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Drought Potential & Trees

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Water use, movement, and transpiration in trees is primarily a physical process based upon available energy (temperature) on a site. Trees living through a drought are stressed and damaged by water limitations for transport and cell health. Trees living under summer drought and large heat loads, are forced to spend any available water to survive. Drought stresses all tree life processes.

Stressing Out

Water is the most limiting ecological resource for most tree and forest sites. As soil-water content declines, trees become more stressed and begin to react to resource availability changes. A point is reached when water is so inadequately available, tree tissues and processes are damaged. Lack of water eventually leads to catastrophic biological failures and death.

Growing periods with little water can lead to decreased rates of diameter and height growth, poor resistance to other stress, disruption of food production and distribution, and changes in the timing and rate of physiological processes like fruit production and dormancy. More than eighty percent (80%) of variation in tree growth is because of water supply variability.

Climate Vulgarities

Climatic variation will always provide times of both water surplus and deficits, with the average being the most cited growing season value. It is non-average growing seasons and periods with exteremes of water availability, interacting with site constraints, like heat loading, which damage trees. Examining climatic patterns can suggest what is normal and what is atypical.

Figure 1 represents land areas in the Southeastern United States which share common climatic patterns during the month of June. Figure 2 represents land areas in the Southeastern United States which share common climatic patterns during the month of August. These two maps represent a composite multi-year average for three climatic attributes impacting trees -- evaporation, precipitation, and temperature. Climate expectations for tree health change over several months of the growing season. Generally, the larger the number listed, the less water stress expected for tree growth over time under normal conditions.

Drought Potential

Figure 3 shows multi-year composite climatic zones based upon annual average evaporation, precipitation, and temperature. As in the previous maps, the larger the number listed, the less water stress expected for tree growth over time under normal conditions. Prolonged drought conditions will be more devestating the higher the number listed, although the risk of drought may be less.

Figure 4 cites a temperature line, an evaporation level, and a precipitation amount forming areas with similar potential for droughts. Hot temperatures, moderate precipitation, and strong evaporation means significant risk of tree stress like drought.

Drought

The term "drought" denotes a period without precipitation, during which water content of soil is reduced to such an extent trees can no longer extract sufficient water for normal life processes. Droughts can occur during any season of the year. Water contents in a tree under drought conditions disrupt life processes.

Trees have developed a series of prioritized strategies for coping with drought conditions listed here in order of tree reactions:

1) recognizing ("sensing") soil / root water availability problems.
2) chemically altering (osmotic) cell contents.
3) closing stomates for longer periods.
4) increasing absorbing root production.
5) using food storage reserves.
6) close-off or close-down root activities (suberize roots).
7) initiate foliage, branch and/or root senescence.
8) set-up abscission and compartment lines.
9) seal-off (allow to die) and shed tissues / organs unable to maintain health.

As drought continues and trees respond to decreasing water availability, various symptoms and damage occurs. Tree decline and death is the terminal result of drought.

Wilting

Wilting is a visible effect of drought. As leaves dry, turgor pressure (hydraulic pressure) pushing outward from within leaf cells decreases causing leaf petiole drooping and leaf blade wilting. The amount of water lost before visible leaf wilting varies by species. Temporary wilting is the visible drooping of leaves during the day followed by rehydration and recovery during the night. Internal water deficits are reduced by morning in time for an additional water deficit to be induced the following day. During long periods of dry soil, temporary wilting grades into permanent wilting. Permanently wilted trees do not recover at night. Permanently wilted trees recover only when additional water is added to soil. Prolonged permanent wilting kills trees.

The relation between water loss from leaves and visible wilting is complicated by large differences among species in the amount of supporting tissues leaves contain. Leaves of black cherry (*Prunus*), dogwood (*Cornus*), birch (*Betula*), and basswood (*Tilia*) wilt readily. Leaf thickness and size alone do not prevent wilting as rhododendrons are extremely sensitive to drought with leaves that curl, then yellow and turn brown. By comparison, leaves of holly (*Ilex*) and pine (*Pinus*) are supported with abundant sclerenchyma tissue (i.e. tough, strong tissue) and do not droop readily even after they lose considerable water.

Closing-Up

One of the earliest responses in leaves to mild water stress is stomate closure. Stomates are small valve-like openings on the underside of leaves which allow for gas exchange and water loss. Stomates often close during early stages of drought, long before leaves permanently wilt. Different species vary greatly in their stomate closing response. Gymnosperms usually undergo more leaf dehydration than angiosperms before they close stomates.

Many trees normally close stomates temporarily in the middle of the day in response to rapid water loss. Midday stomatal closure is generally followed by reopening and increased transpiration in late afternoon. Final daily closure occurs as light intensity decreases just before sundown. The extent of midday stomatal closure depends upon air humidity and soil moisture availability. As soil dries, the daily duration of stomatal opening is reduced. When soil is very dry, stomates may not open at all. Under these dry conditions a tree can not make food and must depend upon stored food being mobilized and transported, if any is available. Drought cause a tree to run on batteries!

Stomatal Control

Trees resist excessive rates of water loss through stomatal regulation. Stomates can be controlled by growth regulators transported from the roots during droughts. Drought effects on roots, stomates and other leaf cells can limit photosynthesis by decreasing carbon-dioxide uptake, increasing food use for maintenance, and by damaging enzyme systems.

One effect of severe drought is permanent damage which slows or prevents stomatal opening when a tree is rewatered. Additional water supplies after a severe drought period will allow leaves to recover from wilting, but stomate opening (necessary for food production) to pre-drought conditions, may not occur for a long period after rehydration.

Stomatal closure will not prevent water loss. Trees lose significant amounts of water directly through the leaf surface after stomates close. Trees also lose water through lenticels on twigs, branches, roots, and stems. Trees in a dormant condition without leaves also lose water. Water loss from tree surfaces depend upon tissue temperature – the higher the temperature, the more water loss.

Leaf Shedding

Premature senescence and shedding of leaves can be induced by drought. Loss of leaves during drought can involve either true abscission, or leaves may wither and die. In normal abscission, an organized leaf senescence process including loss of chlorophyll, precedes leaf shedding. With severe drought, leaves may be shed while still full of valuable materials. Sometimes drought-caused leaf shedding may not occur until after rehydration. Abscission can be initiated by water stress but cannot be completed without adequate water to shear-off connections between cell walls. Oldest leaves are usually shed first. The actual physical process of knocking-off leaves is associated with animals, wind, or rain.

For example, yellow-poplar (*Liriodendron*) is notorious for shedding many leaves during summer droughts, sycamore (*Platanus*) sheds some leaves, and buckeye (*Aesculus*) may shed all of its leaves as drought continues. On the other hand, leaves of dogwood (*Cornus*) usually wilt and die rather than abscise. If water becomes available later in the growing season, some trees defoliated by drought may produce a second crop of leaves from previously dormant buds. Many times these leaves are stunted in appearance.

Photosynthesis

A major drought impact is reduction of whole-tree photosynthesis. This is caused by a decline in leaf expansion, changing leaf shapes, reduction of photosynthetic machinery, premature leaf senescence, and associated reduction in food production. When trees under drought are watered, photosynthesis may or may not return to normal. Recovery will depend upon species, relative humidity, drought severity and duration. It takes more time to recover photosynthetic rates after watering than recovery of transpiration (food demand lag). Considerable time is required for leaf cells to rebuild full photosynthetic machinery.

Failure of water-stressed trees to recover photosynthetic capacity after rewatering may indicate permanent damage, including injury to chloroplasts, damage to stomates, and death of root tips. Often drought can damage stomates and inhibit their capacity to open despite recovery of leaf turgor. When stomatal and non-stomatal limitations to photosynthesis caused by drought are compared, the stomatal limitations can be quite small. This means other processes besides carbon-dioxide uptake through open stomates are being damaged by drought. Drought root damage has a direct impact on photosynthesis. For example, photosynthesis of loblolly pine seedlings were reduced for a period of several weeks when root tips are injured by drought, even after water had been restored.

Growth Inhibition

Growth of vegetative and reproductive tissues are constrained by supply of growth materials, transport, and cell expansion problems. Cell enlargement depends upon hydraulic pressure for expansion and is especially sensitive to water stress. Cell division generating new cells is also decreased by drought.

Shoot Growth – Internal water deficits in trees constrain growth of shoots by influencing development of new shoot units (nodes and internodes). A period of drought has a multi-year effect in many species from the year of bud formation to the year of expansion of that bud into a shoot. Drought also has a seasonal effect of inhibiting expansion of shoots within any one year. The timing of leaf expansion is obviously later than shoot expansion. If shoot expansion is finished early, a summer drought may affect leaf expansion but not shoot expansion. In many trees, injury to foliage and defoliation are most apparent in portions of the crown in full sun. These leaves show drought associated signs of leaf rolling, folding, curling, and shedding.

Cambial Growth – Drought will effect the width of annual growth increments, distribution of annual increment along trunk and branches, duration of cambial growth, proportion of xylem to phloem, and timing and duration of latewood production. Cambial growth slows or accelerates with rainfall amounts.

Cambial growth is constrained by water supply of both the current and previous year. Last year's annual increment sets growth material supply limits on this year's growth. This year's drought will effect next year's cambial growth. Such a delayed effect is the result of drought impacts upon crown development, food production, and tree health. Drought will produce both rapid and delayed responses along the cambium.

Root Growth – Water in soil not penetrated by tree roots is largely unavailable. Trees with widely penetrating and branching root systems absorb water effectively, acting to prevent or postpone drought injury. A large root / shoot ratio reflects high water-absorbing capacity. Good water absorbing ability coupled with a low transpiration rate for the amount of food produced (high water-use efficiency), allow trees a better chance to survive drought conditions.

When first exposed to drought, allocation of food to root growth may increase. This provides more root absorptive area per unit area of foliage and increases the volume of soil colonized. Extended drought leads to roots being suberized to prevent water loss back to soil, and slows water uptake.

Biological Lag Effects

In determinant shoot growth species, environmental conditions during the year of bud formation can control next year's shoot lengths to a greater degree than environmental conditions during the year of shoot expansion. Shoot formation in determinant growth species is a two-year process involving bud development in Summer of the first year and extension of parts within the bud during the Spring of the second year. Drought during the year of bud formation in determinant growth trees decreases the number of new leaves formed in buds and new stem segments (internodes) present. Drought then influences the number of leaves, leaf surface area, and twig extension the following year when those buds expand.

Summer droughts can greatly reduce shoot elongation in species which exhibit continuous growth or multiple flushing. Drought may not inhibit the first growth flush, but may decrease the number of stem units formed in a new bud which will expand during the second (or third, etc.) flush of growth. If drought continues, all growth flushes will be effected.

For example, in Southern yellow pines (*Pinus*), late summer droughts will influence expansion of shoots in the upper crown to a greater extent than those in the lower crown. This is because the number of seasonal growth flushes varies with shoot location in the crown. Shoots in the upper crown normally exhibit more seasonal growth flushes than those in the lower crown. Buds of some lower branches may not open at all in droughts.

Drought Hardening

Trees previously water stressed show less injury from drought than trees not previously stressed. Trees watered daily have higher rates of stomatal and other tree surface water losses than trees watered less frequently. Optimum resource, unstressed pre-conditioning can lead to more severe damage from drought conditions. Trees challenged by drought conditions in this growing season tend to react more effectively to another drought period in the same growing season.

Advantage Pests

Drought predisposes trees to pests because of lower food reserves, poorer response to pest attack, and poorer adjustment after pest damage. Unhealthy trees are more prone to pest problems, and drought creates unhealthy trees. Attacks on trees by boring insects which live in inner bark and outer wood can be more severe in dry years than in years when little water stress develops. But, little water and elevated temperatures can also damage pest populations.

Heat and water deficit stress problems make trees more susceptible to pests and other environmental problems. A number of pathogenic fungi are more effective in attacking trees when trees are under severe water deficit or heat stress. Heat loving bark borers and twig damaging beetle populations can swell under heavy tree heat loads and water deficits. Loss of defensive capabilities and food supplies allow some normally minor pests to effectively attack trees.

Water Tick

A classic pest which thrives under drought conditions at the expense of trees is the parasitic flowing plants called leafy mistletoes (*Phoradendron* spp.). Trees under chronic water stress are especially damaged by mistletoe infections. Mistletoe must use tree gathered water, and generates much lower water potentials than tree leaves in order to pull in a greater proportion of tree water on a per leaf basis. Mistletoe has extremely poor water use efficiency and acts as a "water tick" on tree branches, leading to branch decline and death.

Wet & Wetter

Supplemental watering of trees can be timed to help recover water and minimize pest problems on surrounding plants. Watering from dusk to dawn does not increase the normal wet period on tree surfaces since dew usually forms around dusk. Watering during the normal wet condensate period (dew) will not change pest/host dynamics. Watering that extends the wet period into mornings or begins wet periods earlier in the evening can initiate many pest problems, especially fungal foliage diseases.

Visible Symptoms

In deciduous trees, curling, bending, rolling, mottling, marginal browning (scorching,) chlorosis, shedding, and early autumn coloration of leaves are well-known responses to drought. In conifers, drought may cause yellowing and browning of needle tips. As drought intensifies, its harmful effects may be expressed as dieback of twigs and branches in tree crowns. Leaves at top-most branch ends generate the lowest water potentials, and decline and die. Drought effects on roots cause inhibition of elongation, branching, and cambial growth. Drought affects root / soil contact (roots dry and shrink) and mechanically changes tree wind-firmness. Drought also minimizes stem growth.

Among important adaptations for minimizing drought damage in tree crowns are: shedding of leaves; production of small or fewer leaves; rapid closure of stomates; thick leaf waxes; effective compartmentalization (sealing-off) of twigs and branches; and, greater development of food producing leaf cells. The most important drought-minimizing adaptations of tree roots are: production of an extensive root system (high root / shoot ratio); great root regeneration potential; production of adventitious roots near soil surface; and, effective suberization and compartmentalization of root areas.

Conclusions

Trees only have a limited set of responses to any stressful situation as directed by their genetic material. Trees can only react to water problems in genetically pre-set ways. The eventual result of site limitations and stress like drought, will be death. Effective management, damage control, and minimizing drought stress can provide for long tree life.

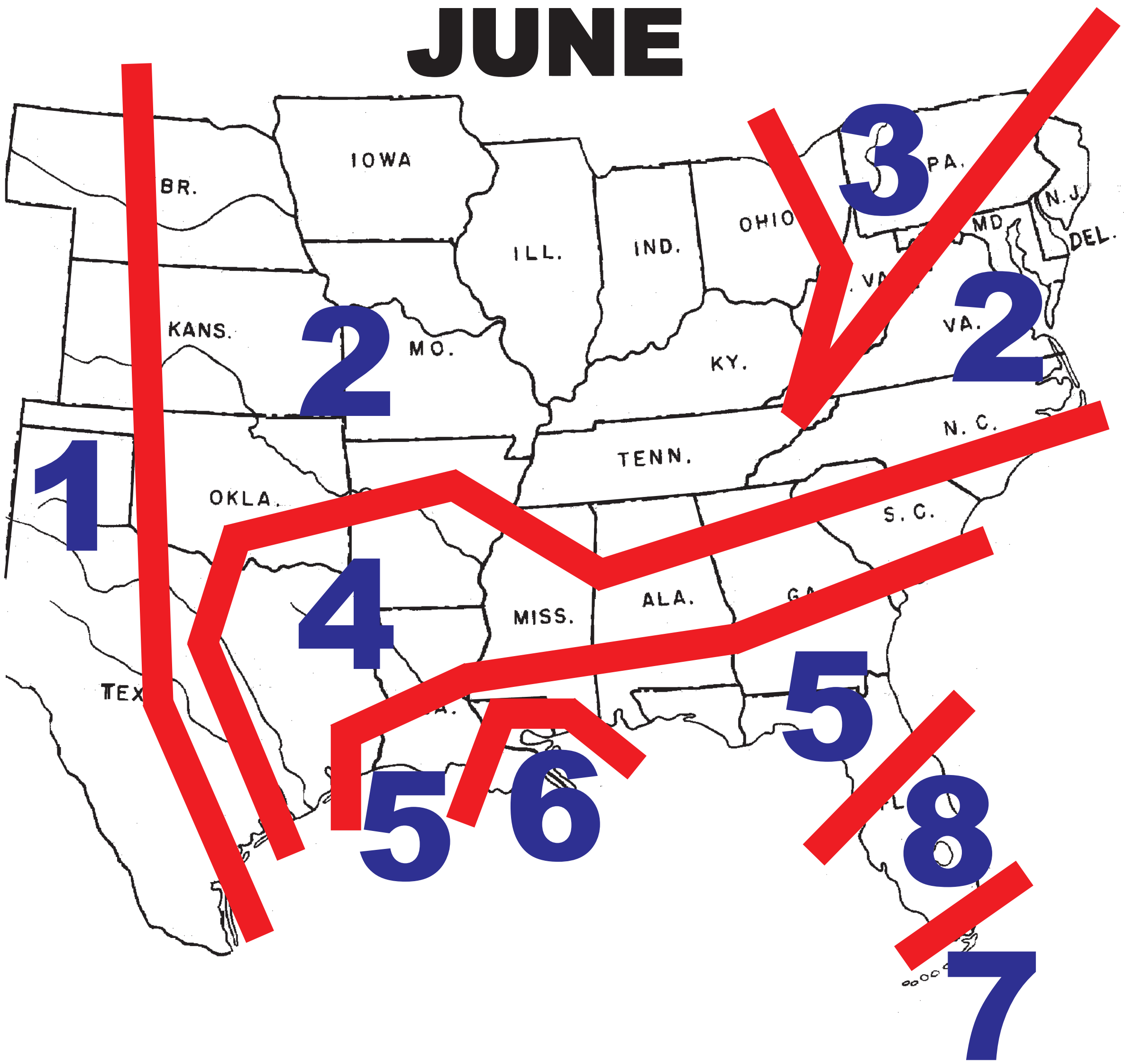

Figure 1: Areas of the Southeastern United States with similar composite multi-year average climatic features for the month of June. Composite data includes evaporation, precipitation, and temperature. Generally, the larger the number, the less water stress expected for tree growth over time under normal conditions.

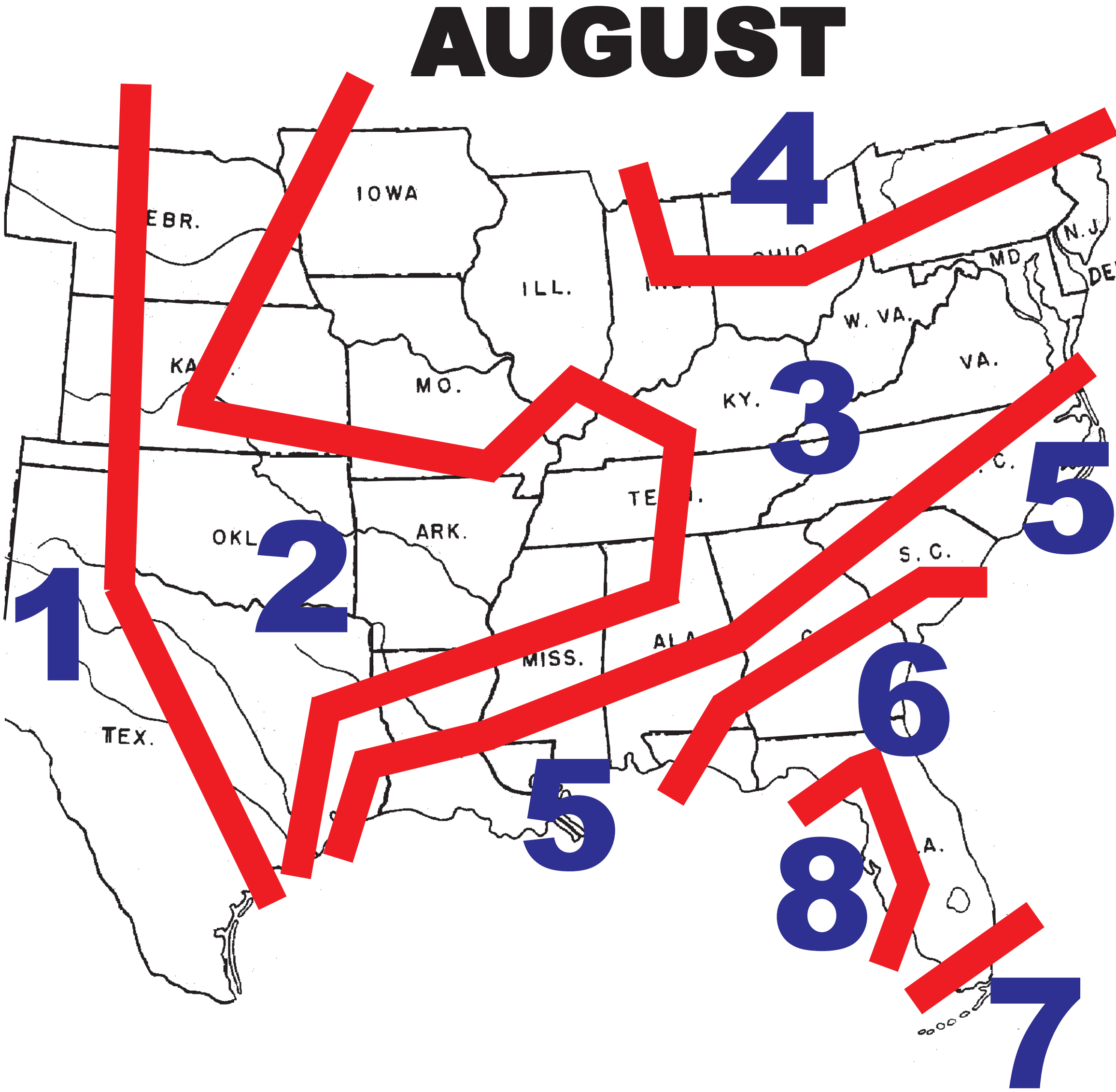

Figure 2: Areas of the Southeastern United States with similar composite multi-year average climatic features for the month of August. Composite data includes evaporation, precipitation, and temperature. Generally, the larger the number, the less water stress expected for tree growth over time under normal conditions.

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COMPOSITE CLIMATE ZONES

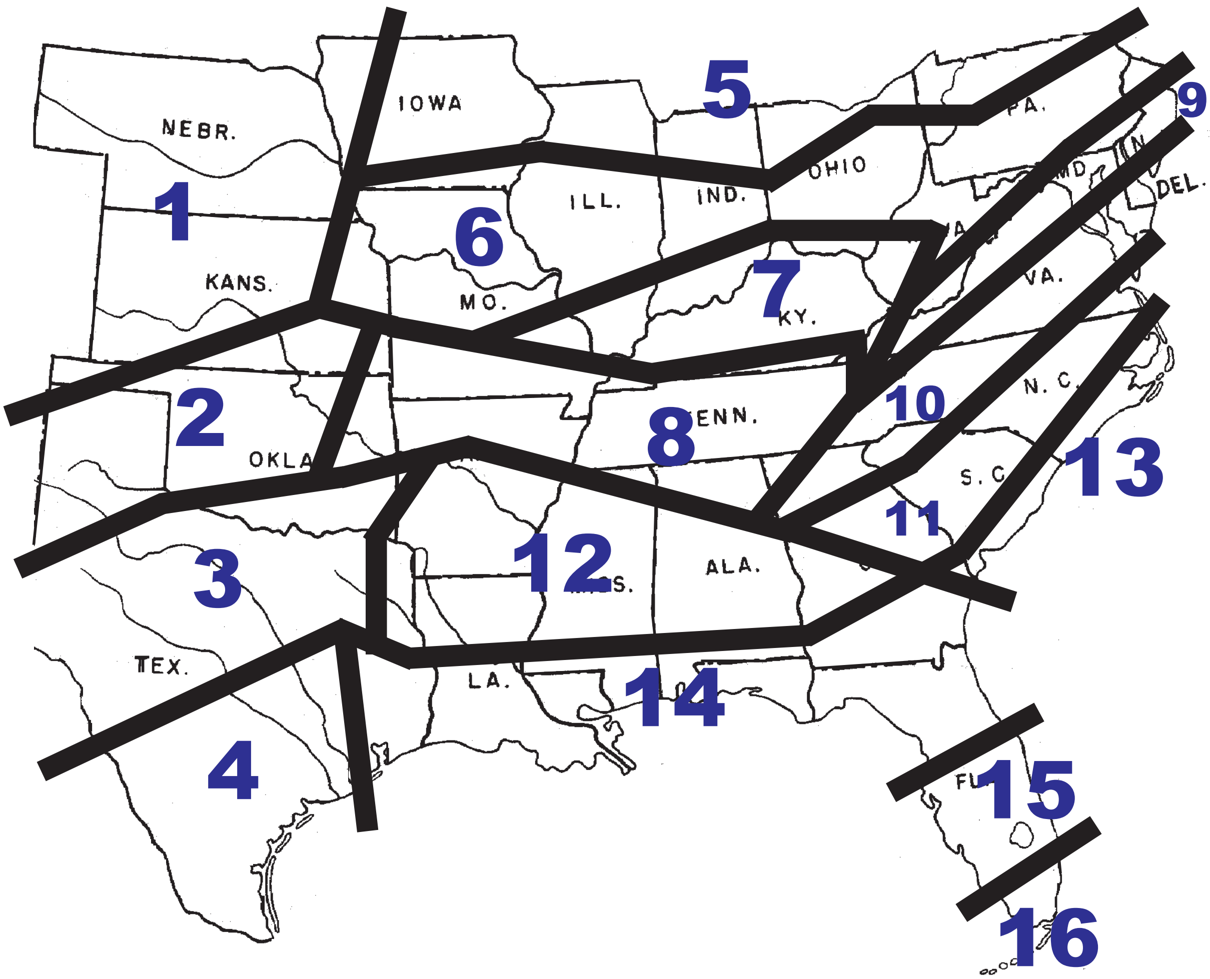

Figure 3: Areas of the Southeatern United States sharing similar composite climatic zones based upon annual average evaporation, temperature, and precipitation. Generally, the larger the number, the less water stress expected for tree growth over time under normal conditions. Prolonged unexpected drought conditions will have a more devastating impact on areas with larger numbers listed, although the overall risk of severe drought is less.

DROUGHT POTENTIAL

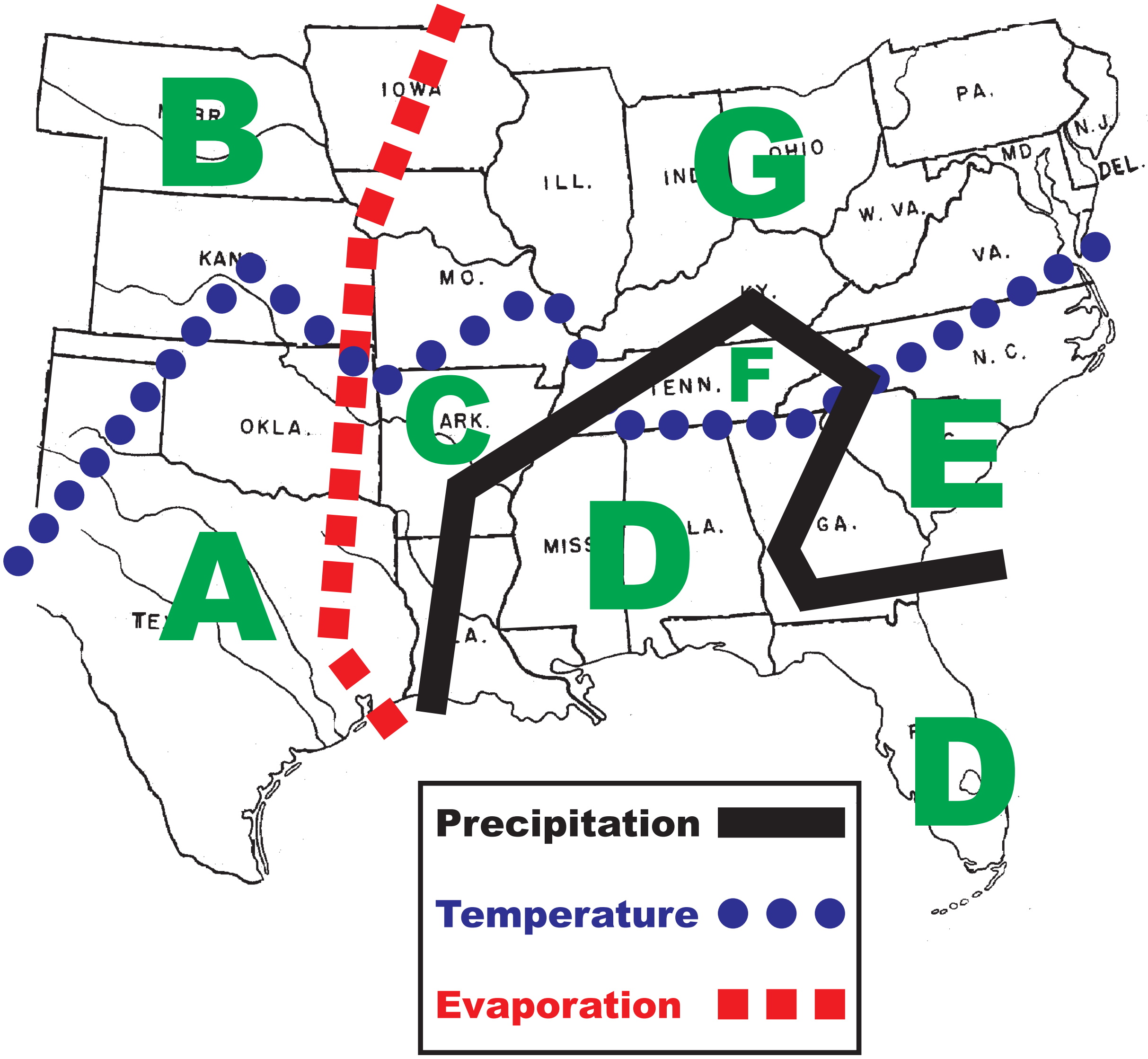

Figure 4: Tree Drought Potential Areas in Southeastern US.

A is greatest potential risk & G is least potential risk.

A & B = marginal for trees with great drought potential;
C & E = hot zone, moderate precipitation, strong evaporation;
D = hot zone, good precipitation, strong evaporation;
F = somewhat cooler, good precipitation, moderate evaporation;
G = cooler on average, less precipitation, moderate evaporation.

Priority order for average climatic values setting up drought impacts:
1) South of heat line (77°F); 2) East of evaporation line (16 inches per month); and,
3) South of precipitation line (60 inches per year).

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