TREE HEAT STRESS SYNDROME

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Georgia can have many hot days during the year. From the North Georgia mountains to the coast, these large heat loads can influence plant growth. Figure #1; Figure #2. Trees and shrubs generally have optimum growing conditions across the range of temperatures from 70°F to 85°F Hot temperatures can injure and kill living plant systems.

A thermal death threshold is reached at approximately 115°F. The thermal death threshold varies depending upon the duration of hot temperatures, the absolute highest temperature reached, tissue age, thermal mass, water content of tissue, and ability of the plant to make adjustments to temperature changes.

A plant's temperature usually runs just above air temperature. Plants dissipate heat by long-wave radiation, convection of heat into the air, and transpiration (water loss from leaves). Transpiration is a major mechanism of plant cooling. Without transpirational cooling, heat radiated to the surroundings and wind cooling are the only means of keeping plant temperatures near air temperatures. Sometimes radiated heat and hot breezes prevent heat dissipation and add to the plant's heat load.

Figure #3 gives three examples of heat loading in a landscape. The first example is the sensible heat generated in a parking lot with a hard surface. The sun beats down with 1000 heat units. The hard surface absorbs and reradiates heat for a total of 2000 heat units. This heat can be reflected onto plants and used to heat air that is blown into or across a landscape, raising heat loading and water loss.

The second landscape example in Figure #3 shows a tree in dry soil. A tree under these conditions shades the surface (dissipating 400 incoming heat units). Everyone knows it is cooler in the shade of a building, awning, or umbrella than in the sun. Without water available for a tree to transpire, a tree simply acts as an umbrella, but can not dissipate heat in its tissues causing internal leaf temperatures to climb. In this example, a total of 600 heat units pass through and are radiated by the tree in dry soil, and 600 heat units are radiated back from the soil, for a total of 1200 heat units on the site. This process of physically blocking sunlight for shade is called "passive shading."

The third example in Figure #3 shows a tree in moist soil with plenty of water available for transpiration. As in the passive shade example above, 400 heat units are physically blocked by the tree visible as shade. In addition, 350 heat units are transferred away from the tree by evaporation of water from the leaves. This transpirational cooling effect in a landscape is called "active shading" because a biologically controlled process is helping dissipate heat. The heat units passing through and radiating from the tree crown amount to 250 heat units. The soil below is radiating 200 heat units (50 heat units are dissipated by water evaporation from the soil). The total heat units in the landscape from the third example is 450, roughly 38% of the heat load in example two and 23% of the heat load in example one.

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Trees can dissipate tremendous heat loads if allowed to function normally. Unfortunately, hot temperatures greatly increase the water vapor pressure deficient (dryness of the air) which cause leaf stomates to close because of rapid water loss and limits transpirational cooling. When transpiration is limited by hot temperatures, plant tissue temperatures can rise above the thermal death threshold.

Associated with rapid water loss and temperature increases in the leaves is a delay or time lag in water absorption by the roots. Leaves can lose water much faster than the roots can absorb water. The difference between water loss from the plant and water gain through root absorption, can initiate many problems. Heat injury can be most prevalent during sunny mid-days and afternoons when air temperatures are high and transprirational cooling is limited. Figure #4 provides a general example of water movement in transpiration and absorption.

Note that a noon-time slow-down in transpiration is caused in-part by water shortages in the leaves. The water shortages of the day are corrected as completely as soil water content allows, by water uptake at night using water column tension (negative pressure) to pull water into the tree. Night uptake by roots can amount to 20-40% of plant water needs.

Heat injury is difficult to separate from water problems, because water and temperature in the plant are so closely bound together in biological and physical processes. Water shortages and heat build-up are especially critical in the leaves, and secondarily, in the cambial and phloem area of twigs and branches. Temperature increases the vapor pressure deficit between leaves and atmosphere, as well as increasing the diffision rate of water across plant layers. Figure #5; Figure #6; Table # 1. Wind can decrease boundary layer resistance to water movement and cause quick dehydration. Wind can also carry large amounts of advected heat.

Daytime temperatures provide the greatest heat load, but night temperatures are also critical for many plant growth mechanisms, especially reproductive structures. Night temperatures are critical for controlling respiration rates in the whole tree and soil environment. The warmer the temperature, the faster respiration processes. Heat stress problems also make the plant more susceptible to pests and other environmental problems. A number of pathogenic fungi are more effective in attacking trees when the host is under water and heat stress.

Heat injury in plants include scorching of leaves and twigs, sunburn on branches and stems, leaf senescence and abscission, acute leaf death, and shoot and root growth inhibition. In leaves, wilting is the first major symptom of water loss excesses and heat loading. Leaves under heavy heat loading progress to senescence, if time is available, and then brown-out and finally abscise. Leaves quickly killed by heat are usually held on a tree by tough xylem tissue and the lack of abscission zone preparation.

The soil surface can be both a heat reflecting and absorbing layer. In full sunlight, soil can reach 150°F. This heat can be radiated and reflected onto landscape plants causing tremendous heat loading. Heat loading causes large amounts of water to be transpired, initiates major metabolic problems, and can generate heat lesions just above the ground / plant contact juncture. Heat lesions are usually first seen on the south/south-west side of stems.

Plants within containers in full sunlight can be under large heat loads that quickly injure roots and shoots. Depending upon color, exposure, and composition, planting containers can quickly absorb heat. For example, black plastic containers can absorb radiation at 9°F per hour until they reach 125°F or more. The sequence in damage begins with inhibition of root growth followed by water uptake decline,. heavy wilting, physical root damage and death, and finally leaf and shoot death.

The duration of hot temperatures for plants must not exceed the plant's ability to adjust, avoid, or repair problems. Less absolute amounts of sensible heat are needed to damage plants as the duration of the temperature lengthens. Temperature effects in plants directly influence water loss, respiration, and photosynthesis. Figure #7. As a general rule, each temperature step, beginning at 40°F and continuing to **58°F, 76°F, 94°F, 112°F,** and 130°F each allow physical doubling of respiration and water loss. Gross photosynthesis generally doubles up to 94°F and then rapidly falls-off.

Heat stress syndrome is a series of metabolic dysfunctions and physical constraints that pile-up inside plants and become impossible for a plant to adjust, avoid or correct. The ten step heat stress syndrome sequence (for C3 plants like trees) is given below:

1. decrease in photosynthesis
2. increased respiration
3. closing down of Ps (turn-over point for Ps and Rs = 95°F)
   - 3a. closed stomates (initiates step ##4 below)
   - 3b. stops CO, capture
   - 3c. increased photo-respiration
4. major slow-down in transpiration (cooling process loss and internal temperature increase)
5. cell membrane leakage (signals changes in protein synthesis)
6. continued physical water loss
7. growth inhibition
8. plant starvation through rapid use of food reserves, inefficient food use, and inability to call on reserves when and where needed
9. toxins generated through cell membrane releases and respiration problems
10. membrane integrity loss and protein breakdown

Plant cell membranes are made of a double layer of lipids (fats/oils) that contain the living portions of the plant cell. As temperature increases, the membranes become more liquid (similar to heating butter and watching it melt). As temperatures increase, plant cells use two strategies to maintain life -- one is to increase the saturated fat proportion in membranes and, the second is to increase structural proteins holding membranes together. As temperatures continue to climb, enzymes and structural proteins are inactivated or denatured, and respirational dead-ends produce toxic materials that can not be destroyed, compartmentalized, or excreted. Plant cell death is the result.

The differences among plants to tolerating heat loads revolve around enzyme protection / deactivation levels which are influenced by pH, solute levels in cells, protein concentration, and protection mechanisms. These tolerance mechanisms are primarily genetically controlled, although each individual usually has a wide range of responses to heat stress.

Treatments for this syndrome include: watering, sprinkling, and misting for improved water supply, reduction of tissue temperature, and lessening of the water vapor pressure deficit; partial shading to reduce advected heat and total incoming radiation; reflection and dissipation of radiative heat using colorants and surface treatments around the landscape and on trees; use of low density, organic, surface covers that have some evaporative attributes as mulches, ground covers, and hard surface blankets; utilization of well designed and constructed active shade structures in the landscape like arbors and trellises; and, establish better tree-literate design and maintenance practices that deal with heat problems.

Figure #1: Average days above 90°F.

(30 year annual averages rounded to next highest class.)

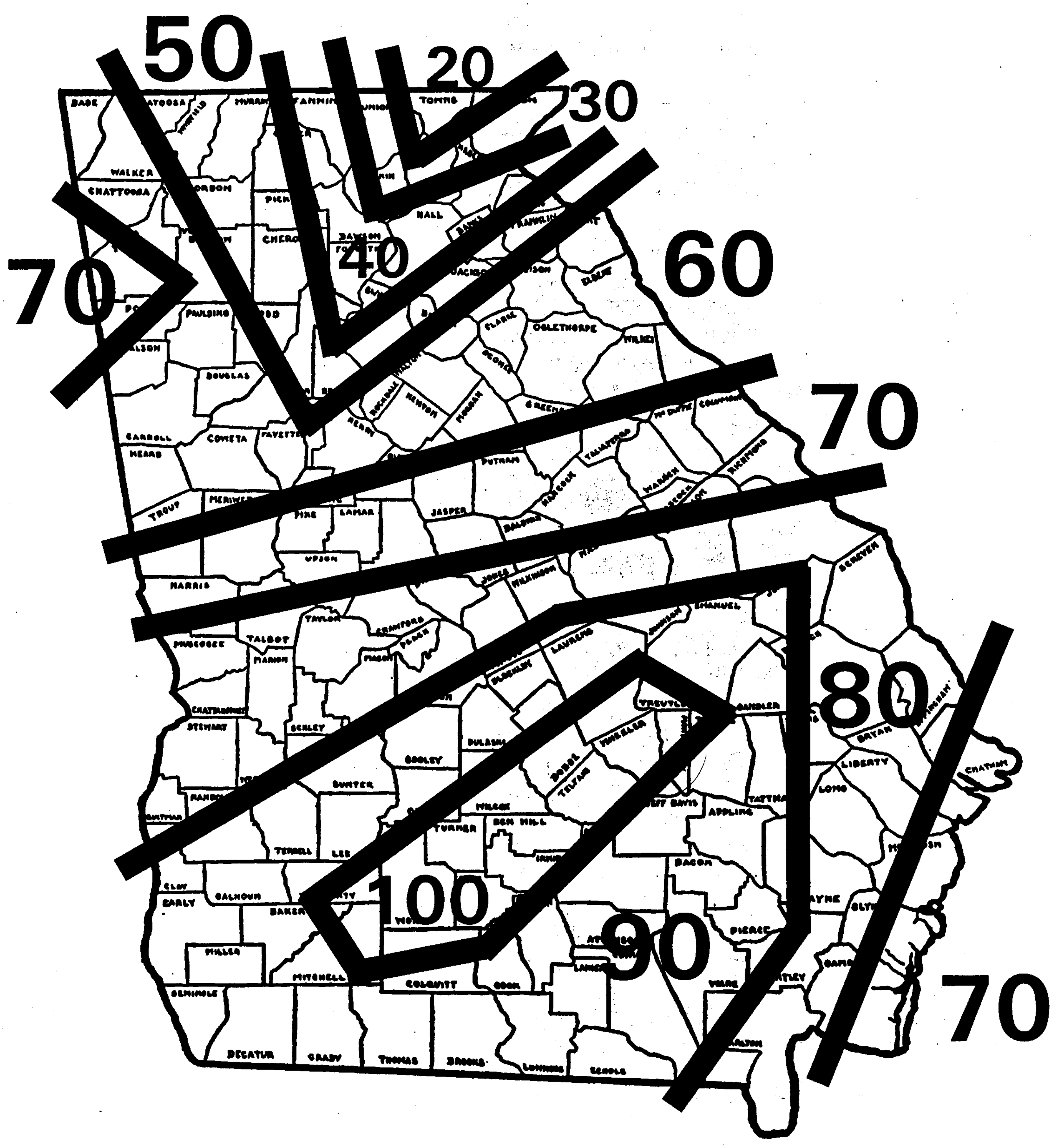

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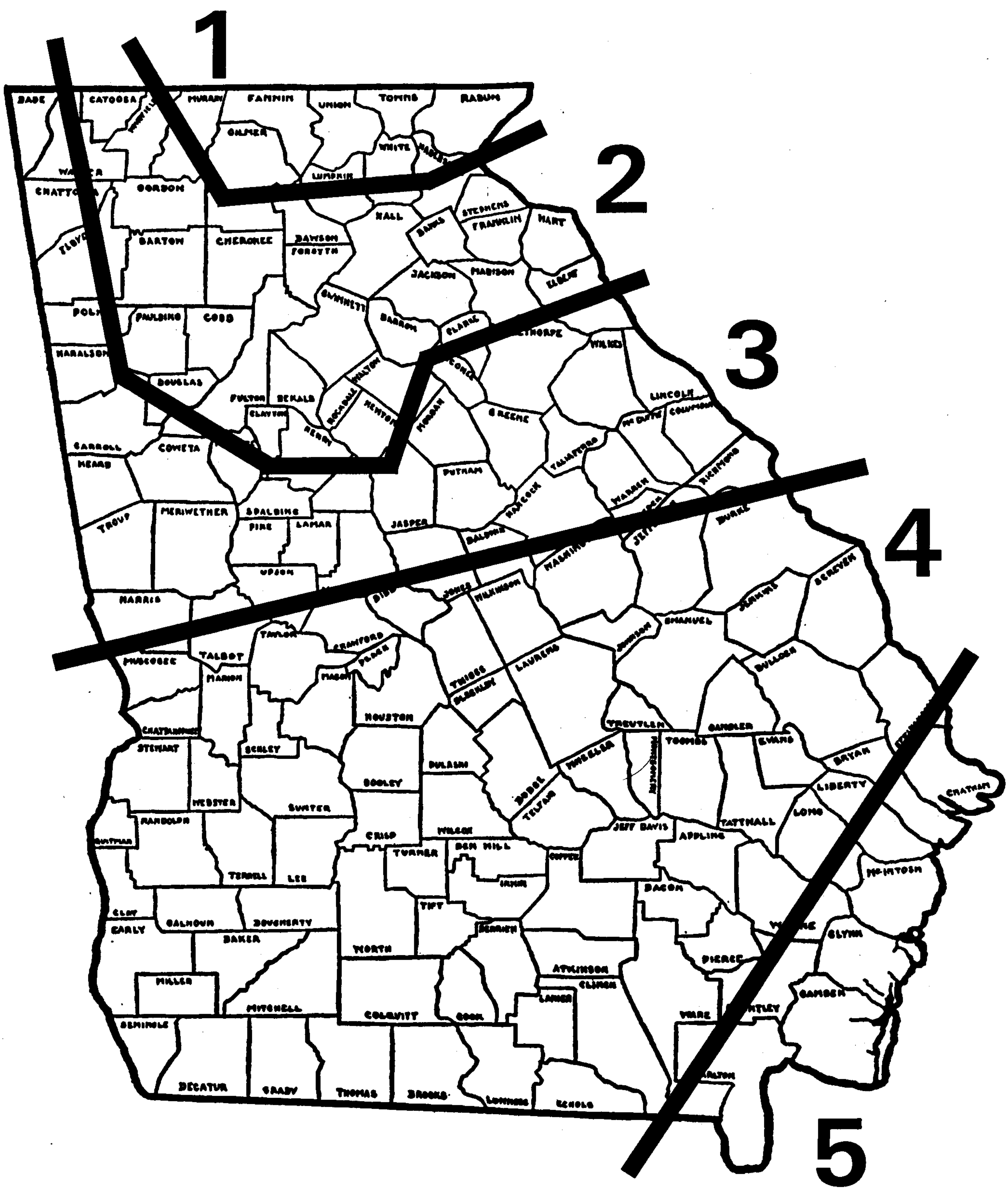
Figure #2: Distinct temperature zones in Georgia. (30 year averages of monthly and annual temperature data analyzed by cluste analysis)



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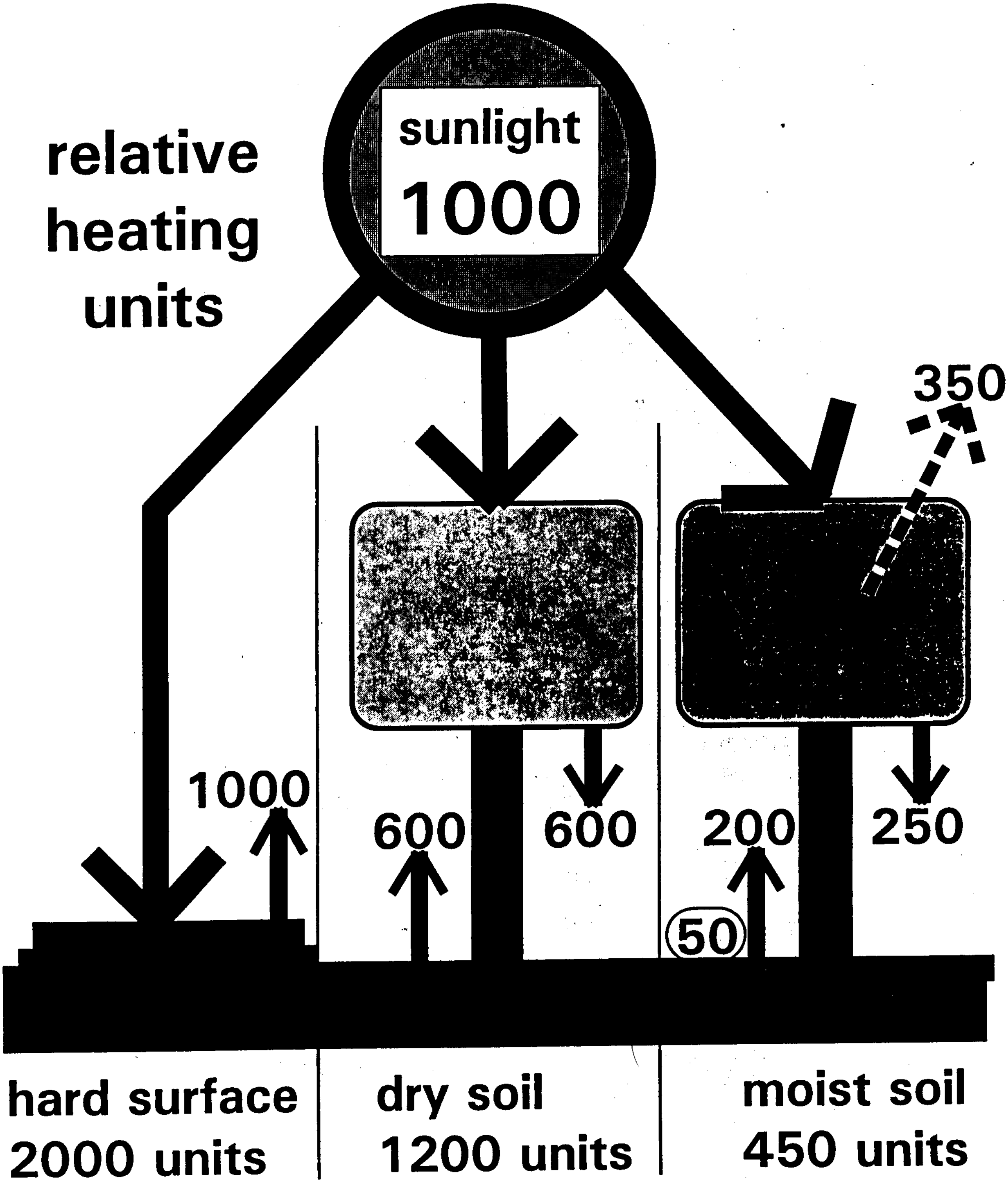

Figure #3: Accumulation of relative heating units under various surface and soil conditions.

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Figure #4: Relative difference between transpiration and absorption of water in a tree during the day.

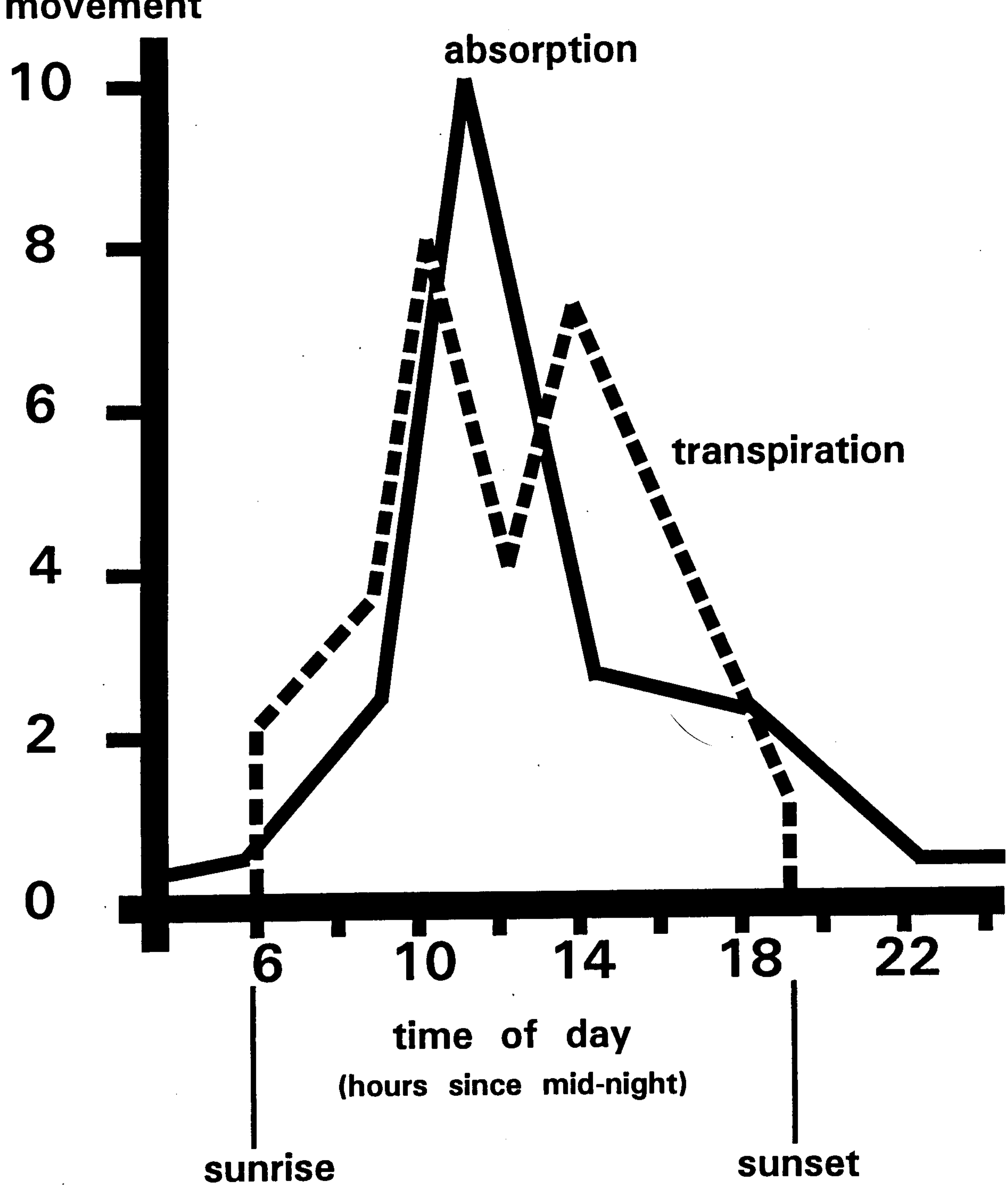

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Figure #5: Relative change over the day between air temperature and relative humidity.

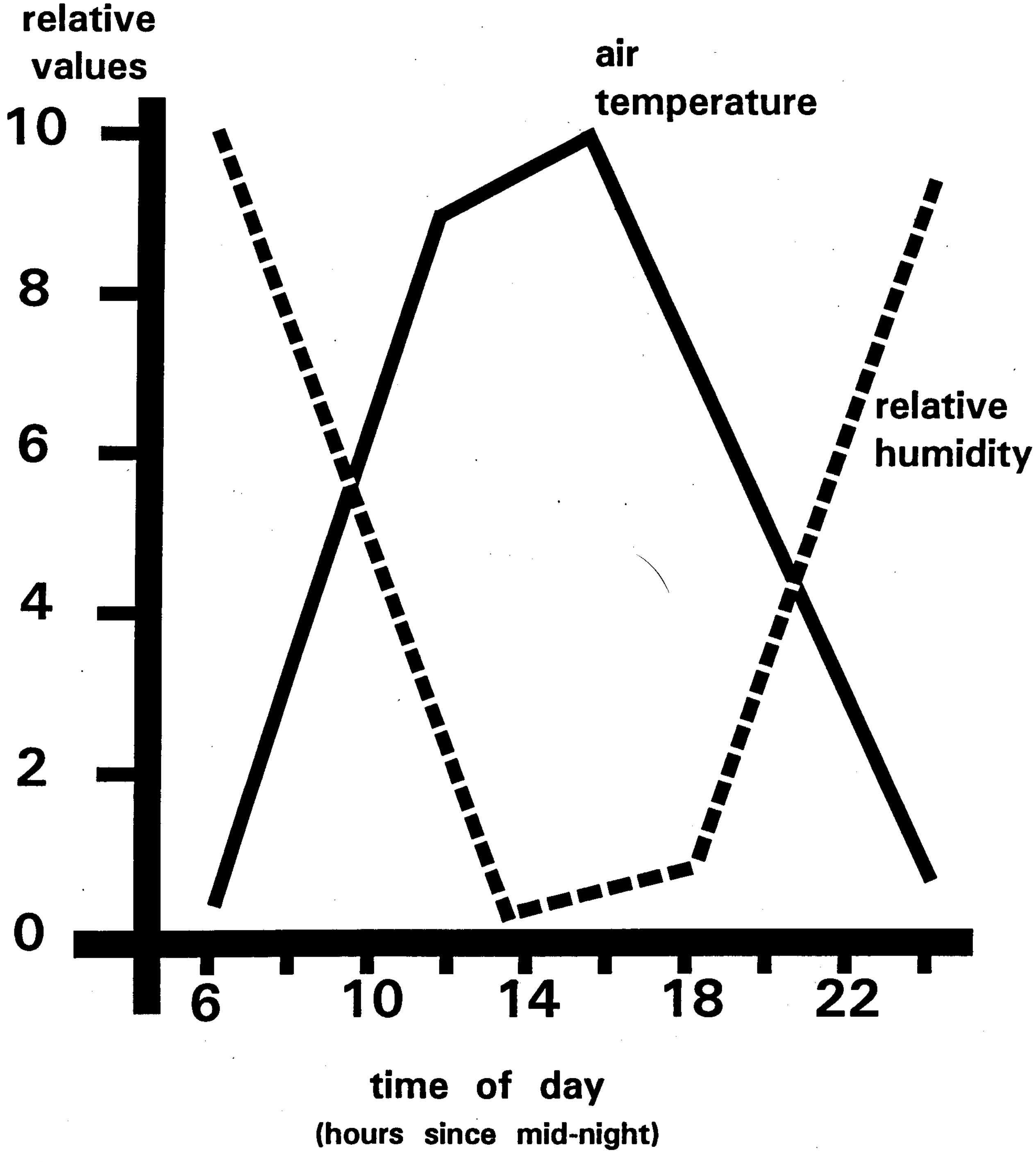

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Figure #6: Effects of temperature changes on water vapor pressure deficit (- VPD).

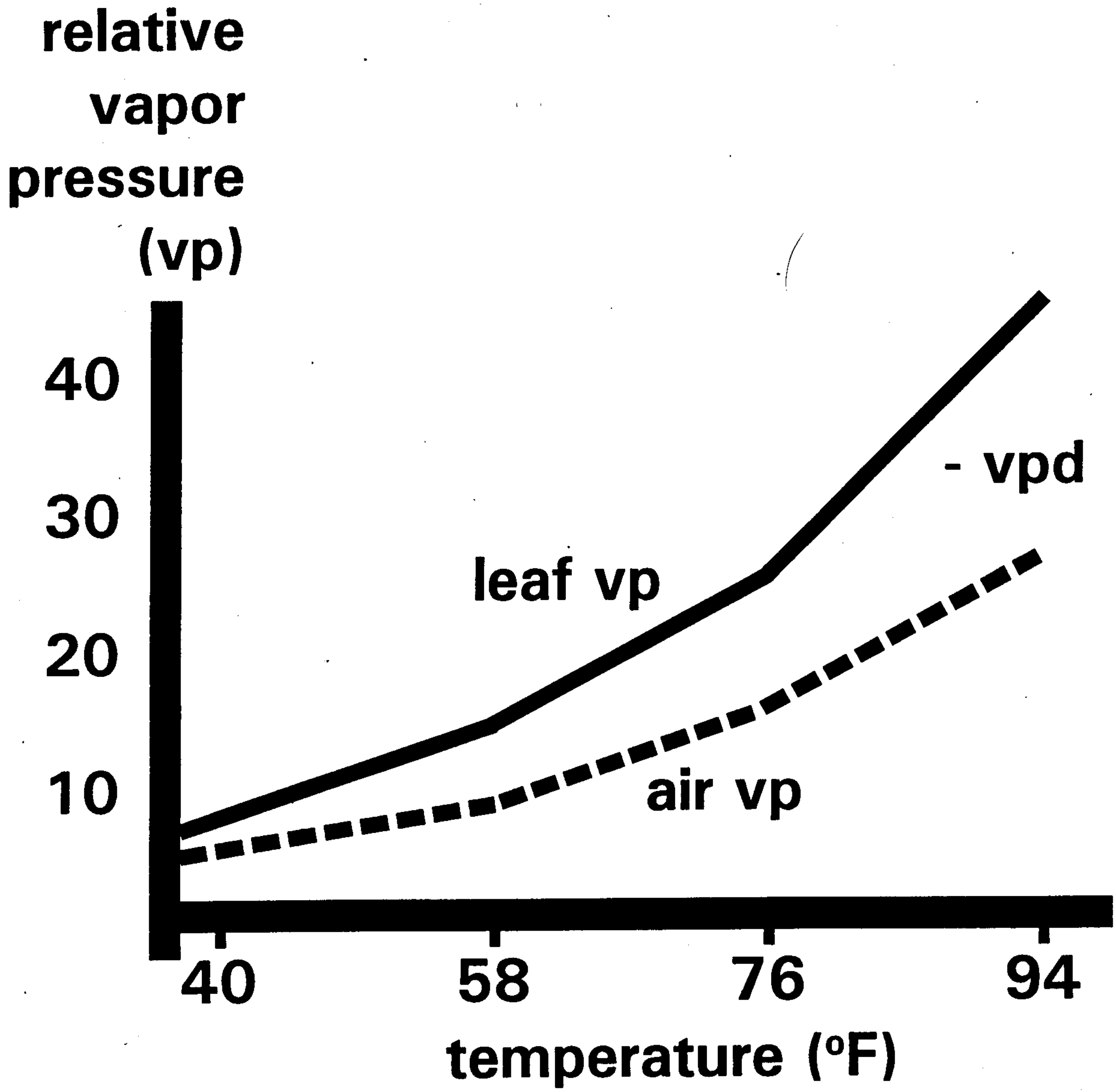

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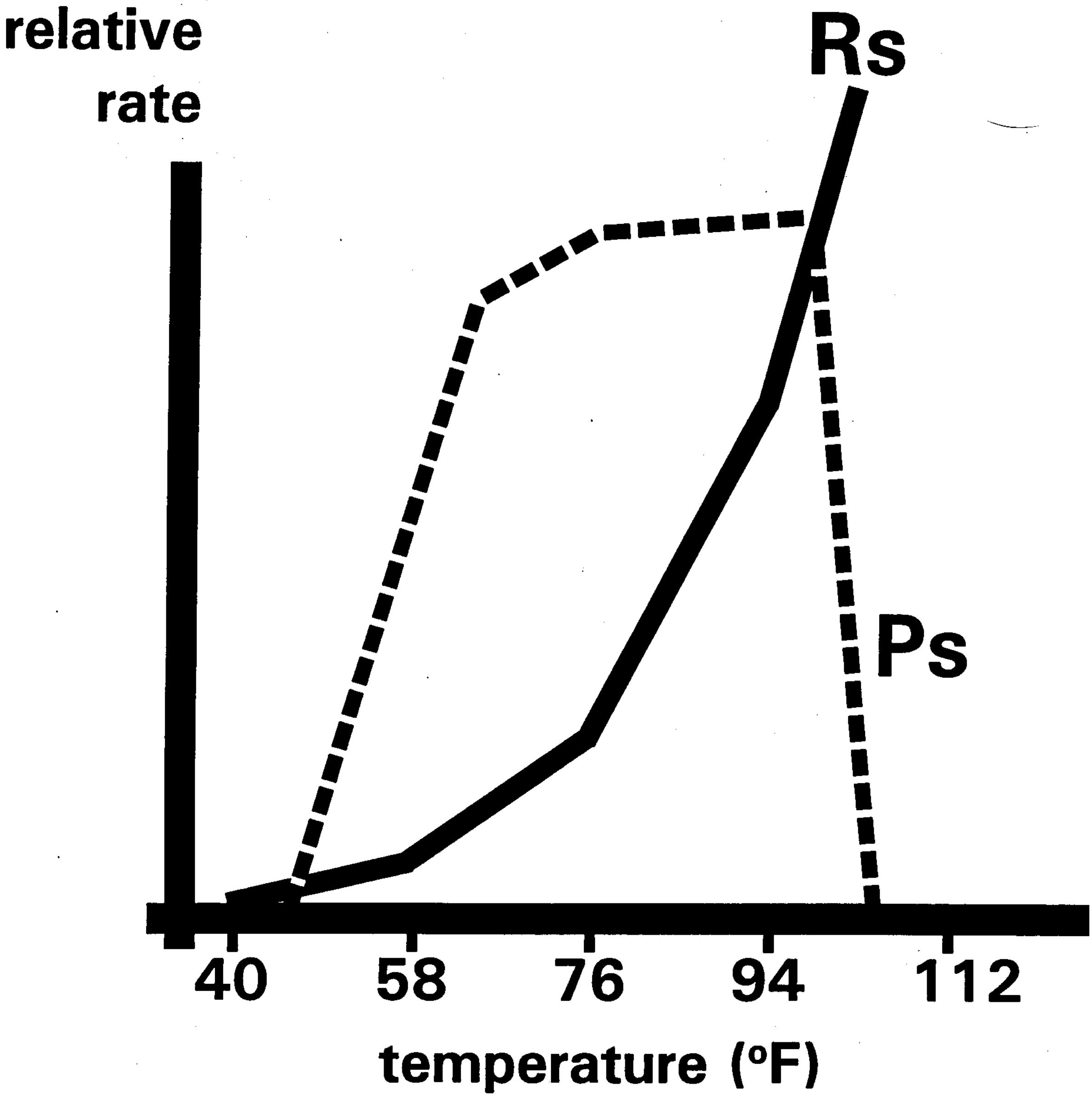
Table 1: Comparison of water potentials at various relative humidities.

Normal range over which plant growth occurs is -0.2 to -15 bars. Drought conditions and damage occurs in the leaf after -15 to -20 bars is reached. The gradient between the leaf at 100% relative humidity (0 bars) and the atmosphere can be great. For example, fog is 100% relative humidity while rain downpours range from 90% to 98% relative humidity. Trees can lose water even during rain storms because at 99% relative humidity, the air is 100 times drier than the inside of a leaf.

relative humidity (%)	water potential (bars)
99.99	-0.14
99.9	- 1.4
99	-14
98	-27
95	-69
90	-142
80	-301
70	-482
60	-690
50	-936
40	-1,237
30	-1,625
20	-2,173
10	-3,108

Figure #7: Effects of temperature changes on photosynthesis (Ps) and respiration (Rs).



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