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Tree Water Loss

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Trees have a vascular system with great water transport capacity. The transport system can deliver water rapidly and preferentially to those parts of the canopy which are most actively transpiring. The transport system is also resistant to environmental stress, especially temperature extremes and pest attack.

Vertical water movement is restricted to the outermost one or two annual increments (rings) in ring-porous trees like oaks. The pattern of water movement is more complex in conifers and diffuse-porous trees since a larger number of annual increments are usually involved (3-15 annual increments). Horizontal water movement, or storage, occurs throughout sapwood increments.

Morning Trees

Water is "stored" in the stem. Water content of heartwood is usually much lower than sapwood. The heavier (more dense) the wood, the less water present in the stem, per unit volume. Although considerable water is passively stored in tree trunks, the volume is small in comparison to seasonal loss by transpiration. Figure 1.

As transpiration increases in morning, root absorption initiated by the current day's water loss does not begin to increase until later due to stem water availability. Leaf water loss must produce sufficient tension in xylem water columns to overcome resistance to water flow through the xylem and from soil into roots. As water is lost to evapotranspiration from leaf cells, a water deficit can be developed severe enough to cause wilting of leaves.

Night Trees

The lag period between leaves transpiring water and strong root absorption of water shows there are significant resistances to water movement in soil, roots, stems, branches and leaves. In evening, as temperatures decrease and stomates close, transpiration is rapidly reduced. Water absorption by roots continue until the water potential in a tree comes into near equilibrium with soil. This absorption process may require all night. As soil dries, there is less water recovery on succeeding nights until permanent wilting occurs. Figure 2. A prolonged, severe water deficit will cause tree death.

Complex Roadmap

The water supply pathway of a tree is a complex series of resistances to water movement, including a stored water component. The path of water flow between roots and foliage is not a simple single path. At each junction (i.e., branch to stem, branch to branch, or leaf to branch) there is a reduction in water conduction (increased resistance).

Because of the greater resistance to water flow associated with tree part junctions, a priority system for water and associated essential element distribution is established by growth regulator interactions between shoot and root. Figure 3 shows an idealized diagram of relative values for water conduction (inverse of resistance) within a tree.

Priorities

The "sun" leaves at the top of a tree canopy are exposed to greater water and thermal stress than leaves lower down, or shaded within the canopy. Because of constrictions in xylem from multiple order lateral branches and twigs, pathway resistance for supplying water to "sun" leaves at the top of the canopy is less than that supplying lower and more shaded leaves on many side twigs.

With increasing water stress, sun leaves which require the most water, are furthest from the point of supply in soil and subject to a greater impact by gravity pulling down on the water columns. An early drought priority which favors the most productive leaves, eventually shifts to favoring the most survivable leaves as drought conditions worsen.

Blown Away

Another drying force acting on a tree is wind. Wind blowing past a tree crown can desiccate a tree, evaporating water from lenticels, buds, fruits, and leaves. Wind decreases the protective blanket of still air around a leaf (boundary layer). With less boundary layer, the drying effect of air on a leaf is greater. Wind movement of leaves stimulates stomate closure, reducing transpiration and food production. Wind can have a cooling effect on leaves lessening transpiration. Unfortunately, wind can also be a source for advected heat, like air coming from over a hot parking lot to a site, greatly increasing transpiration. Figure 4 shows how a small wind velocity increase can quickly increase transpiration.

The site upon which a tree thrives can conspire to constrain water use in many ways. Figure 5 provides general estimates of water potential differences for three site conditions with increasing height in trees. The conditions examined were all in middle of the growing season and included a calm cloudy day, a calm sunny day, and a windy sunny day. Remember in order for water to move up a tree, water potential at a higher point in the tree must be less (more negative). Sun and wind generate larger water deficits.

Water Content

Because of differences in shading and concentration of cell solutions, various locations of a tree crown lose water at different rates. At any one time, different parts of a tree will have different water tensions (deficits). Since water moves from highest concentration (lowest tension) to lowest concentration (greatest tension), tree parts which develop the lowest water concentrations and greatest tensions, like top-most terminal young shoots, obtain water at the expense of older tissue. This type of water stress hastens leaf senescence.

Water concentrations vary widely in different parts of a tree. Under increasing water stress, the upper, more exposed parts of tree crowns are subjected to greater water stress than lower crown parts. Twig and branch death around the outside of a tree crown is a common result of water stress. On the other hand, lower, shaded branches are stressed because they can not compete to pull enough water. These shaded branches produce less food and growth regulators than upper, better exposed leaves.

Speed

Water movement through a tree is controlled by the tug-of-war between water availability and water movement in soil versus water loss from leaves. The average seasonal rate of water movement in selected trees is given in Figure 6. For example, water movement in feet per hour in a ring porous tree like a red oak is 92 ft/hr, in a diffuse porous tree like a basswood is 11 ft/hr, and for a conifer like pine is 6 ft/hr. Note there are some trees which can not rehydrate over a short summer night due to internal resistances to water movement.

Roots

A major portion of an active tree root system is concentrated in the top few moist inches of soil, just below areas rich in organic matter and associated with microorganisms. These roots must absorb water. This ephemeral root system (absorbing roots) take up a majority of water in a tree. Annual roots are not the woody roots seen when a tree is dug. Large woody roots have periderm and any crack or damage is quickly sealed-off so little water flows through these roots.

It is young roots, easily damaged by drought, that are major absorbers of water and essential elements in a tree. These roots are generated, serve, and then are sealed off between 5 and 25 times during the year, depending upon species. A tree may have a single set of leaves per year, but many sets of absorbing roots. Figure 7 demonstrates how critical young roots are for overall tree health. More roots mean more absorbed water, more transpiration, and more food made. More food means more growth and more roots.

Soil Water

As soil dries, the availability of water begins to be limited by decreasing water potentials and hydraulic conductivity. Figure 8. Dimensional shrinkage of both soil and roots occur as soils dry. Soil aeration, soil temperature, and concentration and composition of the soil solution also limit absorption of water by trees. As soils dry, resistance to water flow through soil increases rapidly. The loss of water cross-sectional area through a soil plummets as films of soil water decrease in thickness and discontinuities develop around soil particles. The presence of mycorrhizae (fungal modified tree roots) can act to moderate early drought stress in trees.

Conclusions

Water is the most critical of site resources trees must gather and control. Water movement and control in trees can be summarized as a physical process of evaporation – controlled by temperature and humidity – being utilized to move essential materials from root to shoot. Excessive water loss can prevent tree food production and damage tree life processes.

Citation:

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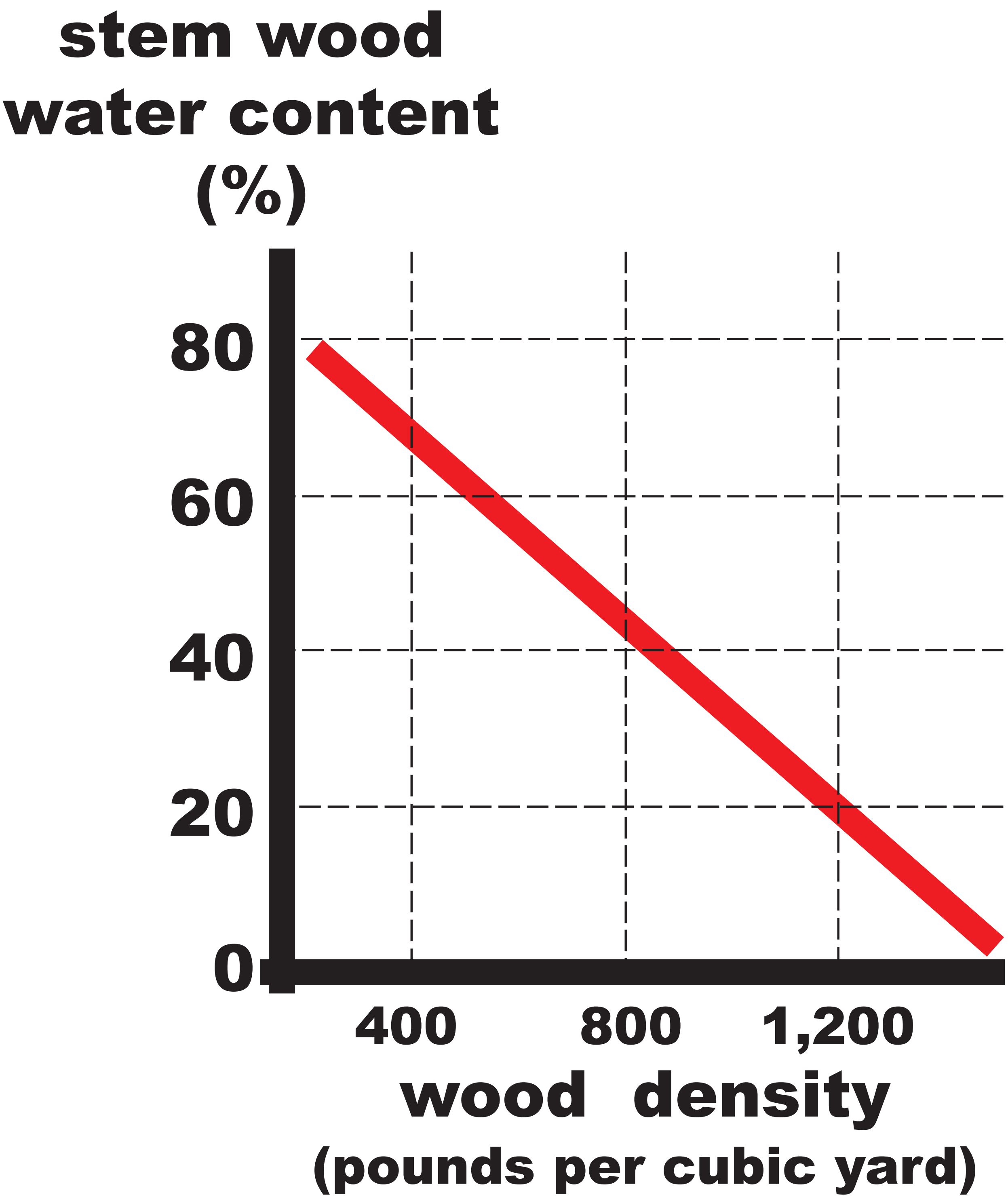

Figure 1: Water available in tree stems with various densities of wood. (after Borchert, 1994)

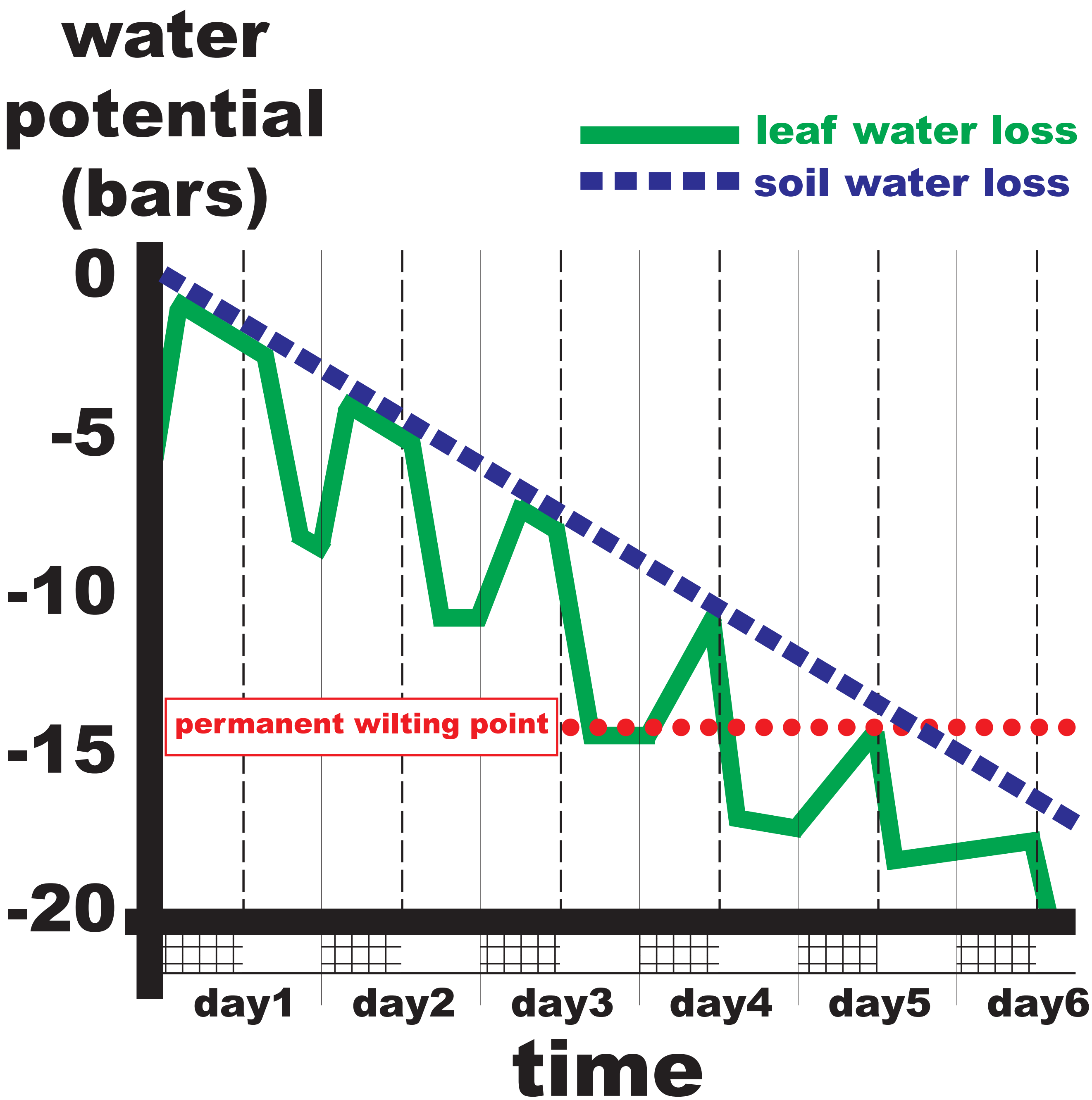

Figure 2: Diagram of daily water potential changes (with no addition of water) as tree leaves and soil dry.
(derived from Slatyer, 1967)

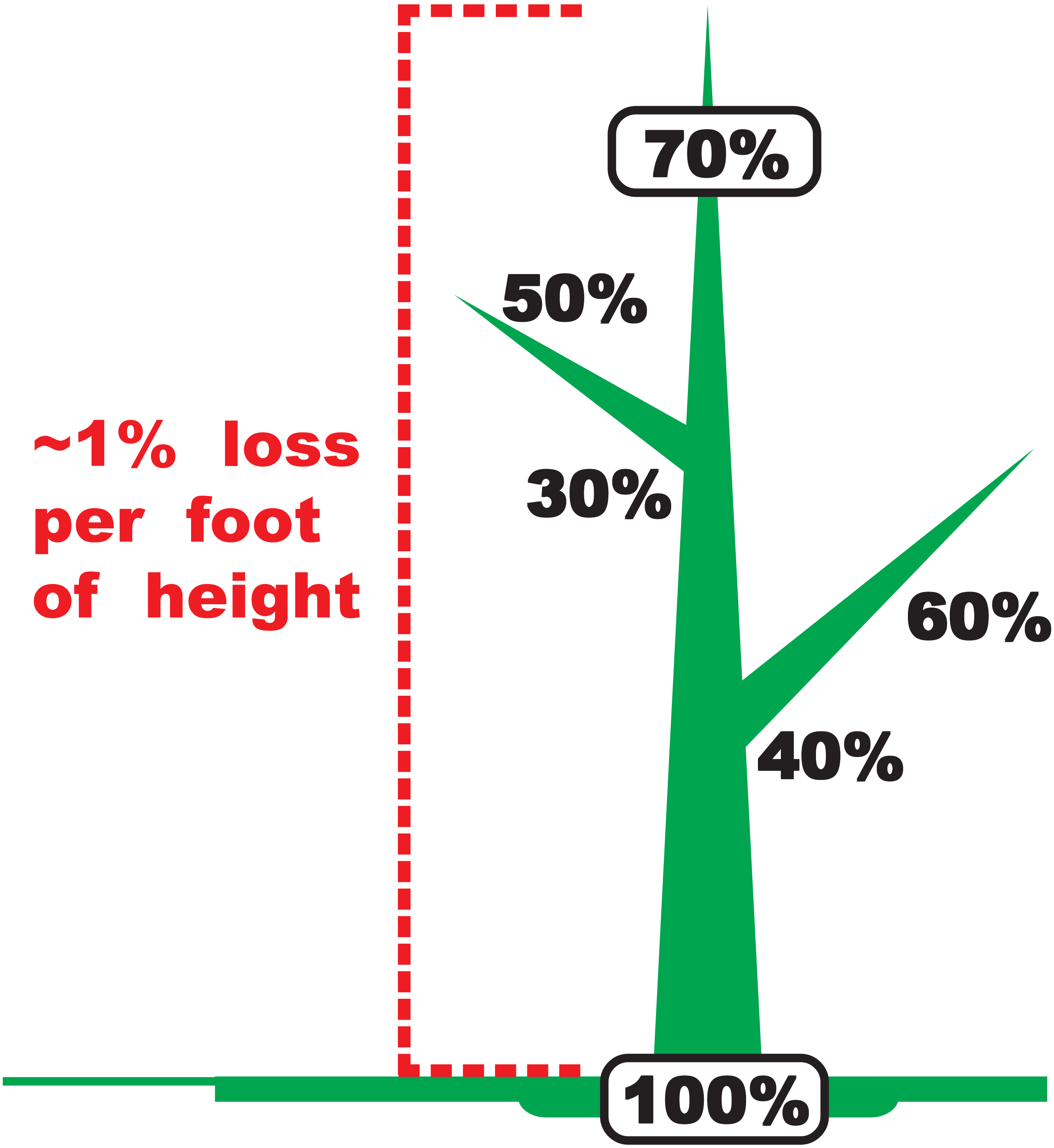

Figure 3: An idealized diagram of relative values for water conduction (inverse of resistance) within a tree. Branch & twig connections (nodes) greatly limit water movement. (derived from Zimmermann, 1978)

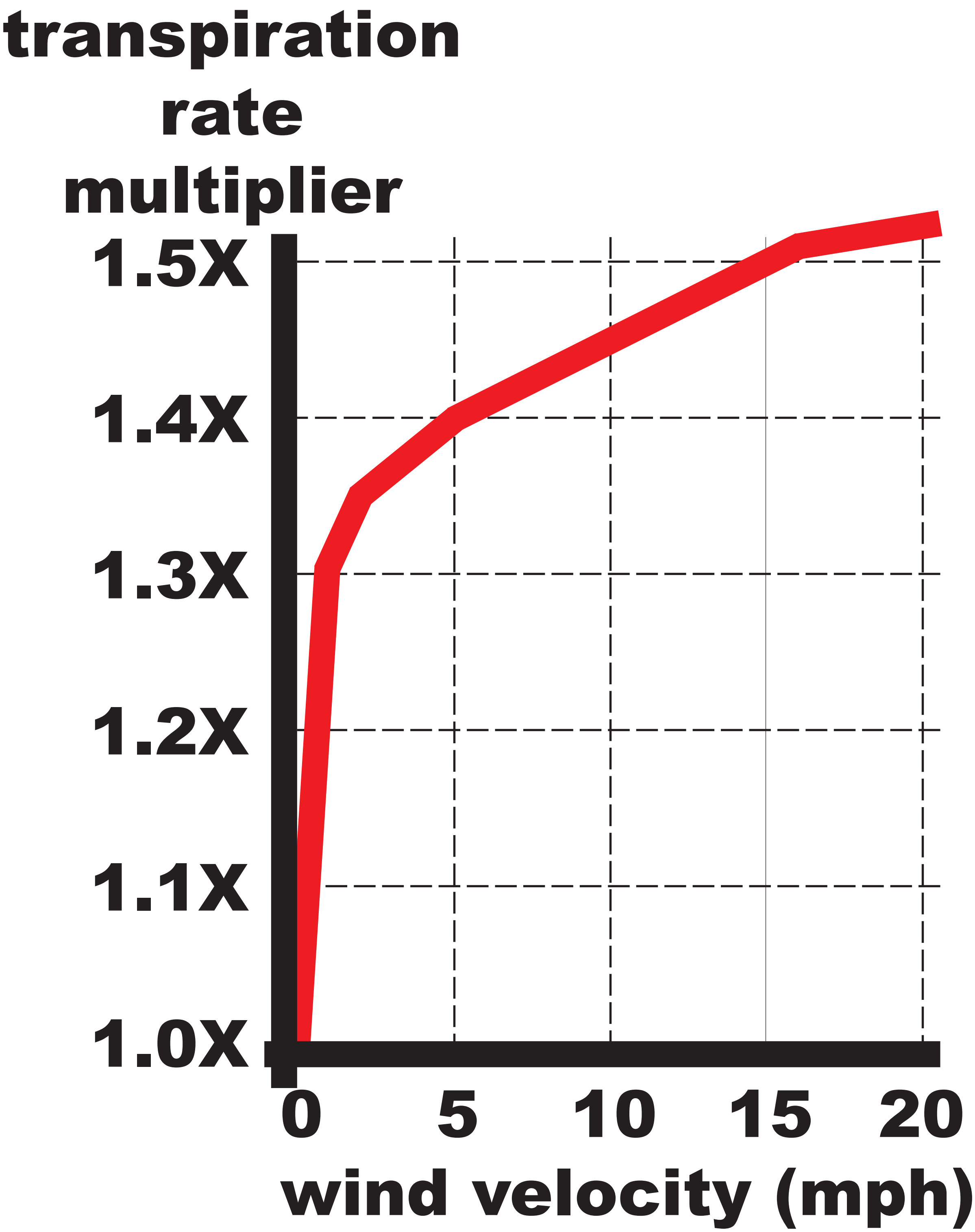

Figure 4: Additional transpiration rate of a tree under various wind speeds in miles per hour compared with transpiration rates under calm conditions. (derived from Kramer & Kozlowski, 1979)

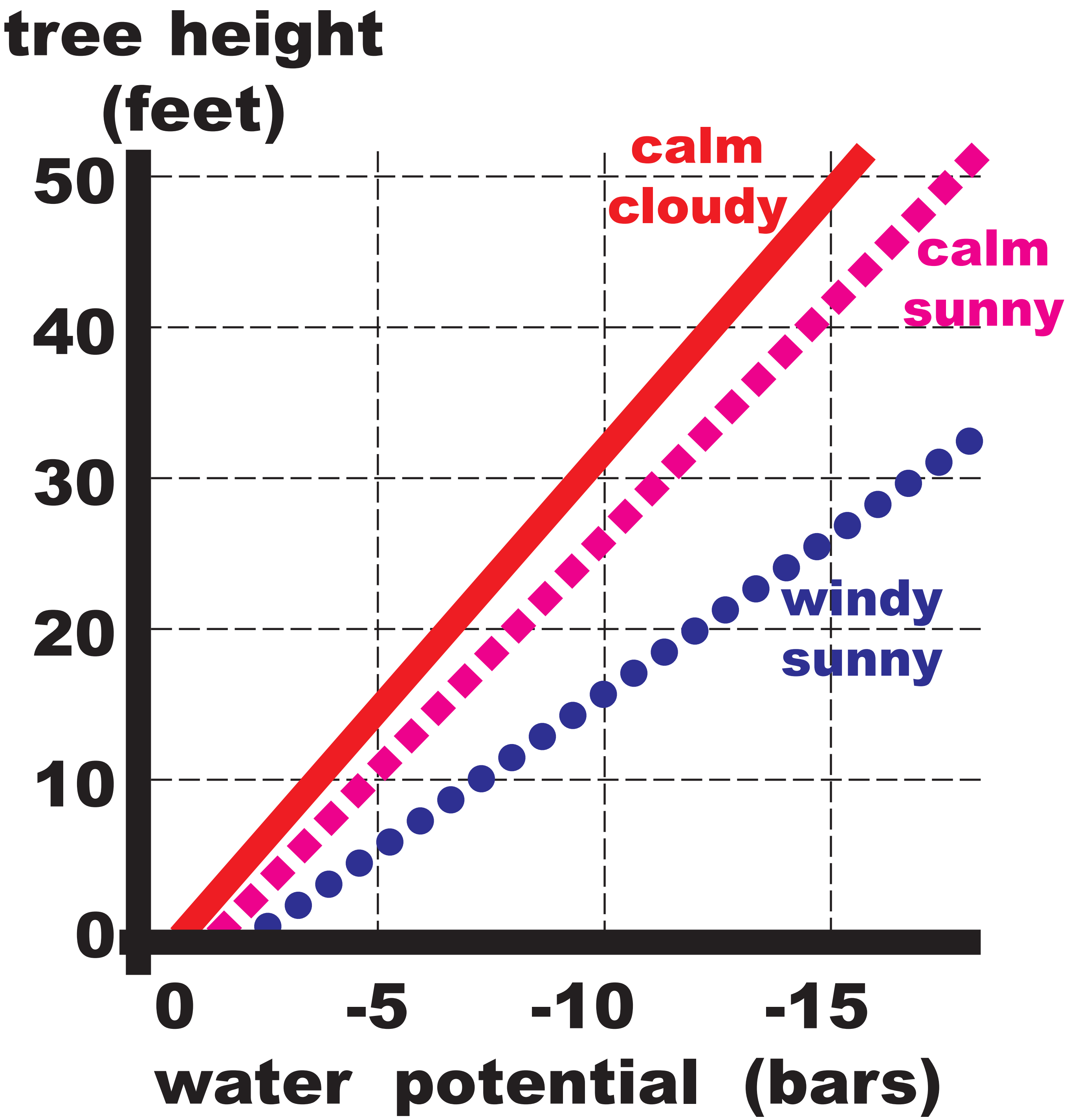

Figure 5: Mid-season water potential values at various tree heights under three site conditions: calm wind and cloudy; calm wind and sunny; and, windy and sunny. (derived from Hellkvist et. al. 1974)

tree species	water velocity (ft/hr)
Ring porous trees	
European red oak	144
black locust	95
red oak	92
ash	85
chestnut	79
tree-of-heaven	72
hickory	62
sumac	53
elm	20
Diffuse porous trees	
balsam poplar	21
black walnut	14
butternut	13
basswood	11
willow	10
yellow poplar	9
maple	8
magnolia	7
alder	7
birch	5
hornbeam	4
beech	4
buckeye	3
Gymnosperms (non-porous) trees	
larch	7
pine	6
spruce	4
hemlock	3

Figure 6: Rough estimate of water velocity through stem vascular tissue for various genus and species of trees in feet per hour, categorized by xylem porosity.

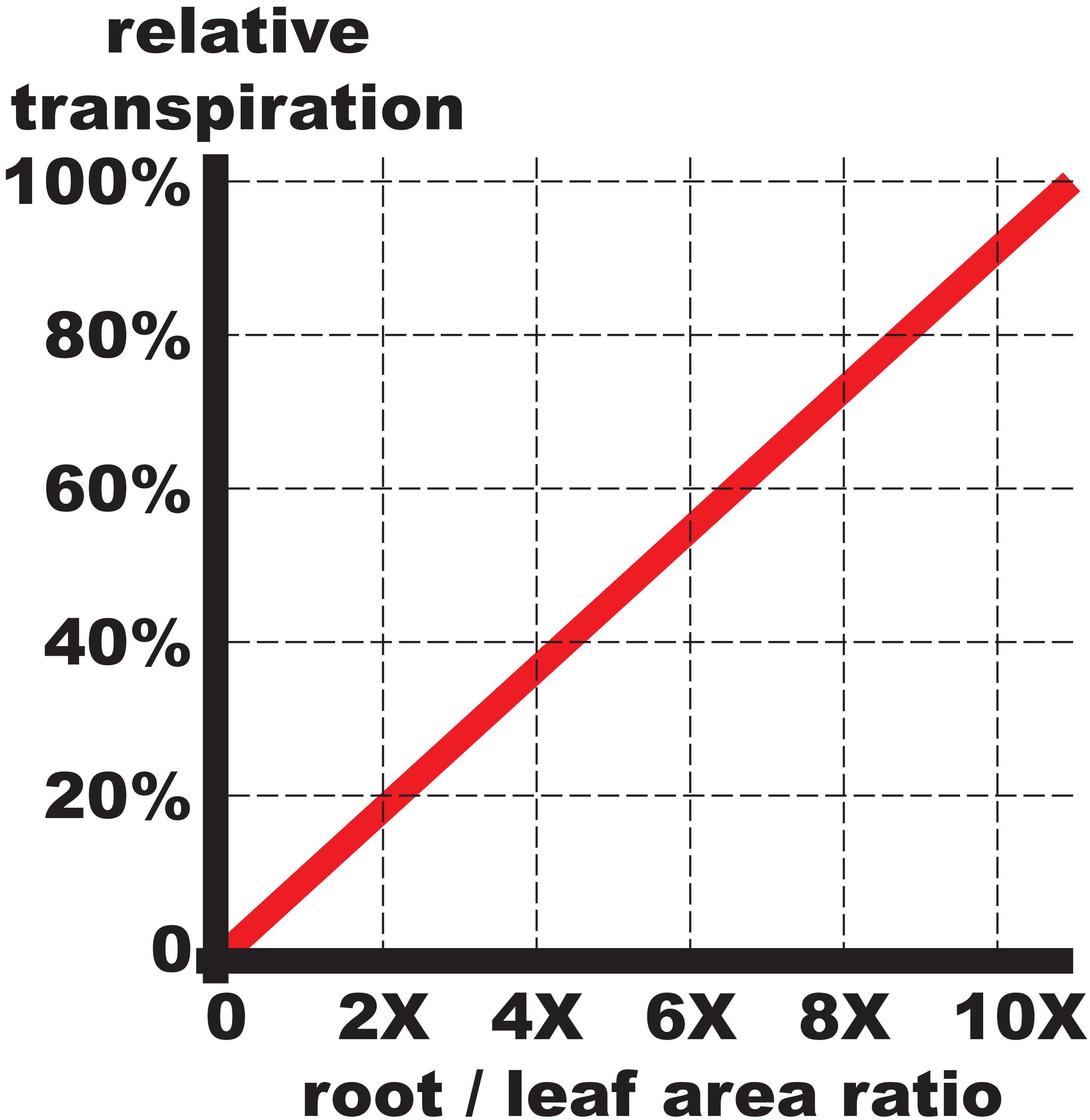

Figure 7: Relative amount of tree transpiration compared with root / leaf area ratio of a tree. Root values were based upon a dry weight basis and leaf values were based upon a square foot basis.
X = leaf area; 2X = two times more root mass than leaf area.
(derived from Parker, 1949)

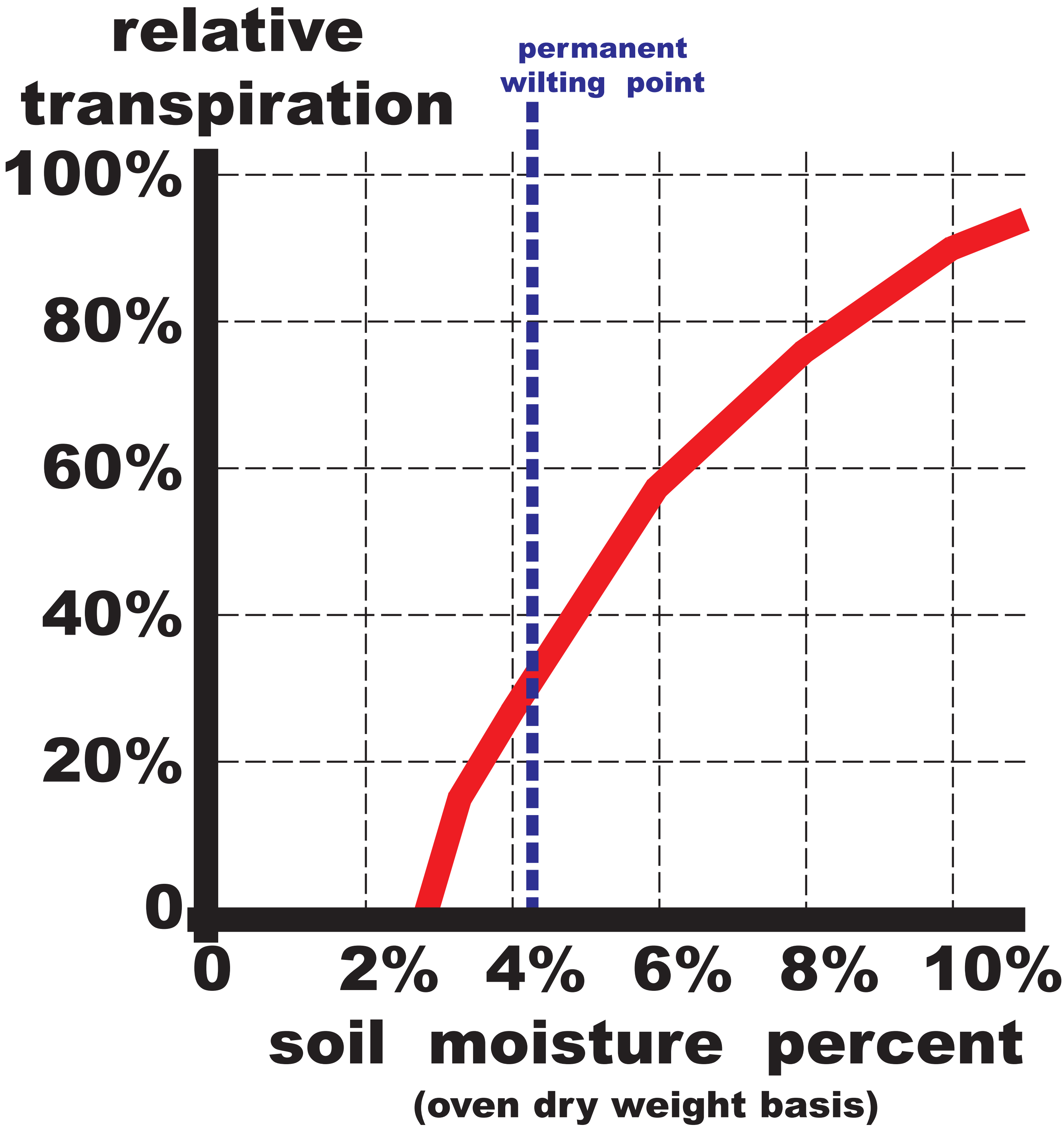

Figure 8: Relative amount of tree transpiration compared with various soil moisture percents based upon oven dry weight basis. (derived from Bourdeau, 1954)