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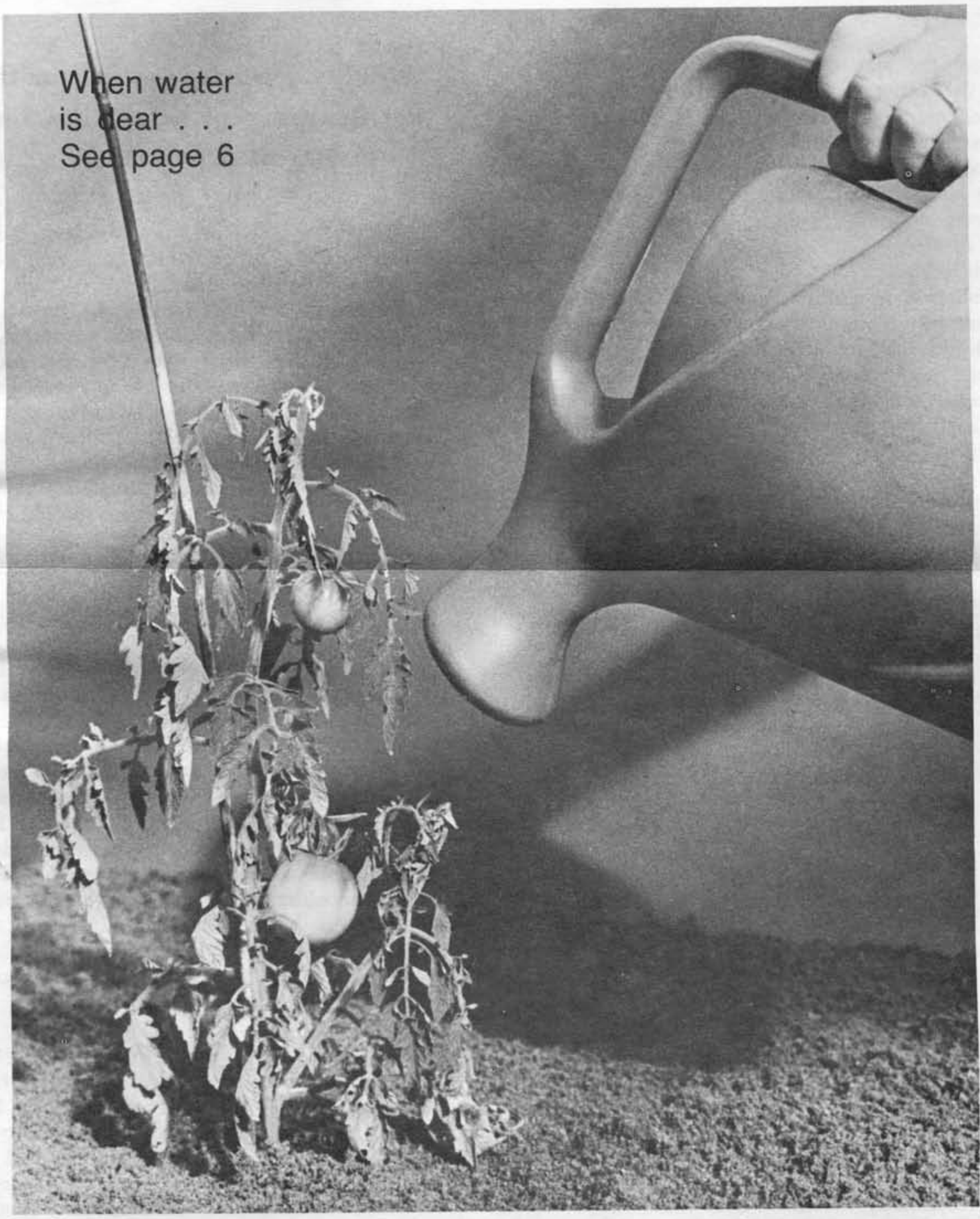
When water is dear . . . See page 6

THE CONNECTICUT AGRICULTURAL EXPERIMENT STATION NEW HAVEN

Long-term studies show Connecticut forest will survive defoliation

By George R. Stephens

Again, the specter of a season with widespread forest defoliation looms ahead. During the past three decades, ever-increasing portions of Connecticut's deciduous hardwood forest have been periodically defoliated by caterpillars. The stark nakedness of a winter landscape prevailing in June, when all should be green, naturally prompts the question, *"Will the forest survive?"* With some relief I can answer with a qualified yes.

Defoliation is a chronic occurrence in the forest, but generally the amount is slight and it usually goes unnoticed. The massive defoliation caused by an erupting population of voracious caterpillars, however, seizes our attention and causes alarm. The gypsy moth has gained great notoriety, but at certain times and places, native defoliators such as elm spanworm, fall and spring cankerworm, oak leaftier, and others have also been numerous and destructive. From the standpoint of effect on trees, however, it is likely that the timing and amount of foliage removed are more important than the defoliator.

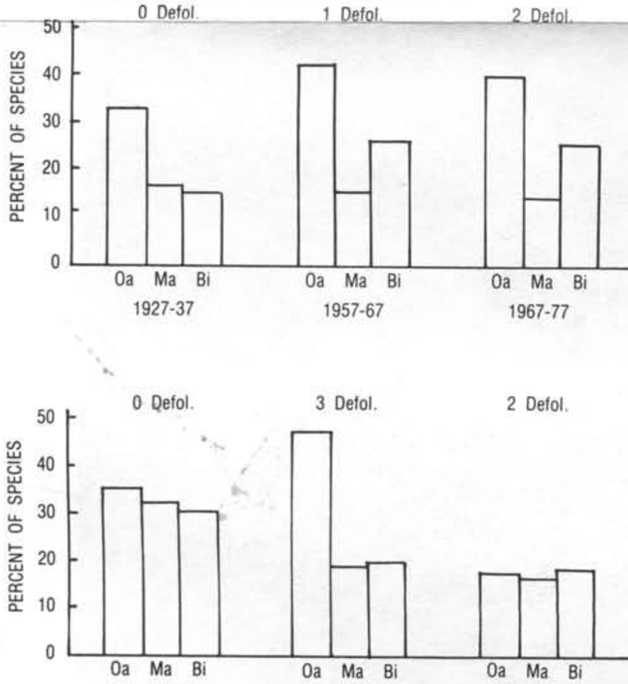

Figure 1. Mortality of major species groups (percent of the number present at the beginning of the decade), with and without defoliation, averaged over all sites. *Oa*, oaks; *Ma*, maples; *Bi*, birches. Top, defoliated in 1964 and 1971-72; bottom, defoliated in 1961-63 and 1971-72.

Mortality depended not only on the amount and frequency of defoliation, but also on the history of defoliation.

Observations of tree persistence, ingrowth and mortality from nine forested tracts scattered across Connecticut during times with and without defoliation give me the facts necessary to answer questions about the relationship of defoliation to tree mortality. Eight tracts have been examined at intervals of a decade, and during years with defoliation, broad classes of canopy defoliation were estimated from the ground and air. The ninth tract was studied annually for four years. For each tree, defoliation was estimated and its condition noted. About 40,000 trees are growing in the nine tracts.

Do trees die in the forest even without severe defoliation? Much of Connecticut's forest is evenaged, that is, the trees within a stand differ in age by not more than 20 years. Characteristically, the large number of stems in an evenaged forest is reduced as the stand grows older and trees become larger. Thus, mortality is a natural event. Generally, the smaller trees below the canopy die first. In a forest less than 50 years old, mortality during a decade without defoliation, 1927-37, averaged about 3 percent annually (Fig. 1). In an older stand in a more recent time, 1959-70, losses were lower, less than 2 percent annually. In general, losses were higher on dry sites than on moist sites and where the population of stems was great rather than small.

Does severe defoliation affect tree mortality? I can assess long-term effects from those tracts observed at the beginning and end of a decade. In 1964 one tract was defoliated 25 to 75 percent. During 1957-67 mortality on that tract averaged about 2 percent annually and did not differ from that expected on undefoliated tracts. On tracts defoliated 25 to 75 percent three times during 1961-63, mortality increased during 1957-67, especially on the drier sites; however, the increase on any site was never more than a dou-

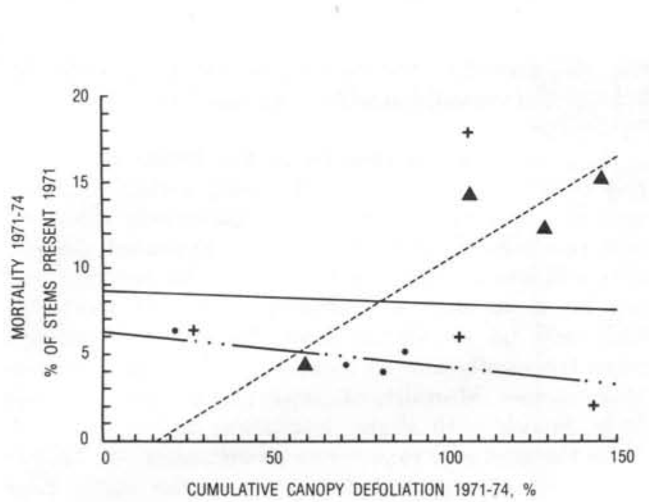

Figure 2. Mortality of major species groups during 1971-74 (percent stems present in 1971) in relation to the cumulative canopy defoliation of the group, averaged over all sites. Maple-birch (●), oak (▲), other major species (+).

bling. Similarly, on a tract defoliated twice, during 1962 and 1967, the annual mortality during 1959-70 averaged slightly more than 3 percent. On a nearby dry site, defoliated only in 1962, annual mortality during 1959-70 was less than 2 percent. Thus, mortality in the stands defoliated once in a decade did not differ from undefoliated stands. Where stands were defoliated two or more times in a decade, mortality increased, but the increase was never more than a doubling.

What effect does subsequent defoliation have? Earlier, I remarked that increasing portions of the forest have been defoliated periodically during the past three decades. The same tracts that were defoliated three times during 1961-63 were again defoliated twice during 1971-72 (Fig. 1, lower). Mortality ranged from 1.4 to 2.4 percent annually in these tracts, a small increase over the expectation for undefoliated stands. However, on the tract previously defoliated once in 1964, but defoliated twice during 1971-72, annual mortality was higher, 2.2 to 3.0 percent. This was well above the expectations (Fig. 1, upper). Therefore, it appears that mortality after defoliation depends not only on the severity and frequency of the current defoliation but also on the history of defoliation. Severe defoliation followed by increased mortality apparently reduced the amount of mortality that occurs after subsequent defoliation by eliminating susceptible trees.

Do marked increases in mortality occur during or soon after severe defoliation? So far all mortality has been averaged over a decade. Averaging smooths the effect of large changes in one or two years during the long interval. One tract was examined annually during 1971-74 to determine the amount of defoliation and condition of the trees. Portions were sprayed to prevent or limit defoliation. In a sprayed area where not more than a third of the canopy was defoliated in any year, mortality during 1971-74 was 1.2 to 2.3 percent annually, about the same as in other undefoliated stands. In an area almost completely defoliated in 1971 and defoliated about a third in 1972, annual mortality ranged from 1.3 to 3.5 percent. Mortality increased within a year after severe defoliation.

Thus, whether observations are taken over a long or a short interval the answer is the same. A single defoliation in a decade produced no noticeable effect on long-term tree mortality. Repeated defoliation was followed by increased mortality and the increase was evident soon after defoliation. Mortality depended not only on the amount and frequency of defoliation, but also on the history of previous defoliation.

Why are there so many large dead trees in the forest? Although the observation that defoliation was followed by not more than a doubling of normal mortality may provide some comfort, we may still be uneasy about the gaunt skeletons of large, lifeless-looking trees that dot our wooded hillsides. Normal mortality usually removes the small, overtopped or weakened trees and these pass unnoticed. Loss of larger trees that project into the canopy is clearly visible. Mortality after defoliation sometimes includes larger trees. In general, the older the forest, the larger the trees; hence, the more noticeable the loss. On a tract examined annually during 1971-74 where the canopy received minimal defoliation, loss of canopy trees was only a fifth of total mortality (Table 1). However, where the canopy was severely defoliated in 1971 and partially defoliated in 1972, loss of trees from the canopy comprised 40 percent of total mortality. Mostly pole-sized trees, 6 to 12 inches in diameter, died. Only 3 percent of mortality was from larger trees.

Are all tree species affected similarly? Connecticut's forest contains many species of trees, and we know that some species are more favored by defoliators than others. Aerial estimates of defoliation tell how much of the canopy was removed from a stand, but they tell nothing about individual species. The annual observations of defoliation in the forest plots provide information on individual species. In general, oaks are defoliated more often and more severely than are maples and birches. Even in years when defoliation is absent on other species, oaks may be

Table 1. Mortality of canopy trees during 1971-1974.

Cumulative defoliation	Mortality of canopy trees	
Percent	% canopy trees	% total mortality
51	3	19
103	6	21
122	8	27
138	14	41

partially defoliated. When defoliation of other trees is light to moderate, defoliation of oak is noticeably greater. Thus, oaks tend to be defoliated more frequently and more heavily than other species, especially maples and birches.

This greater defoliation of oaks is reflected in greater mortality. Comparison of cumulative canopy defoliation during 1971-74 with mortality during that same period showed that mortality of oak increased as canopy defoliation of oak increased (Fig. 2). On the other hand, despite increased canopy defoliation of maples, birches or other species, mortality was slight and unchanged.

Does defoliation actually cause hardwood trees to die? The answer is: probably not, but defoliation weakens trees and makes them susceptible to other insects and diseases that may kill them. For example, Heichel and Turner completely defoliated young red maple and red oak trees at our Lockwood Farm in June of three consecutive years. No trees died, but the defoliated trees produced fewer and smaller leaves in subsequent years and some twigs were attacked and killed by a fungal disease. Dunbar and I reported earlier the association of attack by the twolined chestnut borer and mortality of defoliated oak (*Frontiers of Plant Science*, 27:1, 1974). Recently dead or dying oak showed evidence of attack by the beetle, whereas apparently healthy oak did not.

What will the outcome be in the 1980s? If we can rely on the observations of the past, a single defoliation in a decade will have no measurable effect on tree mortality during the decade. Repeated defoliation will increase the mortality, but the increase will not be more than a doubling of normal mortality. Oak will be defoliated more heavily and perhaps more frequently and its mortality will be greater than other species. Mortality of maple and birch will change little. Stands with slight defoliation and low mortality in the past may experience greater mortality following severe or repeated defoliation in the 1980s. Ecologically, this reduction in susceptible trees may make the forest less vulnerable to future defoliation, but loss of valuable oak will diminish the economic value of the forest for timber production.

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A new (?) insect pest of red pine in Connecticut

By Mark S. McClure

Red pine, *Pinus resinosa* Ait., is native to North America and grows naturally in the northeastern United States and southeastern Canada. In Connecticut, New Jersey, and southern New York where red pine has been planted extensively for reforestation and landscaping, trees are being ravaged by a small, exotic, soft bodied insect, the red pine scale, *Matsucoccus resinosae* B&G.

The red pine scale attacks the branches primarily in the lower part of the crown and feeds on the sap beneath bark flakes. Infested branches become severely discolored and distorted and then die. Because this insect has two generations each year and each female can produce up to 600 offspring, populations of *M. resinosae* build rapidly and kill a tree within 5 to 10 years. No red pines have survived attack by this scale and no native natural enemies effectively control numbers of scale.

We have yet another destructive pest of red pine with which to contend.

Since its introduction into the United States and initial discovery in Easton, Connecticut in 1946, surveys have been conducted periodically to determine the area infested by the scale and its rate of spread toward the natural range of red pine. The southern part of the natural range of red pine lies only 50 miles north of the present infestation. Red pine scale has spread mainly by wind dispersal of young nymphs at the rate of about 2 miles each year. It inhabited most of western Connecticut in 1979 (Fig. 1).

During a survey in 1979, I found many red pines outside the area infested with red pine scale showing the same injury, discoloration of needles and death,

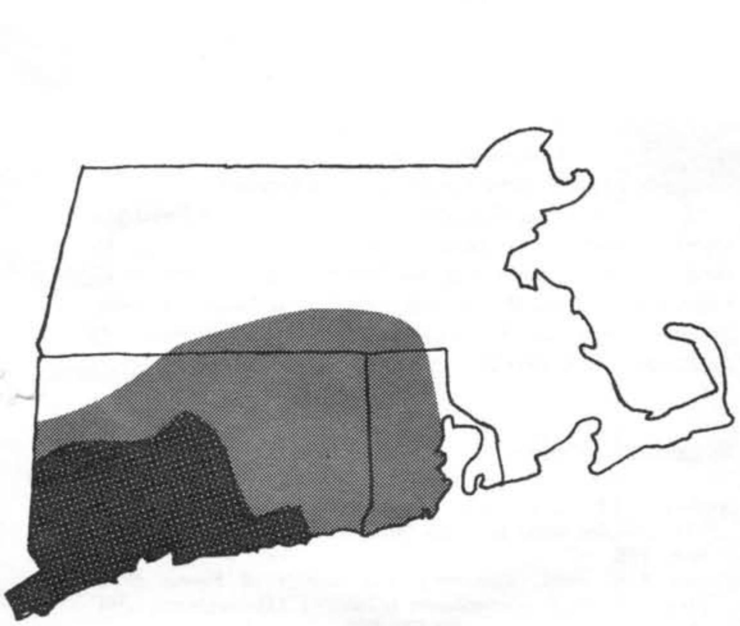

Figure 1. Distribution of the adelgid, *Pineus boerneri* (gray area) on red pine in southern New England. The black area gives the distribution of red pine scale, *Matsucoccus resinosae*, in 1979 in Connecticut.

caused by feeding of the scale. This discovery prompted me to ask whether red pine scale had recently spread rapidly or whether an unrecognized insect was responsible.

While examining branches from injured trees, I found a small, aphid-like insect known as an adelgid. It resembled *Pineus coloradensis* (Gillette) (Fig. 2), another adelgid which for years has been considered harmless to red pine. Had *P. coloradensis* become a pest, or more likely, had I found a new insect pest of red pine? Several bits of evidence suggested to me that a different insect was responsible. The unknown adelgid was feeding beneath bark flakes on twigs and at the base of needle sheaths, while *P. coloradensis* feeds on the needles. I also noticed consistent morphological differences between *P. coloradensis* and the unknown adelgid (Fig. 2).

To confirm these differences, I experimented in the greenhouse. I transferred both types of adelgids onto young, uninfested red pines. After seven weeks, I recorded the number of adelgids that survived and whether they were feeding on the twigs or the needles. The results confirmed that two species of adelgid infest red pine in Connecticut, one much more harmful than the other. Upon closer examination I observed that the harmful adelgid was *Pineus boerneri* Annand (= *Pineus laevis* Maskell?), previously reported on pines in California. My identification was confirmed by experts.

There have been no reports of injury to red pine resembling that from adelgids within the tree's natural range, which includes northern New England. Yet, I found adelgid nymphs on red pine branches that I collected in Washington County, Vermont in February 1976. Since characteristics of adults provide the only basis for distinguishing the adelgid species, I could not identify the specimens from Washington County, Vermont. However, the presence of adelgids on apparently healthy trees at the center of the natural range of red pine raised important questions in view of my discovery of a harmful adelgid in Connecticut. Were the Vermont adelgids *P. boerneri*, or were they *P. coloradensis* or another harmless species? If the adelgids were *P. boerneri*, why did the infested red pines have no apparent injury?

To address these questions and to determine the distribution of adelgids and the extent of their injury to red pine in New England, I sampled 30 sites in Connecticut outside the area infested by red pine scale and 46 sites throughout Maine, New Hampshire, Vermont, Massachusetts, and Rhode Island during July and August 1980. At each site I recorded the percentage of red pines showing injury, and I collected two branches from 10 trees. In the laboratory I counted the number of adelgids beneath 50 bark flakes and on 50 needles on each branch and identified all adults.

P. coloradensis is the only adelgid species I found in the natural range of red pine in northern New England (Table 1). It occurred at 49 of 76 sites, including the site in Vermont where I collected adelgid nymphs in 1976. I collected *P. boerneri* at three sites in south-central Massachusetts, all five sites in Rhode Island, and 20 sites in northeastern Connecticut (Table 1).

Red pines were badly discolored and dying at all six sites where densities of *P. boerneri* were more than 50 beneath 100 bark flakes. Even where densities of *P. boerneri* were lower, trees at 16 of 22 sites showed injury from adelgids. This indicates that *P. boerneri* is a common and destructive pest of red pine in southern New England. *P. coloradensis*, although distributed throughout the sampling area, exceeded 50 individuals on 100 needles only at three of 49 inhabited sites. Red pines were damaged by *P. coloradensis* only at these three sites where densities exceeded 100 individuals on 100 needles. Because all three sites where

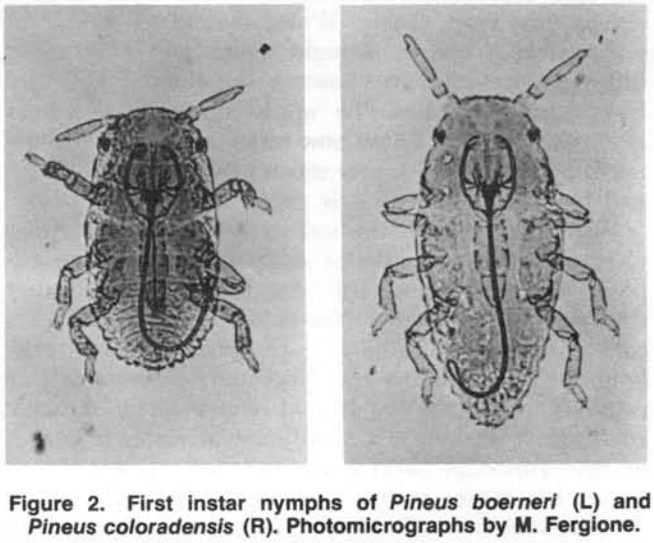

Figure 2. First instar nymphs of *Pineus boerneri* (L) and *Pineus coloradensis* (R). Photomicrographs by M. Fergione.

Table 1. Number of red pine sites sampled in the six New England states which were inhabited with *Pineus boerneri* and *Pineus coloradensis*.

	P. boerneri		*P. coloradensis*	
State	Present	Absent	Present	Absent
Maine	0	11	8	3
New Hampshire	0	6	4	2
Vermont	0	8	7	1
Massachusetts	3	13	16	0
Rhode Island	5	0	3	2
Connecticut	20	10	11	19
Total	28	48	49	27

P. coloradensis was numerous are south of the natural range of red pine, it may be that unsuitable habitats for red pine in southern New England reduced resistance of the trees to adelgid attack.

Because *P. boerneri* is firmly established in Connecticut and Rhode Island and is invading adjoining Massachusetts (Fig. 1), this adelgid probably is not really new; it probably has inhabited southern New England for many years. It likely escaped detection until now because the damage caused by red pine scale masked the potential destructiveness of *P. boerneri*. Also, *P. boerneri* probably was mistaken for *P. coloradensis*, its less injurious counterpart.

My discovery of *P. boerneri* means that we have yet another destructive pest of red pine with which to contend. I am studying factors that may control *P. boerneri* or limit its spread into the natural red pine growing areas of the northeastern United States and southeastern Canada.

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Conserving moisture in home gardens in times of restricted water use

By David E. Hill

In years of abundant rainfall and full reservoirs we can cope with short periods of summer drought by ample watering. Our only limit is our willingness to pay the cost of the amount of water required for satisfactory crop yields. When dwindling stocks of water restrict use in drought years, we must apply different strategies to conserve the limited moisture that nature supplies. To apply these management strategies we must know how much water is lost, how much a soil will hold, how much is available to plants, and how much the crop is going to use.

Water is lost from the soil in several ways. Excess water drains away. Water evaporates from the exposed soil surface and from the leaves of plants that extract it from the soil. Water entering the soil percolates downward, filling pore spaces between the grains. Gravity drains the large pores. The small or capillary pores remain full of water after drainage ceases in 24-48 hours. This volume of water is known as *field capacity*. Crop roots use most of this stored water, but some evaporates through the soil surface. As soil dries, the soil's capacity to retain water, mostly as surface films, eventually exceeds the plant's ability to absorb it. When the soil moisture is low, crops respond by wilting during the heat of the day but gradually recover at night. At some point, however, plants remain permanently wilted, even at night. The volume of water at this point in time is known as the *permanent wilting point*. The difference between the volume at field capacity and the volume at permanent wilting point is known as the *available water holding capacity* of the soil. Table 1 reveals that the variation in available water storage in an 8-inch plow zone or an 18-inch root zone in Connecticut soils is almost two-fold.

Incorporating organic materials into the soil before planting will increase its moisture holding capacity.

Porous sandy soils with few capillary pores retain about an inch of water in their plow zone while silt

Variations in climate that we experience are always a topic of conversation. We never seem to be at a loss for words because we seldom experience average weather. Instead, we are subjected to a constant barrage of dry and wet spells, cold and hot spells. Rainfall was below average in 1980 and so far in 1981 it does not seem to be adequate to restore reservoir and ground water supplies to normal.

In summer months our parched lawns and gardens remind us of drought but winter droughts generally go unnoticed until prolonged periods of rainfall deficit result in lowered reservoirs and ground water tables.

Long-term weather records tell us that our average rainfall in Connecticut is 46 inches, but the average varies between 42 and 50 inches at different weather stations. The records also tell us that the average rainfall is evenly distributed in each month of the year.

We have experienced 8 years in the past 25 in which mother nature has provided less than our average allotment. Severe water deficits were experienced in 1957, 1970, and 1980; but the droughts of 1962-1966 were the most severe and long lasting. Drought years tax our plants, reservoirs become dangerously low, and recharge of groundwater is minimal. Often usage must be curtailed to conserve water. Watering of plants is often restricted or prohibited. But even in years of bountiful rain, month-long droughty periods are the rule, rather than the exception.

In only 2 of 25 years has rainfall for each month during the growing season from June through September met our expected state averages. Forty of the 100 growing months experienced severe deficits ranging from 1-3½ inches; an additional 14 months had deficits less than 1 inch.

loams with abundant capillary pores retain nearly two inches of water in their plow zone. Most full-grown crops will use about 0.2 inches of water on a clear dry day and less than half of that on a cloudy day. Thus, sandy soil will retain only a 5-day supply while silt loam will retain almost a 10-day supply. But simple arithmetic will not help us balance plant needs for moisture. As the available supply diminishes, the plants become stressed and physiological changes occur. Wilting is common; it is a harmless mechanism that protects plants from moisture deficiency. Plants under stress respond in other ways: Growth is stunted. Root crops become less succulent and taste less sweet. Tomato plants, unable to extract water from the soil for transpiration rob moisture from the fruit causing blossom-end-rot.

Because abundant soil moisture produces normal growth and high quality food, we wonder what we, as home gardeners can do to conserve water and prevent plants from suffering water stress.

First, organic materials can be incorporated into the soil. Living plants (green manure), animal manure, and leaf-mold are commonly added. All store additional water for crop growth. In recent experiments, I found that 3 inches of leaf-mold rototilled into a coarse loamy sand increased the available water from 0.5 inches to 1.3 inches in the plow zone. This is a 4-day additional supply. In a loamy soil, however, the available supply was increased only 0.3 inches, which is a 2-day supply. In the loamy soil, the leaf-mold reduced germination of deeply-planted seeds and eventual yield because the soil remained wetter and cooler in early spring. Thus, the benefits of leaf-mold are greater in sandy soils than in loamy soils. Although green manure increases the moisture-holding capacity, its effects last only one season whereas leaf-mold lasts 2-3 years.

Second, mulches can be used at the surface to retard evaporation. Losses by evaporation can be substantial. In lysimeter studies at our Valley Laboratory in Windsor, at least 70% of the rain falling on bare soil between June and September was lost by evaporation. These losses would diminish if the soil were shaded by growing plants or if rain and watering were rare. After prolonged droughts, the moisture contents of mulched and unmulched soils would differ little. However, in the mulched soil, almost all water is transpired through the plants and little is lost directly through the soil surface.

Organic mulches, such as salt hay, straw, grass clippings, and leaves, conserve moisture in the root zone of the soil. These materials also cool the soil and sometimes delay flowering and maturation of fruit. Paper and plastic mulches reduce evaporation, but soils under paper and aluminized plastic that reflect the sun's energy may dry due to increased transpiration as the

Table 1. Average available water storage in soil texture classes expressed as inches of water.

	In an 8" plow zone	In an 18" root zone
Loamy sand	1.0	1.9
Sandy loam	1.3	2.8
Fine sandy loam	1.3	2.9
Very fine sandy loam	1.4	3.2
Loam	1.6	3.2
Silt loam	1.9	3.6
Silty clay loam	1.9	3.7

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crops mature. Soil moisture is depleted faster under reflective mulches than non-reflective mulches. In a recent study at Lockwood Farm, the more rapid drying of soil under paper mulch caused a 50% greater loss of tomato fruit from blossom-end-rot compared to losses in bare soil; losses under grass clippings were 50% less and raw leaves 80% less than under bare soil. Although losses of tomatoes from blossom-end-rot were least under raw undecomposed leaves, total yields were only slightly higher than in bare soil. We have seen similar responses with peppers and eggplant and even a suppression of yields of broccoli compared to bare soil. This is thought to be caused by substances released from the leaves during early decomposition. Therefore, grass clippings (not from lawns treated with herbicides) and black plastic film seem to conserve moisture best during the growing season without serious side effects.

Third, uncontrolled weeds compete with crops for moisture and nutrients. Handweeding and scalping the soil can reduce weeds, but deep hoeing prunes roots. Also, commercial growers and home owners have an abundant array of selective herbicides to combat weeds.

Finally, the way we irrigate our crops can conserve water. Water must penetrate 6-8 inches, the depth of most roots. Excess water will leach beyond the roots, carrying valuable nutrients with it. If insufficient water is applied, it penetrates shallowly and may be lost by evaporation. The evening seems to be the best time to water. Watering in the daytime encourages greater losses of water by evaporation and watering in the early morning may discourage friendly pollinating insects.

The strategy for conserving water is clear. Incorporating organic materials in the soil before planting will increase its moisture holding capacity. In the dry summer months mulches will reduce evaporation and will improve moisture supplies, produce larger plants, and increase yields. Daytime wilting of plants is a warning that moisture supplies are becoming low and it is time to apply at least an inch of water, if available. Even if water usage is restricted, conservation will generally shepherd the plants through dry times. When water use is restricted, without conservation measures in the home garden, the only alternative is to hope for rain.

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