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Trees are always undergoing dehydration-hydration (drying / wetting) cycles due to the rate of absorption of soil water by roots lags behind the rate of transpiration from tree crowns. Trees dehydrate during the day, particularly on hot, sunny days. Trees continue to refill with water day and night. Trees obtain almost all of their water from soil. Under some conditions other sources of atmospheric moisture in the form of dew or fog may prevent or postpone dehydration of tree crowns.

The rate of absorption of water by roots can be impeded by: A) low soil moisture content; B) small or slow-growing root system; C) poor soil aeration; D) low soil temperature; E) poor soil-tree root contact; F) high concentration of materials in the soil solution like salts; and, G) combinations and/or interactions of A-F above.

Soil Waters

Water within soil consists of: (Figure 1)

1. **Gravitational water** = occupies large soil pores and drains away under the influence of gravity. It is available to trees but usually drains away too fast to be important.
2. **Capillary water** = the most important source of water for trees, is held in films around soil particles and in small pores between soil particles.
3. **Hygroscopic water** = water still remaining in air-dry soils which is held so tightly by soil particles it moves only as vapor and is generally unavailable to trees.
4. **Water vapor** = water in the soil atmosphere as a gas which is not used directly by trees.

After a rain, the rate of water drainage through a soil decreases rapidly with time until it stops. When water drainage out of a saturated soil stops, soil is traditionally considered to be at "field capacity." Field capacity is considered the upper limit of tree-usable soil water. The lower limit of tree-usable soil water is traditionally considered to be the "permanent wilting point." The wilting point is a soil water content below which trees cannot extract enough water for survival. Note tree foliage can wilt for a number of internal and external reasons before soil reaches the permanent wilting point.

Soil Water

Tree survival and continued success are dependent upon soil pore spaces holding a good mix of air and water. Appreciating how much water a soil can hold, and providing an adequate supply for a tree, is essential for good tree health care. Trees pull water from soil pore spaces. Soil texture is one of many items impacting pore space and tree-usable water.

Soil texture, the mix of different basic particle sizes in a soil, can be summarized by the percent clay, sand and silt present. Figure 2 provides a description of soil textures by general name. Note only clay and sand are shown here because silt would be the remainder. Figure 3 provides specific soil texture names and compositions by showing each particle size classification. Note clay contents greatly impact soil water-holding pore space.

In each soil, texture helps determine how many water holding pores (micro-pores) are present. Figure 4 provides the percent of water holding pores, at field capacity in uncompacted soils, are present compared with total soil pore space. Some soil pore spaces hold water more tightly than trees can exert force to remove the water. Figure 5 shows the amount of unavailable water held by soils with various textures. This water can not be pulled from soil and into a tree through transpiration.

Available Water

Figure 6 shows the total amount of water which could be held against gravity in a soil (saturation not flooded). This concentration of soil water is the most water a soil can hold without any water draining away. The soil is said to be at field capacity. Figure 7 shows the total amount of tree-available water present in soils of various textures. Subtracting Figure 5 from Figure 6 produces Figure 7. In Figure 7, the top line on the graph is the total water in a soil. The bottom line on the graph is the amount of water unavailable to a tree due to soil surfaces and pore spaces holding water too tightly, and to trees not being able to generate enough force to remove water from soil.

Drops To Drink

For example, a tree's roots occupy an area of loam soil three feet deep. Use Figure 5 to determine the total unavailable water in loam soil which is given as 1 inch of tree unavailable water per foot of soil depth, or 3 inches of water are unavailable for tree use in the whole three feet deep loam soil. Use Figure 6 to determine the total amount of water per foot held in a loam soil which is 3.1 inches of water, or 9.3 inches of total water in a loam soil three feet deep. The shaded area of Figure 7 shows the inches of water available for tree use per foot of soil.

In this example, Figure 7 = Figure 6 minus Figure 5, providing the answer of 2.1 inches of tree-available water per foot of soil, or 6.3 inches of tree-available water in loam soil three feet deep (2.1 inches water X 3 feet soil depth). If evapotranspiration loss from a site is estimated to be 1/3 inch of water per day, 18.9 days (~19 days) of tree-available water would be present in a loam soil three feet deep.

Movement

When a soil is wet, the rate of water movement and absorption by tree roots can be great, if soil is well oxygenated. Resistance of wet soil to water movement is low because only small forces are necessary to pull water through water-filled pores. As soil dries, resistance to water movement increases in soil and in a tree.

Water movement into a tree becomes a problem because soil-root contact is lost from root shrinkage while resistance to water movement increases due to root suberization and compartmentalization. Pathways for water movement in soil become thin and convoluted, with many water connections narrow and broken. Soil hydraulic conductivity (inverse of resistance) falls as the amount of fine texture particles in soil increase. Figure 8.

Water in the portion of soil not permeated by roots is largely unavailable for absorption. Capillary movement of soil water from more wet to dry regions in soil with a moisture content below field capacity is slow. Soil immediately surrounding tree absorbing roots dries rapidly. Continuous root extension into zones of moist soil is critical for sufficient absorption of water to replace water lost by transpiration, if no precipitation or irrigation occurs.

Elemental

A small portion of tree-available essential elements are present as ions dissolved in the soil water solution. Most of cations are near surfaces of clay and humus / organic material particles because of electronic charge attraction. Anions like nitrate, bicarbonate, phosphate, sulfate, and molybdate, can be found near organic materials having anion exchange sites. Phosphorus and potassium do not move far in a soil, requiring tree roots to grow and continue to "mine" soil.

Soils

As soils dry, there is less and less water sticking to surfaces of soil particles and left in pore spaces between particles. Sandy soils dry rapidly because spaces between particles are large. Little water sticks to the surface of sand particles. In clay soils, water is held tightly on and between clay surfaces, with some water held so tightly, it is difficult for a tree to exert enough pull (tension) to capture this water from soil.

As soil water contents decline, tree leaves must develop large water tensions in order to pull up the last bits of water from soil. Some point occurs when water tension in the leaf is so great, tissue is damaged while water loss continues. Even tree death does not stop water movement. Standing dead trees continue to be a pathway of water loss from soil.

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, which are major absorbers of water and essential elements. 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 9 demonstrates how critical young roots are for tree health -- more roots absorbing water, more transpiration occurring, and more food produced. More food means more growth and more roots.

Soil Water

As soil dries, availability of water begins to be limited by decreasing water potentials and hydraulic conductivity. Figure 10. 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. As soils dry, resistance to water flow through soil increases rapidly. The loss of water cross-sectional area through soil plummets as films of water decrease in thickness and discontinuities develop around soil particles. The presence of mycorrhizae (modified root / fungi) can act to moderate early drought stress in trees.

Conclusions

Water is the most critical of site resources trees must gather and control. A great deal of water within a growing site can be used by trees. A significant amount of soil water remains unavailable depending upon soil texture and compaction extent. Interactions between trees, soils, water, and a sustainable site are complex. Water shortages can prevent tree food production and damage tree life processes. Soil features (primarily pore space) govern tree success.

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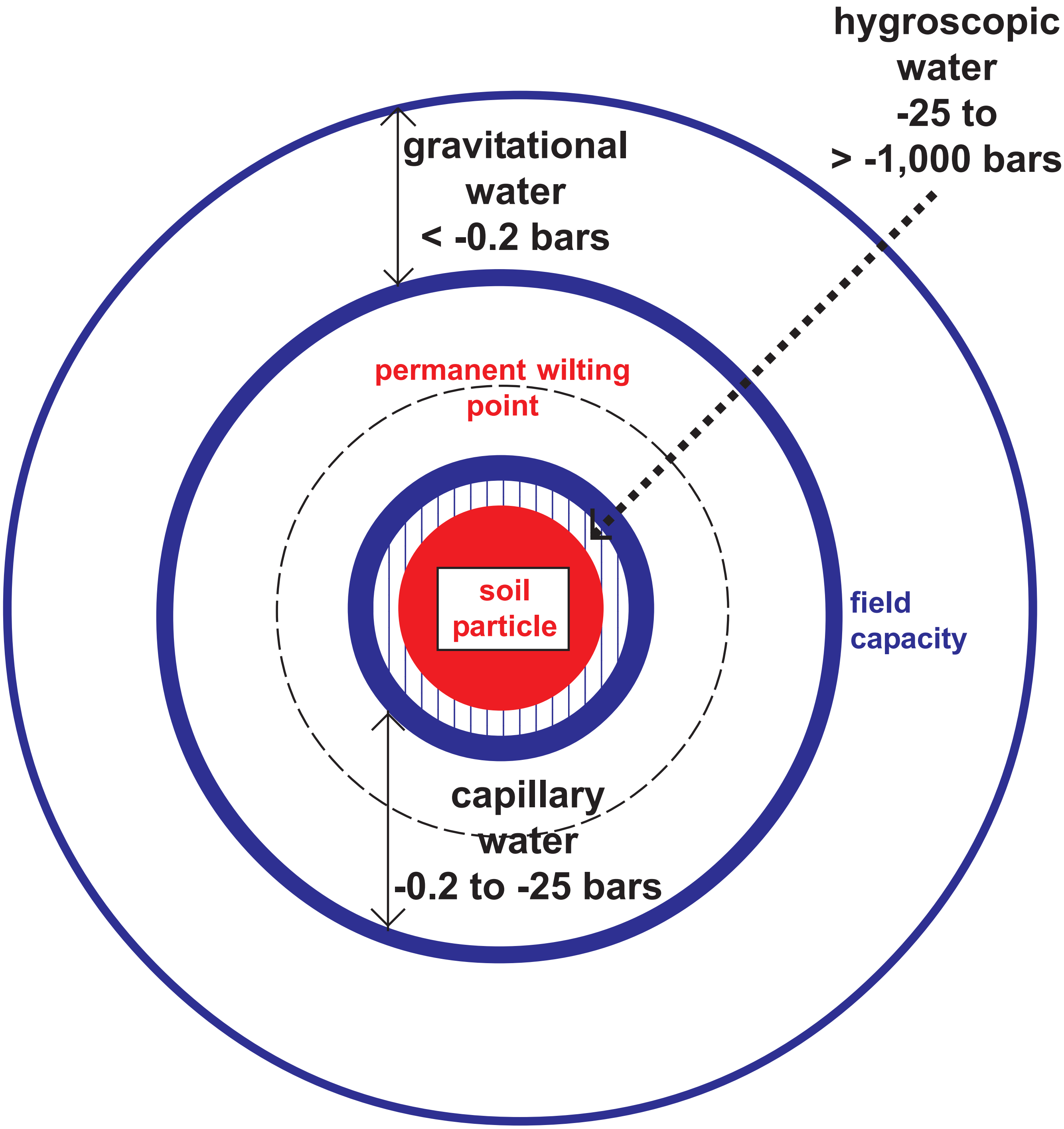

Figure 1: Idealized view of water layers surrounding a single soil particle. Tree available water is held loosely in the outer (low energy) areas as far inward as the permanent wilting point level (dotted circle). Water closer than the permanent wilting point to the soil particle can not be extracted by a tree. (after Brady, 1974)

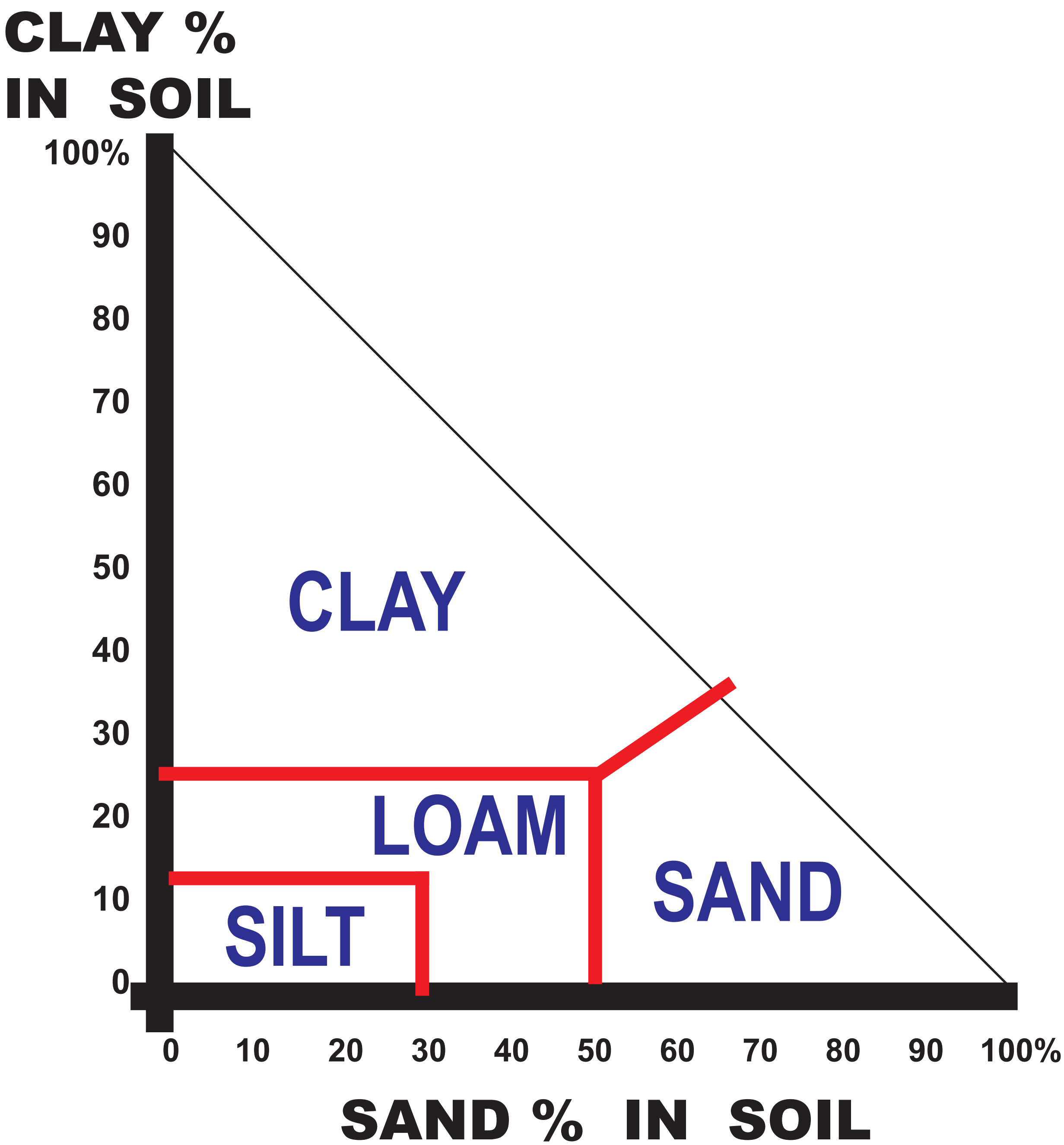

Figure 2: Soil texture names for various mixtures of particle sizes.

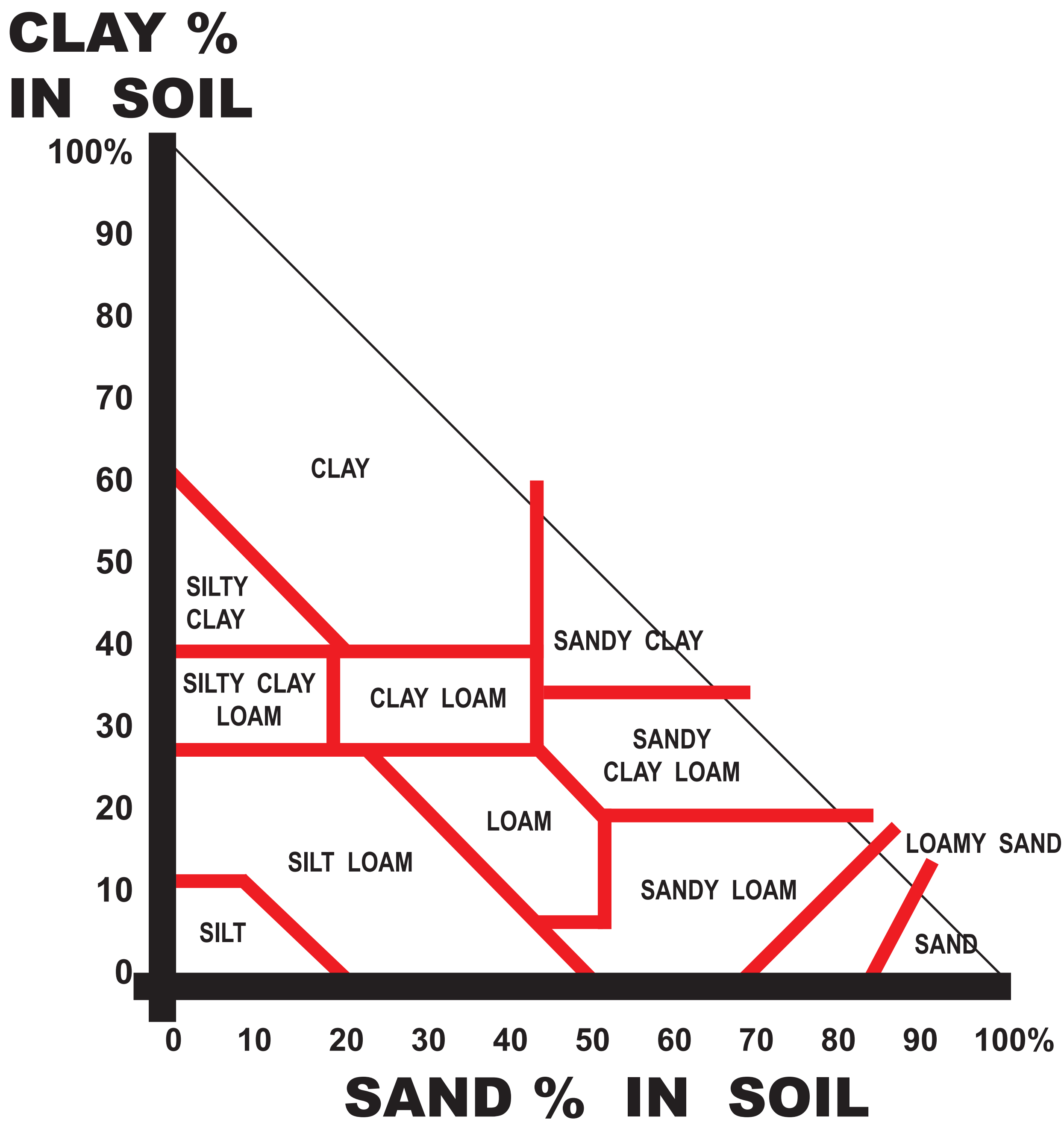

Figure 3: Soil texture types and associated particle size percentages of sand (large / coarse) and clay (small / fine). Silt is a mid-sized particle.

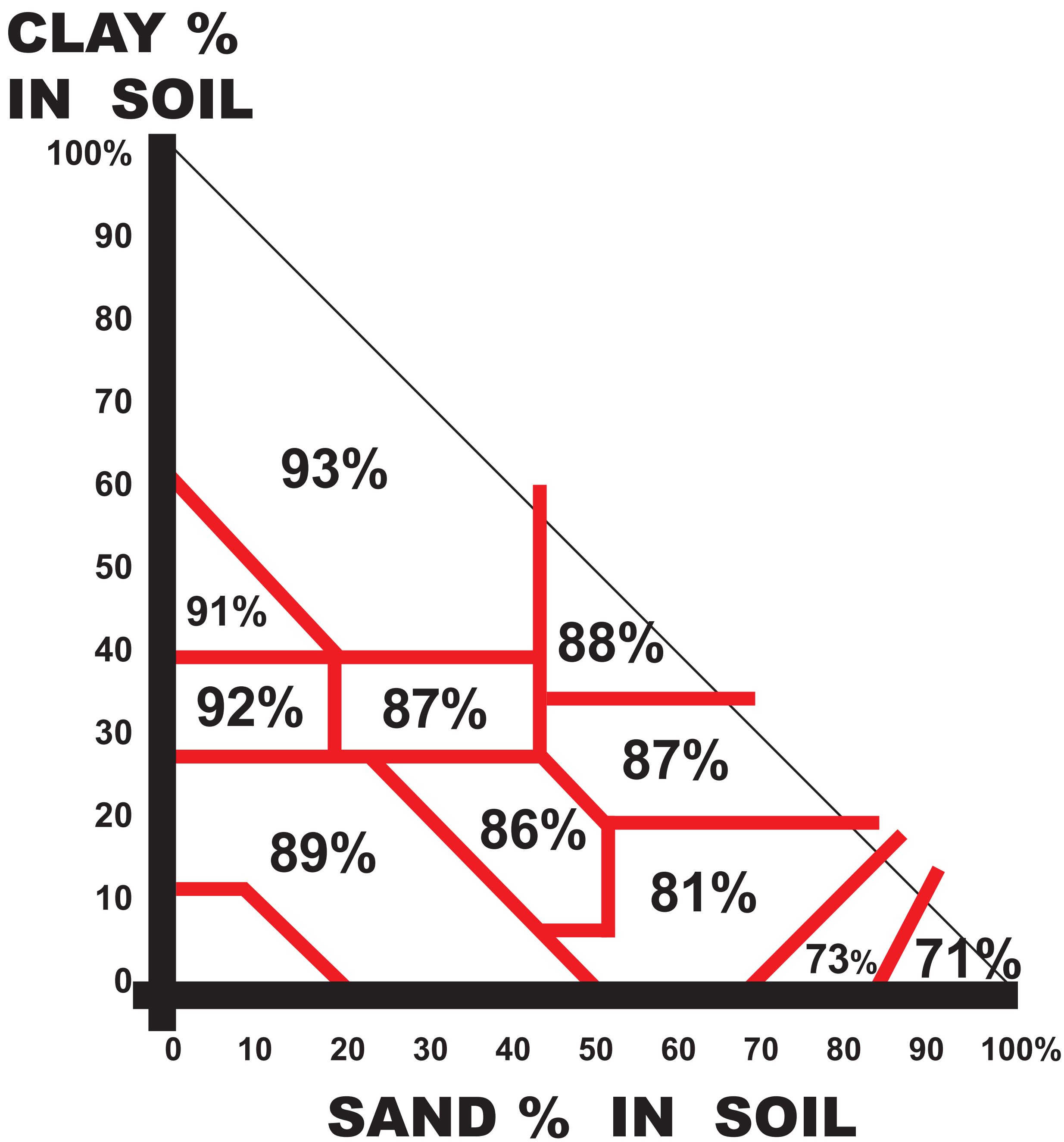

Figure 4: Approximate percent of water containing pore space (micropore) compared to all pore space in uncompacted soils of various textures at field capacity.

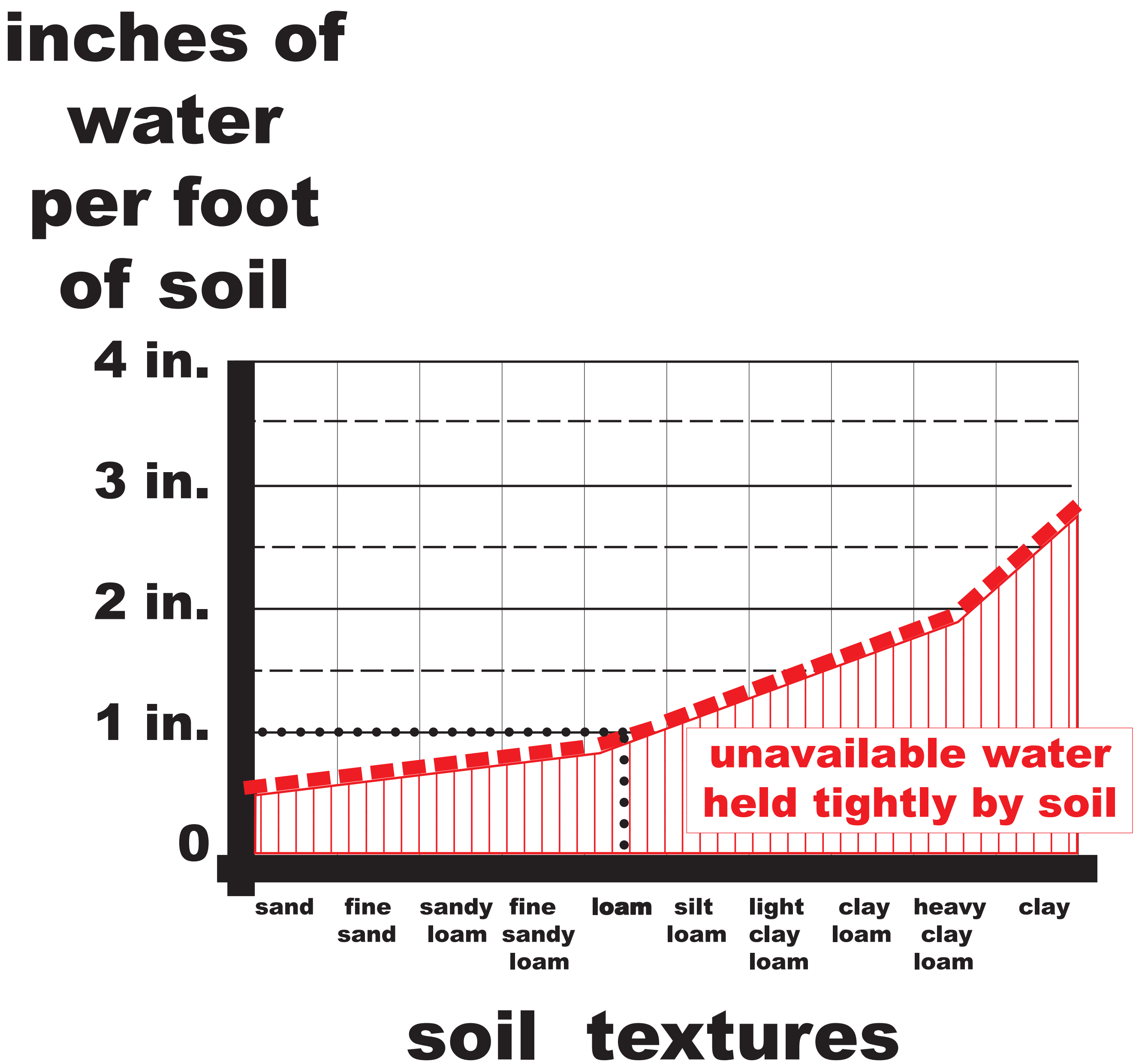

Figure 5: Unavailable water per foot in soils of various textures. The large dotted line represents permanent wilting point. (Small dotted lines are for an example in text.)

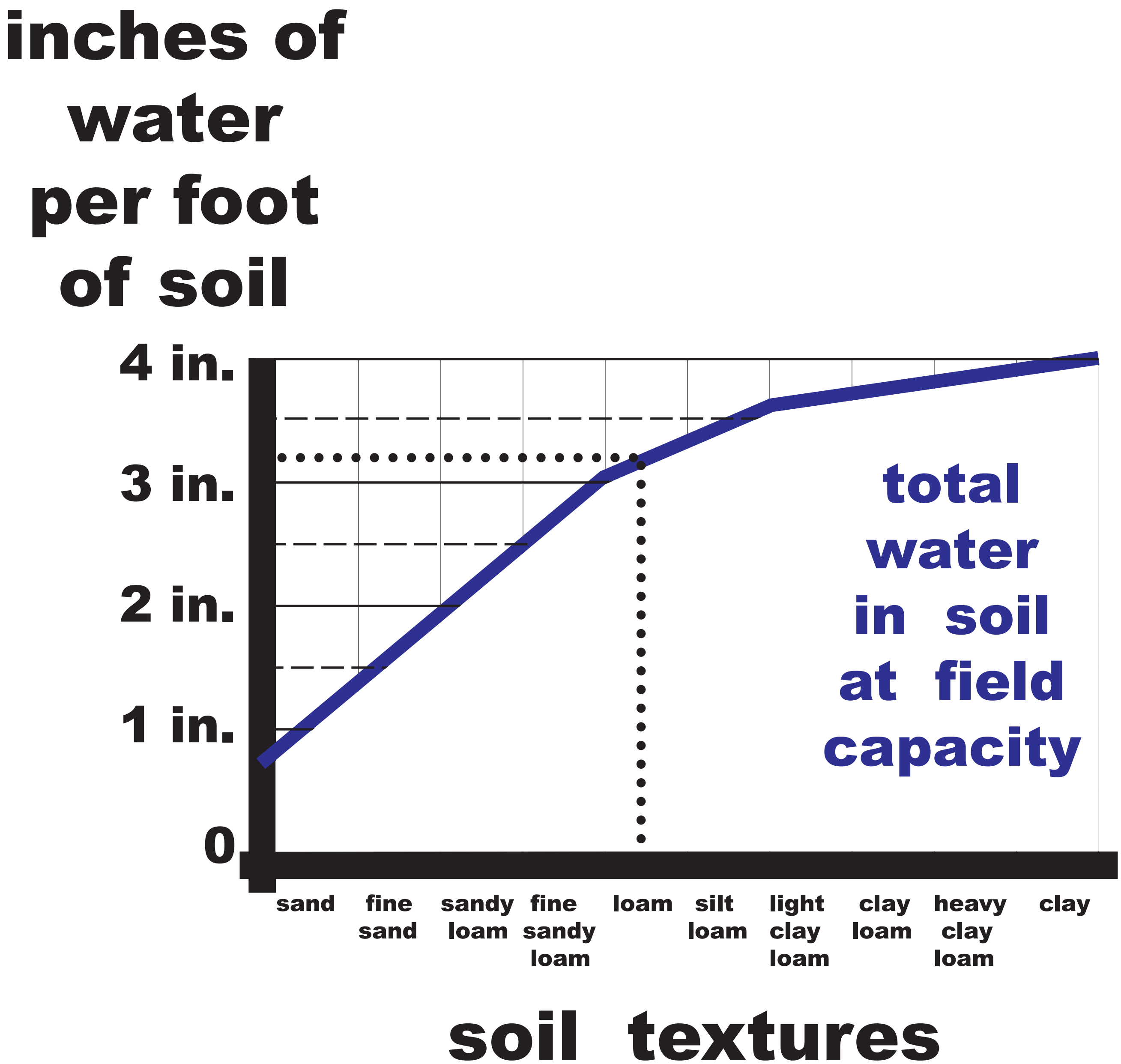

Figure 6: Total water held in soil against the pull of gravity (field capacity) for various soil textures.
(Small dotted lines are for an example in text.)

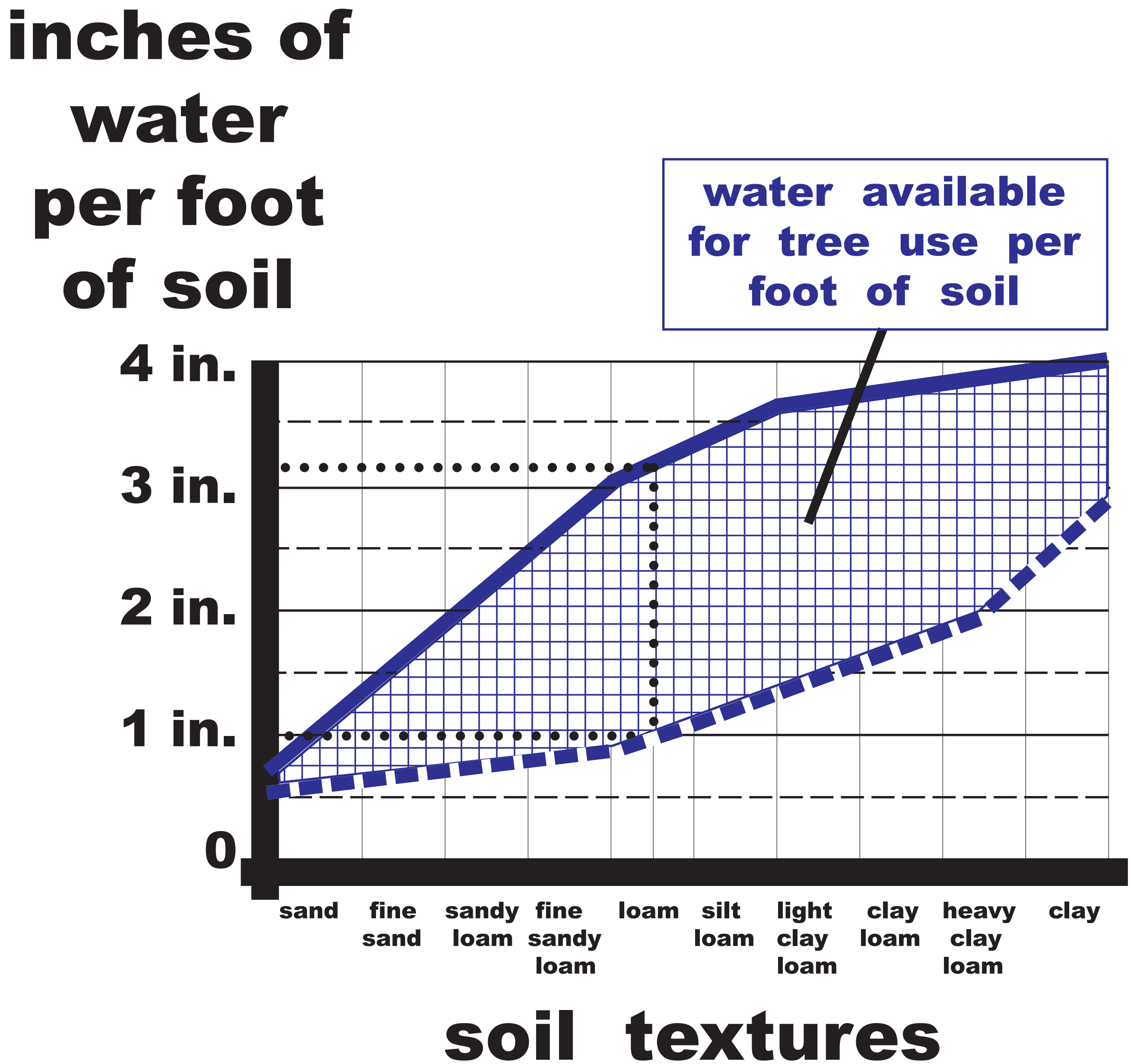

Figure 7: Difference between total water at field capacity and unavailable water held by soil. (Figure 5 subtracted from Figure 6). (Small dotted lines are for an example in text.)

soil texture	hydraulic conductivity (inches per hour)
sand	8.3 in/hour
loamy sand	2.4
sandy loam	1.0
loam	0.52
silt loam	0.27
sandy clay loam	0.17
clay loam	0.09
silty clay loam	0.06
sandy clay	0.05
silty clay	0.04
clay	0.02

Figure 8: Saturated hydraulic conductivity of non-compacted soils with various textures. Note soil structure plays a strong role in aeration and water conductivity in soil but is not considered here.

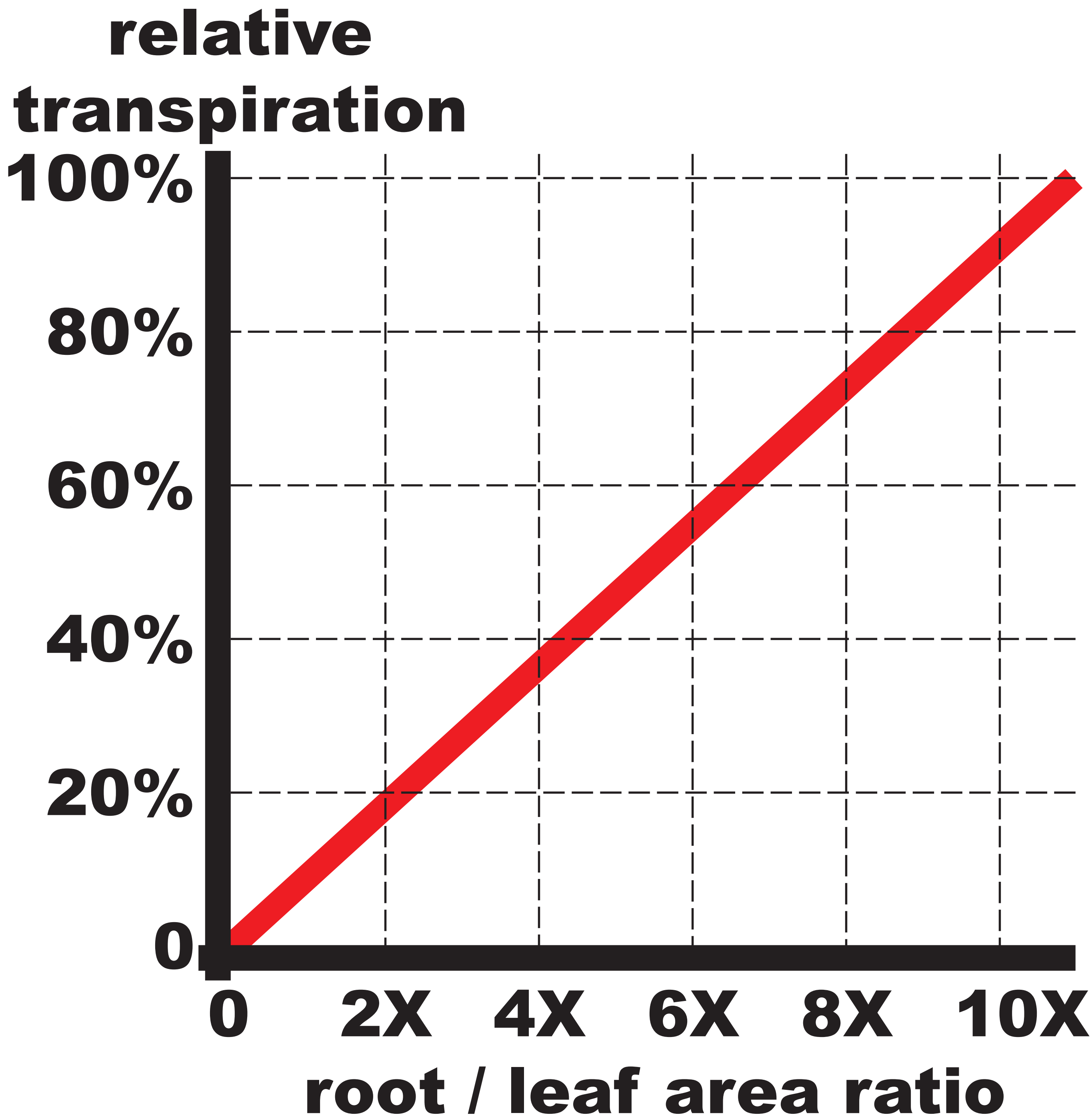

Figure 9: Relative amount of tree transpiration in percent compared with root / leaf area ratio of a tree. Root values were on a dry weight basis and leaf values were on a square foot basis. X = leaf area; 2X = two times more root mass than leaf area. (derived from Parker, 1949)

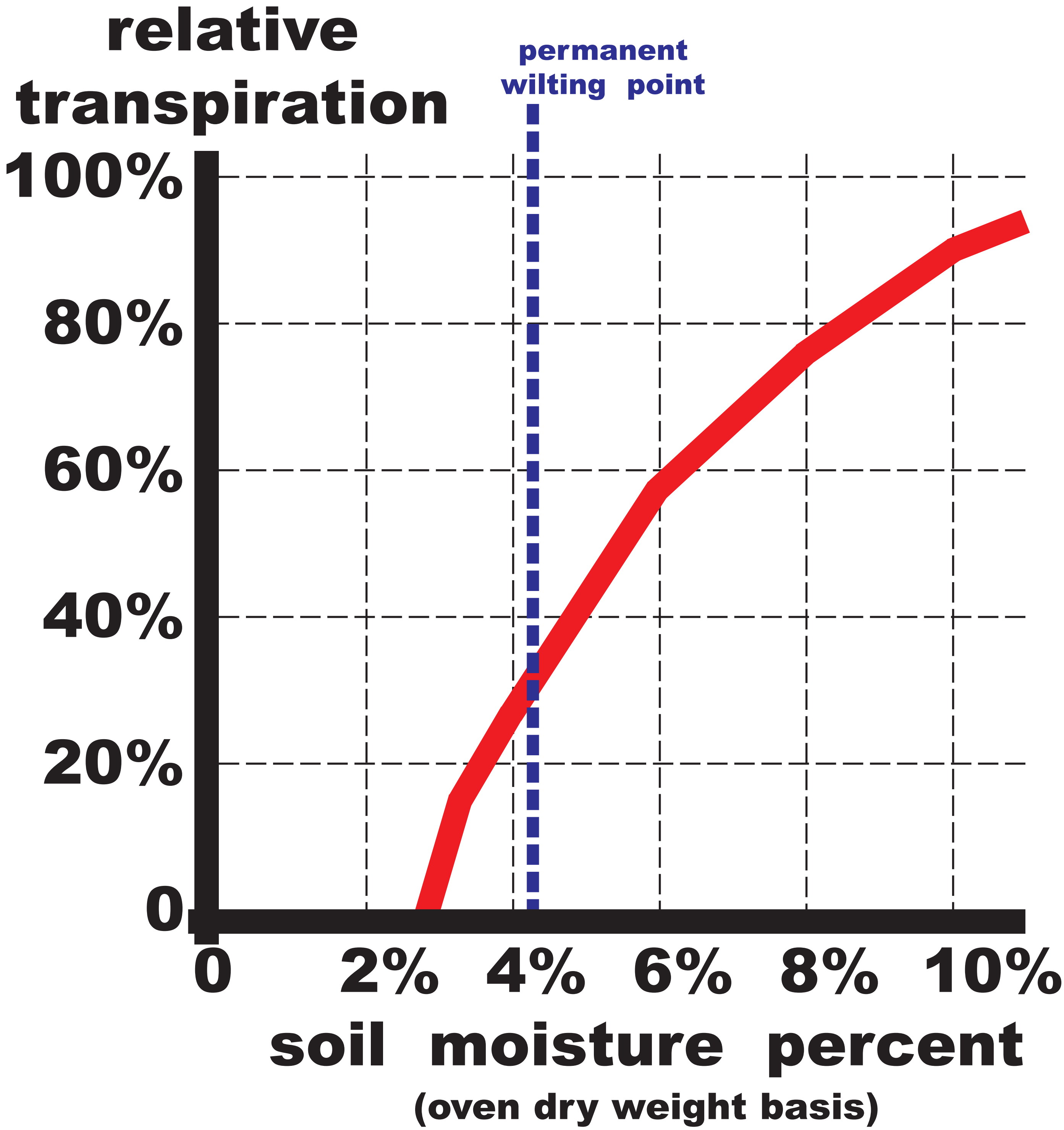

Figure 10: Relative amount of tree transpiration in percent compared with various soil moisture percents based upon an oven dry weight basis. (derived from Bourdeau, 1954)