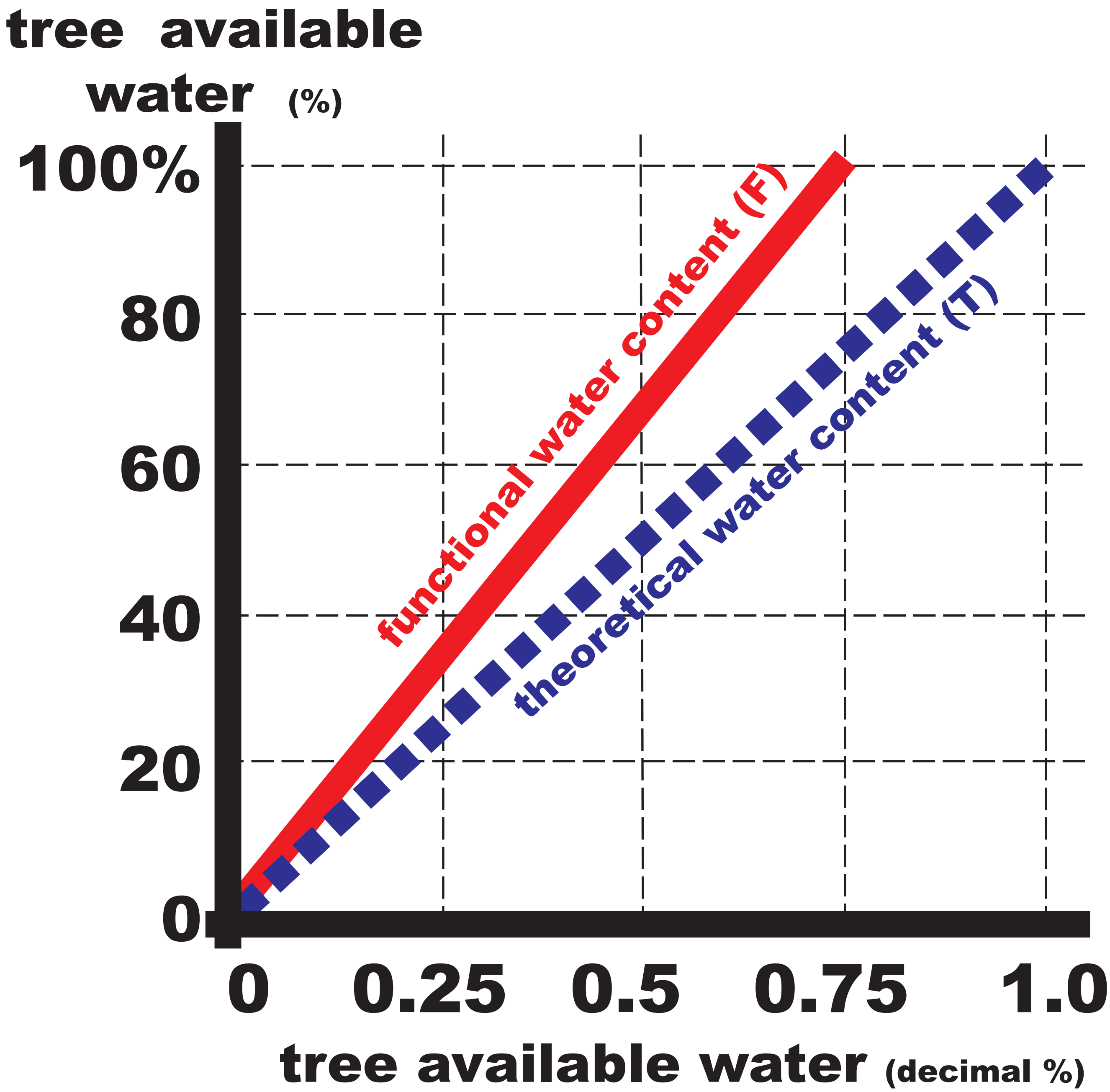


Figure 9: Estimate of functional tree available water in a soil compared with theoretical water availability. Functional water availability to a tree is less than the actual calculated amount of water in a soil. As soil dries, water is held progressively more tightly and soil / root interface behaves as if there is less water in soil. (after DeGaetano, 2000)

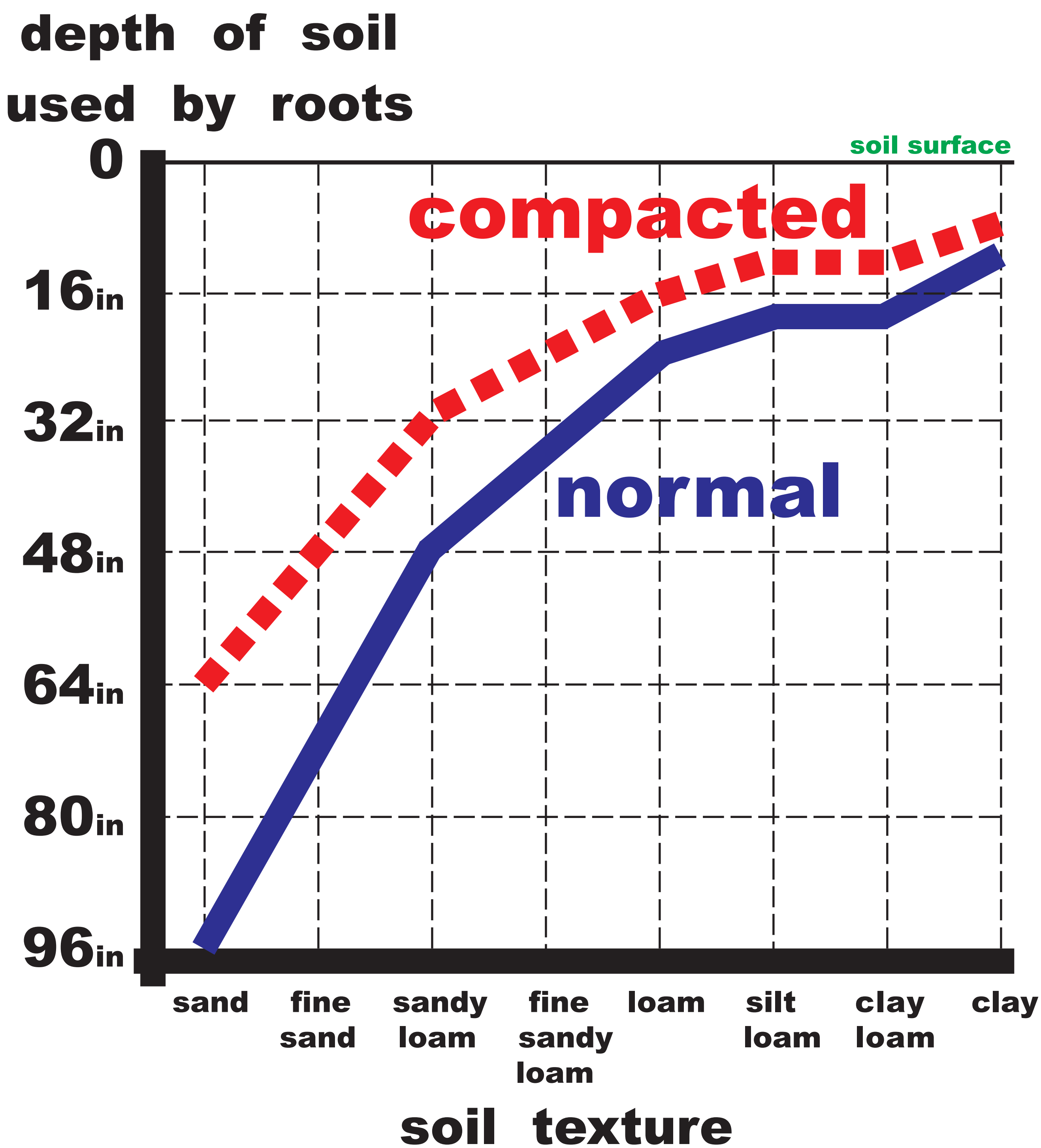


Figure 10: Effective soil depth used for defining biologically available resource depth in soils of various textures.
(solid line = normal; dotted line = moderate compaction)

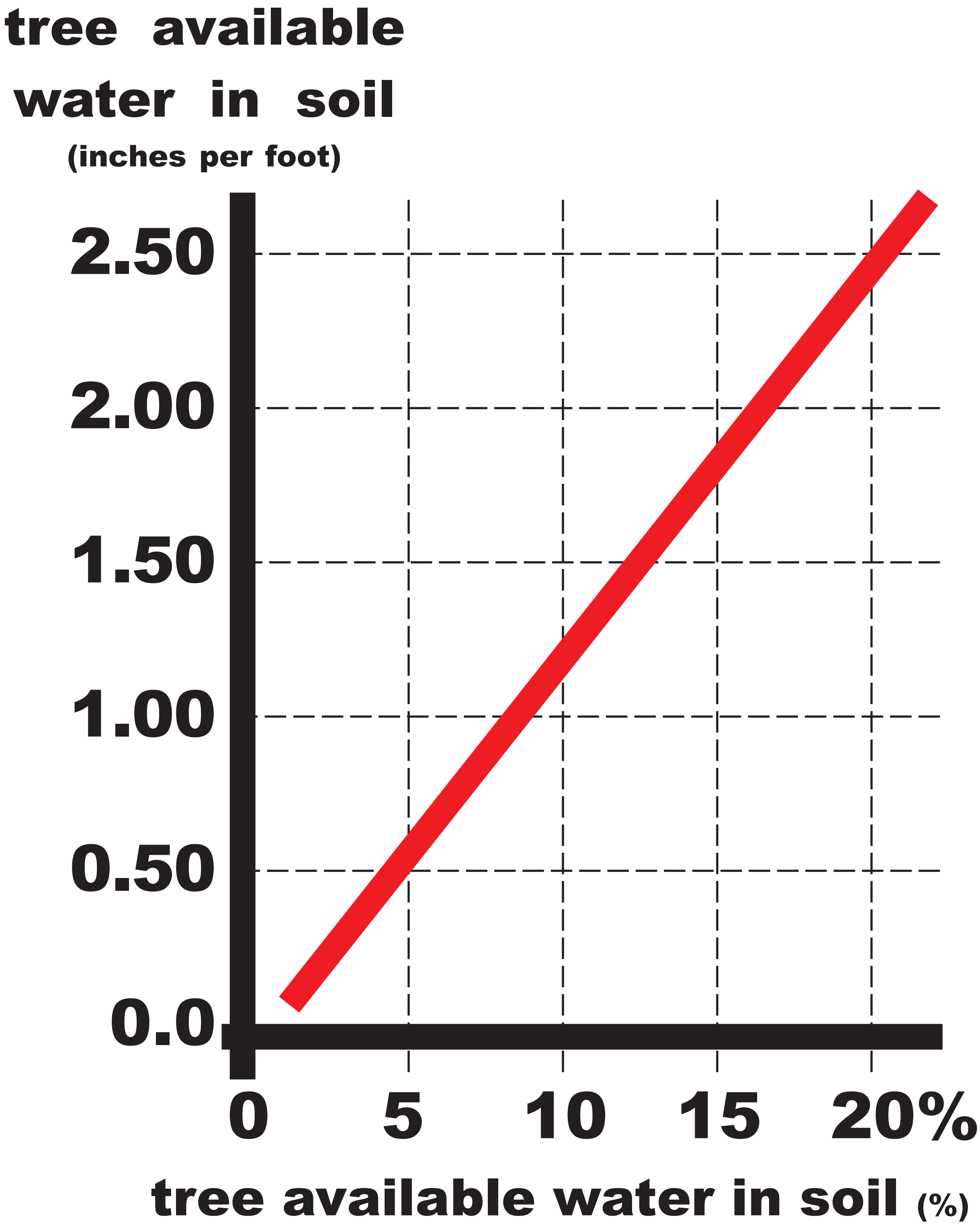


Figure 11: Estimated relationship between percentage of tree available water in soil and number of inches of tree-available water per foot of soil.

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