Heat Stroke in Trees

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Summer has provided a number of hot and dry weeks for people and trees. Many of the old, young, and soil-limited trees have been damaged. The combination of drought and harsh site conditions provided in parking lots, along streets, on open squares, and surrounding pavement have led to a number of tree symptoms. The old term "heat stroke" fits trees where heat loads have been extreme and caused problems.

Temperatures

Trees have optimum growing conditions across the range of temperatures from 70°F to 85°F. Hot temperatures can injure and kill living tree 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 tree to make adjustments to temperature changes.

Tree temperature usually runs just at or slightly above air temperature. Trees dissipate heat by long-wave radiation, convection of heat into the air, and transpiration (water loss from leaves). Transpiration is a major mechanism for dissipation of tree heat loads. Without transpirational cooling, more ineffective means are used to dissipate heat like heat radiation to surroundings and wind cooling.

Trees can dissipate tremendous heat loads if allowed to function normally and with adequate soil moisture. 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 so can limit transpirational cooling. When transpiration is limited by hot temperatures and the tree is surrounded by non-evaporative surfaces (hard surfaces), leaf temperatures may rise above the thermal death threshold.

Keeping Up

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 tree and water gain through root absorption, can initiate many problems. Figure #1 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 closing stomates.

The water shortages of the day are corrected as completely as soil water content allows by water uptake at night. The force or energy for this nighttime water absorption when stomates are closed is through tension in the water column (remaining negative pressure) pulling water into the tree. Night uptake by roots can amount to 20-40% of tree water needs.

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Hot Water

Heat injury is difficult to separate from water problems, because water and temperature in trees are so closely bound together in biological and physical processes. Water shortages and heat buildup are especially critical in the leaves, and secondarily, in the cambial and phloem area of twigs and branches. Increased temperatures increase the vapor pressure deficit between leaves and atmosphere, as well as increasing the diffusion rate of water across plant layers. Figure #2; Figure #3; Table #1.

In tree leaves, wilting is the first major symptom of water loss excesses and heat loading. Leaves under heavy heat loads may progress through senescence (if time is available), 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. Rewatering after heat damage and drought may initiate quick leaf abscission.

Hot Air

Advected heat is carried on the wind, heating and drying tree tissues as it passes. Advected heat from neighboring hardscapes can heat and dry landscapes and trees. Advected heat can power excessive water evaporation of water in trees and landscapes to dissipate heat generated somewhere else. Wind also decreases the protective boundary layer resistance to water movement and can lead to quick dehydration. Structures and topographic features can modify or block advected heat flows across a site.

Double Trouble

Daytime temperatures obviously provide the greatest heat load, but night temperatures are also critical for many tree growth mechanisms, especially new leaves and reproductive structures. Night temperatures are critical for controlling respiration rates in the whole tree and soil environment. The warmer the temperature, the geometrically faster respiration precedes.

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 stroke is a series of metabolic dysfunctions and physical constraints that pile-up inside trees and become impossible to adjust, avoid or correct. Figure #4.

Additional Stress

Since nitrogen is physiologically demanding, moderate concentrations of nitrogen fertilizers can damage trees under large heat loads. The internal processing of nitrogen fertilizer inputs require stored food (CHO) be used. When no food is being produced in the tree, transport systems are only marginally functional, and respiration is accelerating, nitrogen applications should be withheld. Excessive heat loads and supplemental nitrogen lead to excessive root food use. Fertilizer salt contents or activity in the soil can also be damaging when soil moisture is limiting.

Heat stress problems make trees 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 or heat stress. Heat injury includes scorching of leaves and twigs, sunburn on branches and stems, leaf senescence and abscission, acute leaf death, and shoot and root growth inhibition. Loss of defensive capabilities and food supplies allow some minor pests to effectively attack trees.

Hot Soil

The soil surface can be both a heat reflecting and absorbing layer. In full sunlight, soils can reach 150°F. This heat can be radiated and reflected into a landscape and onto trees causing tremendous heat loading. As discussed before, excessive heat loading causes large amounts of water to be transpired, initiates major metabolic problems, and can generate heat lesions just above the ground / tree contact juncture (root collar -- stem base area). Heat lesions are usually first seen on the south / southwest side of stems.

The duration of hot temperatures can not exceed a tree's ability to adjust, avoid, or repair problems or death results. Less absolute amounts of sensible heat are needed to damage trees as the duration of the hot temperature lengthens. In other words, the more dysfunctional and disrupted growth functions become due to heat loading, the easier it is to develop further stress problems.

Melting Membranes

Living tree cell membranes are made of a double layer of lipids (fats/oils) that contain the living portions of the cell. As temperature increases, membranes become more liquid (similar to heating butter and watching it melt). As temperatures increase, 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. Respirational dead-ends and by-products produce toxic materials that are difficult to transport away or destroy, compartmentalize, or excrete. Tree cell death is the result.

Tolerance

The differences among trees to tolerating heat loads revolve around enzyme effectiveness and membrane health. The better enzymes and membranes can be protected from heat effects, the more effective the tree will be in dealing with large heat loads. Protection or deactivation of enzyme systems in trees are influenced by pH, solute levels in cells, protein concentrations, and protection mechanisms. The ability of a tree to continue functioning demonstrate tolerance mechanisms which are primarily genetically controlled, although each individual usually has a wide range of responses to heat stress.

Internal changes within the living tree as heat loading effects increase:

1. Decrease in photosynthesis (Ps) and increase in respiration (Rs).
2. Closing down of Ps (turn-over point for Ps and Rs = 95°F).
3. Closed stomates stop CO2 capture and food production.
4. Major slowing of transpiration (loss of heat dissipation, increase of internal temperature, and transportation / absorption problems).
5. Increasing cell membrane leakage.
6. Continued physical water loss and dehydration.
7. Cell division and expansion inhibited, and growth regulation disrupted.
8. Tree starvation through rapid use of food reserves, inefficient food use, increased photo-respiration, and inability to call on reserves when and where needed.
9. Toxins generated (cell membrane releases and respiration problems) and deficiencies of elements and metabolites occur.
10. Membrane integrity loss and protein breakdown.
11. Local cell death, tissue lesions, and tissue death.

Treatments for heat stroke in trees include:

A) Watering, sprinkling, and misting for improved water supply, reduction of tissue temperature, and lessening of the water vapor pressure deficit;

B) Partial shading to reduce total incoming radiation but not filter photosynthetically active radiation;

C) Reflection and dissipation of radiative heat using colorants and surface treatments around landscapes and on trees;

D) Block or channel advected heat away from trees and soils;

E) Use of low-density, organic, surface covers, mulches or composted materials which minimize water loss, do not add to heat loading on-site, and do not prevent oxygen movement to roots;

F) Cessation of any nitrogen fertilizer applications in or around trees, and resumption only after full leaf expansion in the next growing season;

G) Prevent or minimize any soil active / osmotically active soil additions which increase salt index or utilize soil water for dilution or activation;

H) Be cautious of pesticide applications (active ingredients, carriers, wetting agents, and surface adherence) performance under hot temperatures and with damaged trees;

I) Minimize green-wood pruning (trade-offs between wounding responses, transpiration loads, and food storage reserve availability.);

J) Utilization of well-designed and constructed active shade structures in the landscape like arbors and trellises; and,

K) Establish better tree-literate design and maintenance practices which deal with heat problems and monitor other stresses. (treat causes not symptoms!).

Table 1: Comparison of water potentials at various relative humidities. Normal range over which tree 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 inside of a leaf at 100% relative humidity (0 bars) and the surrounding 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 98% 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
5	-4,044
1	-6,217

Figure #1: Relative difference between transpiration and absorption of water in a tree during a sunny day with adequate soil moisture.

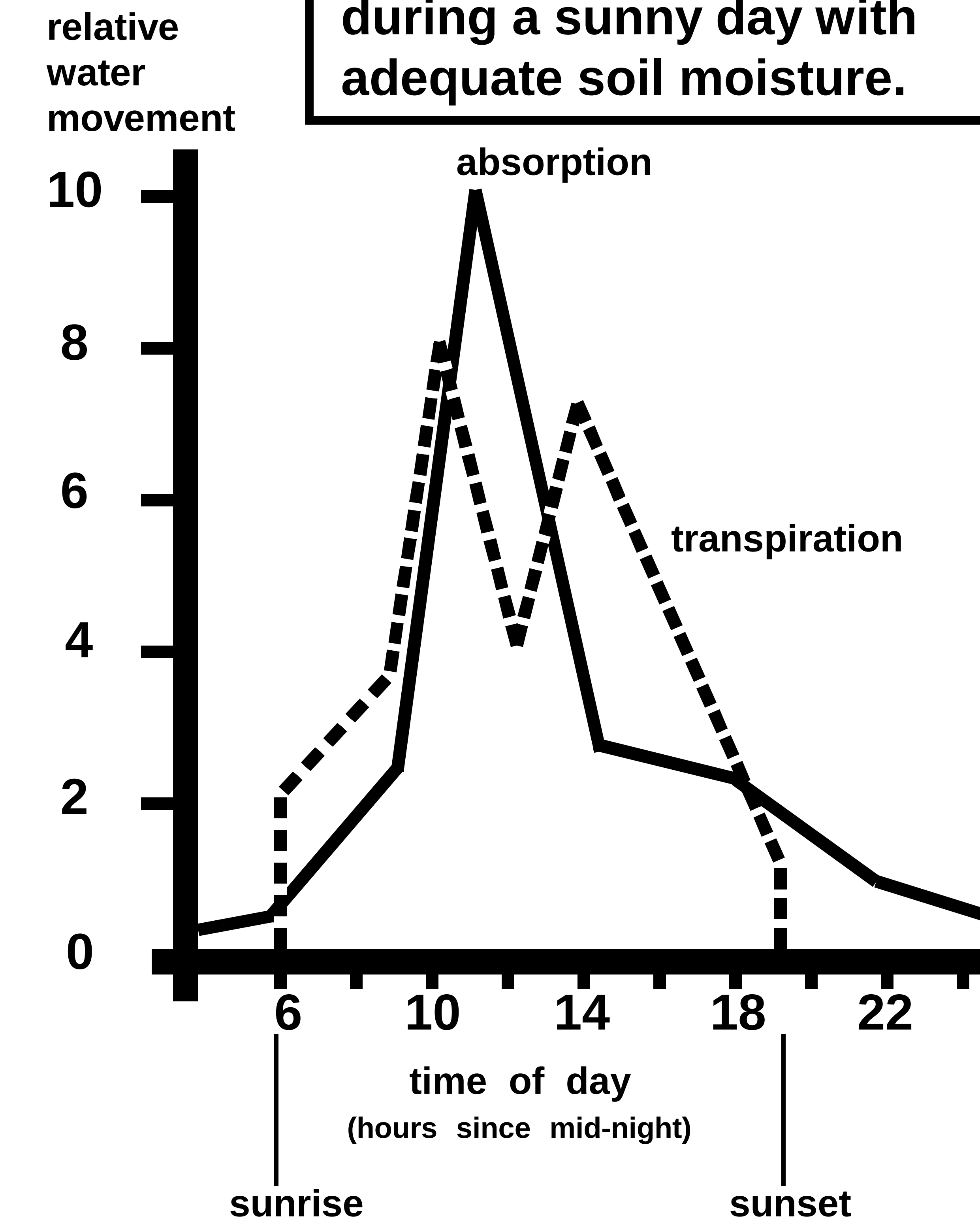

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Figure #2: Relative change over the day between air temperature and relative humidity.

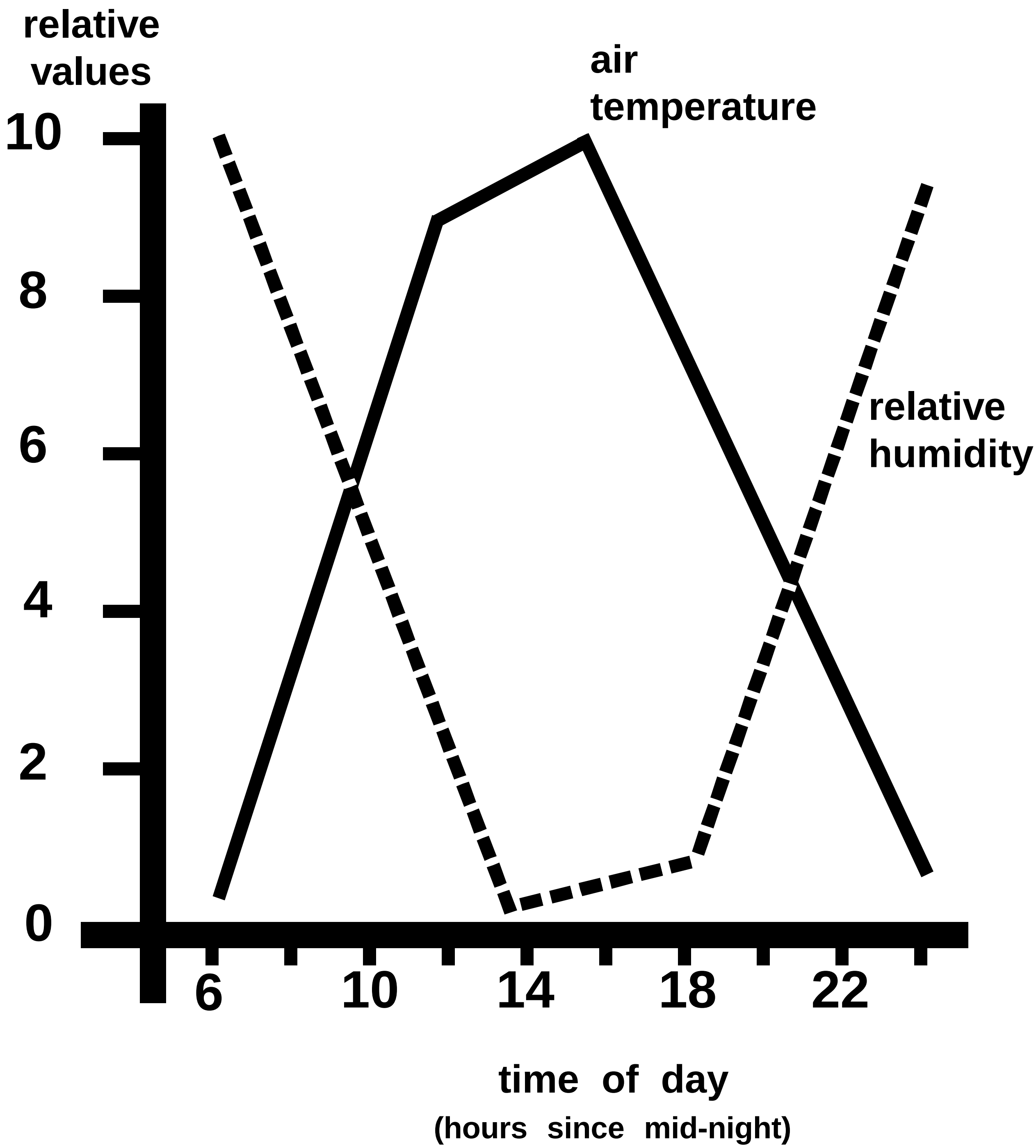

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Figure #3: Effects of temperature changes on water vapor pressure deficit (- VPD), or dryness of the air.

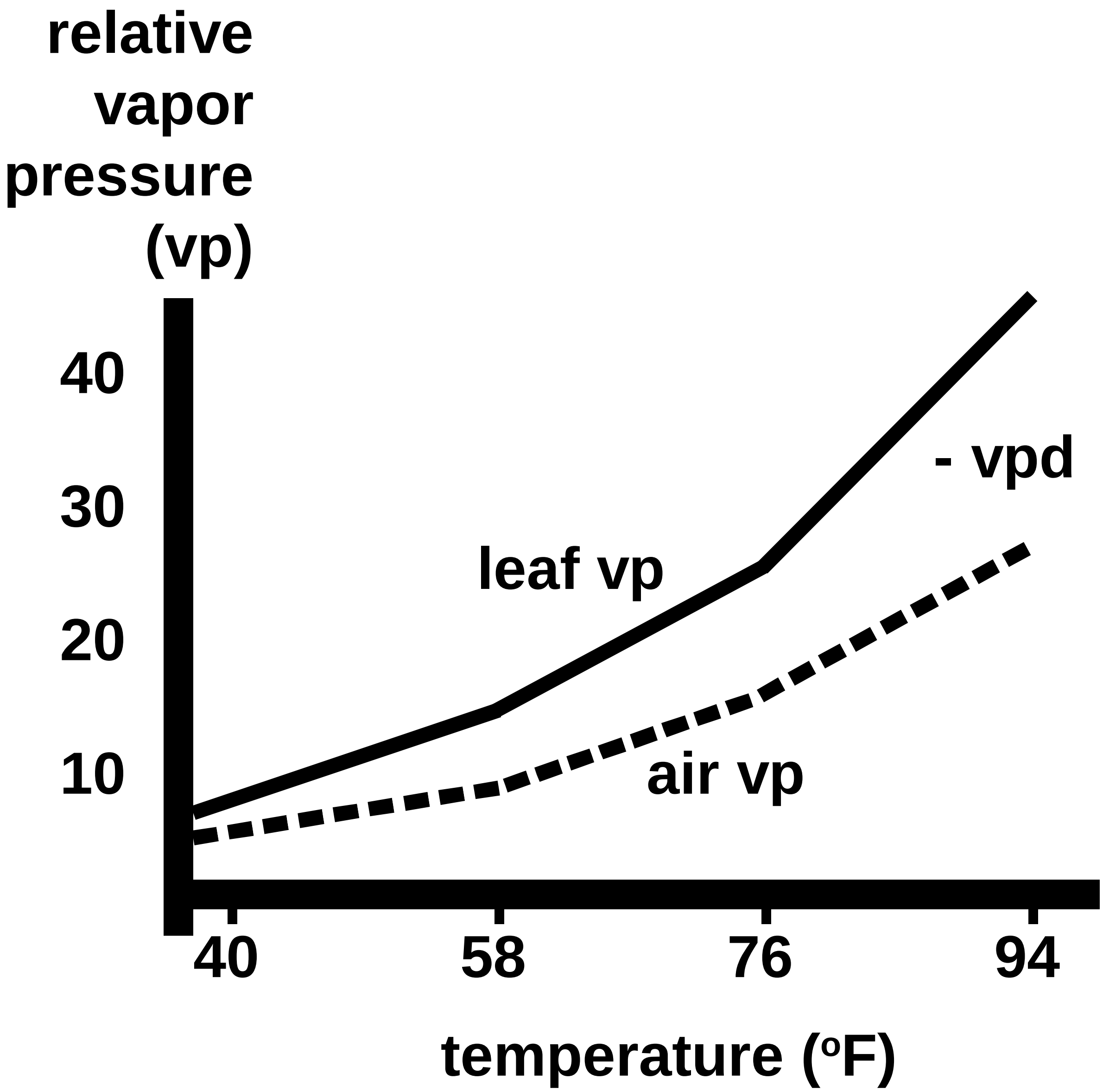

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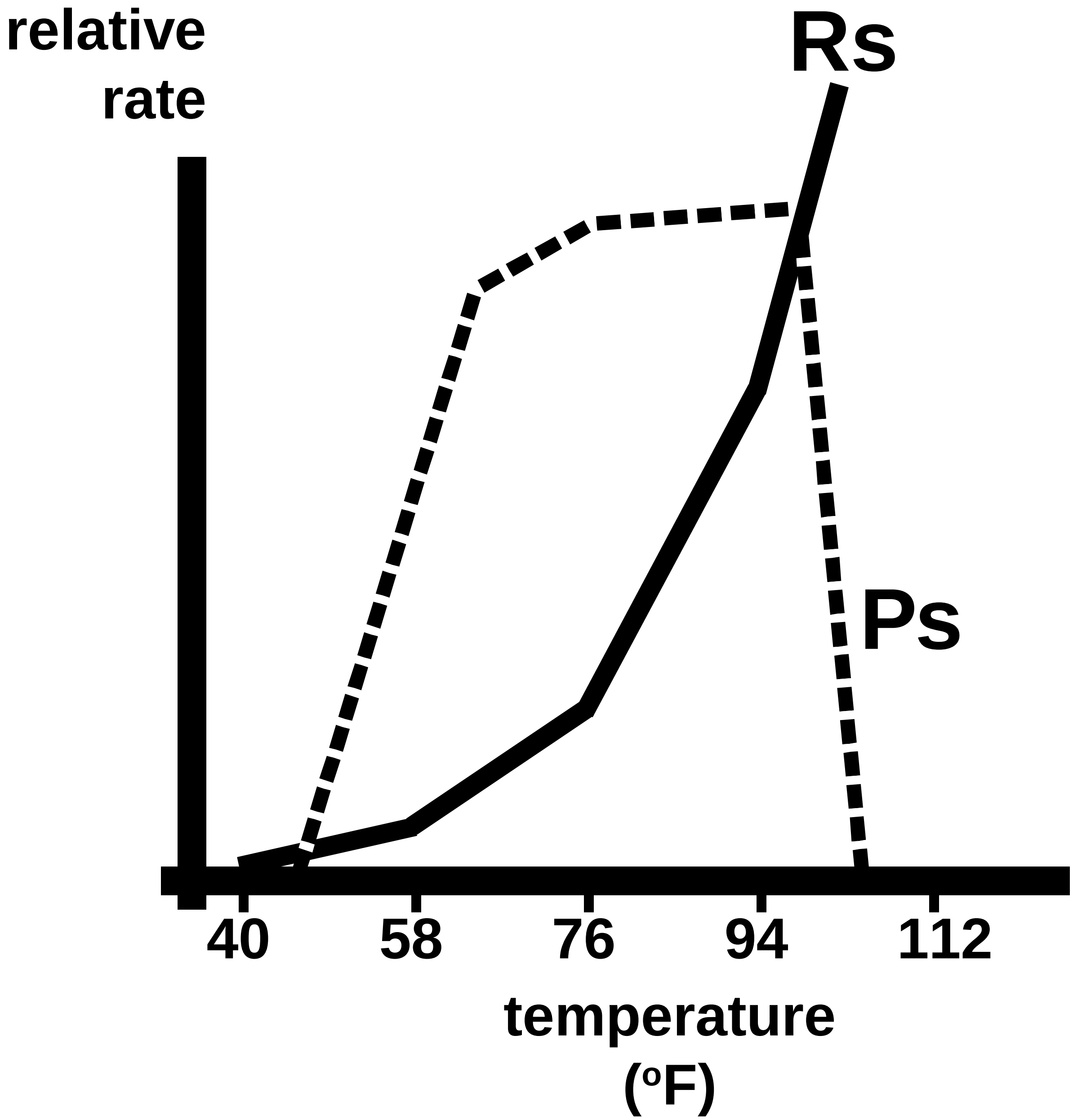
Figure #4: Effects of temperature changes on photosynthesis (Ps) and respiration (Rs).



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