RESPONSES OF TREE CROWN CONDITIONS TO NATURAL AND INDUCED VARIATIONS IN THROUGHFALL

Theodor D. Leininger[1]

Abstract—Concentrations of greenhouse gases, such as carbon dioxide, methane, and oxides of nitrogen, in the atmosphere are predicted to double in the next one hundred years. Forecasts of climatic variation across the southeastern United States resulting from these increases range from higher average temperatures and decreased summertime precipitation to lower maximum temperatures and greater precipitation. Since 1993, the effects of increased and decreased precipitation have been studied on an upland hardwood forest in the Walker Branch Watershed near Oak Ridge, TN. Soil moisture was altered by gravity-driven transport of throughfall from a 'dry' (-33 percent of ambient) treatment plot across an ambient treatment plot to a 'wet' (+33 percent of ambient) treatment plot. Beginning in August 1996, crown conditions of saplings and mature trees were monitored annually for responses to seasonal and treatment-related differences in soil moisture. The crown condition classification system developed by the USDA Forest Service, Forest Health Monitoring Program (FHMP) was used to rate tree crowns according to five variables: crown diameter, live crown ratio, foliage density, foliage transparency, and crown dieback. Preliminary analyses indicate differences in crown condition variables between soil moisture treatments and between years within treatments. A full analysis of five years of data, including August 2000, is presented. Results are discussed in relation to climate change predictions for the southeastern United States, and the usefulness of the FHMP crown condition classification system for monitoring forest health in a changing environment.

INTRODUCTION

Researchers have predicted concentrations of atmospheric greenhouse gases, such as carbon dioxide, methane, and oxides of nitrogen, to double in the next one hundred years (Edmonds and others 1984; Freidli and others 1986), thereby increasing the greenhouse effect and leading to an estimated increase in global mean temperature of between 1.5 and 4.5^{o} Celsius (National Academy of Sciences 1983). Uncertainty exists in the predictions of how climate will be altered by the predicted increases in greenhouse gases. Depending on which climate change models are used, forecasts of climatic variation resulting from increases in greenhouse gases range from decreases in summertime precipitation from 5 to 10 percent and increases in wintertime precipitation (Karl and others 1991) to greater summertime precipitation with lower maximum temperatures and higher minimum temperatures (Idso and Balling 1992).

The Throughfall Displacement Experiment (TDE), located on Walker Branch Watershed at the Oak Ridge National Laboratory near Oak Ridge, Tennessee, was designed to study changes in ecological processes that might occur by decreasing hydrologic inputs to one area of a forest while increasing them in an adjacent part of the forest (Hanson and others 1998). Since 1996, indicators of tree crown health have been monitored in response to throughfall displacement in the canopy of this upland hardwood forest in eastern Tennessee. Measurements of crown responses to either increased or decreased soil moisture resulting from displaced throughfall, were estimated for crown variables using a protocol developed for the Forest Health Monitoring Program (FHMP), State and Private Forestry of the US Forest Service (USDA Forest Service 2001).

This research was designed to utilize the unique hydrological manipulations occurring on the TDE site in an attempt to document any changes in tree crown appearance occurring from decreased or increased soil moisture resulting from the manipulation. This research has as its basis general principles of ecophysiological responses of plants to their environment. For example, a plant growing in soil that begins to dry out will typically allocate more carbon resources to roots at the expense of shoots in an effort to obtain more water. If this effect were to become great enough, tree crowns with reduced mass would appear more transparent, less dense, and perhaps exhibit branch dieback. These crown symptoms are typical of those associated with oak decline, a disease syndrome common in eastern hardwood forests (Ammon and others 1989) and often triggered by drought events (Maass 1989, Myers and Killingsworth 1992, Tainter and others 1990). An objective of this study was to determine the usefulness of the FHMP crown rating protocol in evaluating oaks (*Quercus* spp.) in decline.

[2]Project Leader, USDA Forest Service, Southern Research Station, Center for Bottomland Hardwoods Research, P.O. Box 227, Stoneville, Mississippi, 38776

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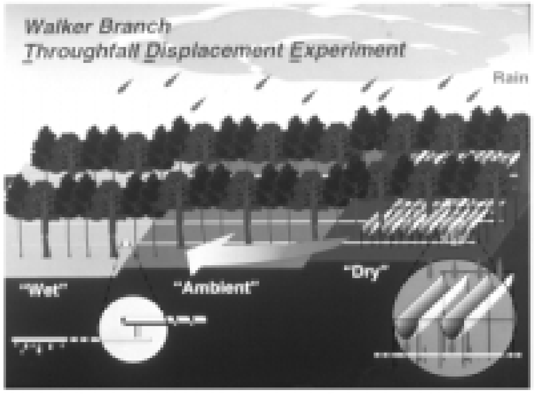

Figure 1—Schematic diagram of the Throughfall Displacement Experiment, Walker Branch Watershed, Oak Ridge National Laboratory, Oak Ridge, TN. Throughfall is captured in plastic troughs beneath the canopy of the Dry plot, flows by gravity through pvc pipes across the Ambient plot, and is released through small holes onto the Wet plot.

METHODS

The site for the Throughfall Displacement Experiment was chosen because of its uniform slope, consistent soils, a reasonably uniform distribution of vegetation, and its position just below the ridge top of the Walker Branch Watershed. The forest on the Walker Branch Watershed is upland hardwood dominated by white (*Quercus alba* L.) and chestnut (*Q. prinus* L.) oaks, sugar maple (*Acer saccharum* Marsh.), and yellow-poplar (*Liriodendron tulipifera*) in the overstory, red maple (*A. rubrum* L.) and blackgum (*Nyssa sylvatica* var. *sylvatica* Marsh.) in the midstory, and flowering dogwood (*Cornus florida* L.) and sourwood (*Oxydendrum arboreum* (L.) DC.) in the understory. There are about 20 tree species on the watershed. Changes in ecological processes resulting from this large-scale manipulation of throughfall will be evaluated in light of the more than 25 years of reference data collected on the Walker Branch Watershed. Complete information about the TDE study is available on the Internet at: www.esd.ornl.gov/programs/WBW/TDEAAAAA.HTM.

Since 1993, one third of the throughfall released by the forest canopy on the TDE has been captured by an array of troughs and is moved from one section of the forested area by way of a gravity-fed system of pvc pipes to another section of forest (figure1). The area from which one third of throughfall is being removed is the DRY plot, the area receiving the water captured on the DRY plot is the WET plot, and the area in between which receives an unaltered amount of throughfall is the AMBIENT (AMB) plot. Thus, in terms of ambient throughfall, the DRY plot receives 67 percent of ambient throughfall while the WET plot receives 133 percent of ambient throughfall.

Throughfall is intercepted in about 2000 subcanopy troughs (0.3 x 5 meters) suspended above the forest floor on the DRY treatment plot and is then channeled into the pvc pipe system (figure 1). These catchment-pvc pipe systems have been placed at regular intervals from the top of the site to the bottom. Each treatment plot is 80 x 80 meters. Reductions in soil moisture on the DRY plot were expected to be equivalent to the driest growing seasons of the 1980's drought, which resulted in reduced tree growth of some species.

Each 80 x 80 meter plot is further sub-divided into 64 sub-plots with 10 x 10 meter dimensions. Treatment plots are surrounded by a buffer of 10 x 10 m sub-plots. Each tree on the site greater than 10 centimeters was mapped and measured for height and diameter at the beginning of the study and is remeasured on a regular basis. The health of 30 randomly selected trees of various species throughout the understory, midstory, and overstory on each treatment plot was estimated using the FHMP crown condition rating protocol (USDA Forest Service 2001).

The FHMP crown condition rating protocol consists of five variables: diameter, live crown ratio, foliage density, foliage transparency, and dieback. Crown diameter is the average of the widest transect anywhere in the crown and the transect perpendicular to that, measured on the ground in meters. Live crown ratio is the percentage of the length of the live crown compared to total tree height. Foliage density is the percentage of crown branches and leaves that block light coming through a one-dimensional view of the crown taken as a whole. Foliage transparency is the percentage of the amount of skylight visible through the live, normally foliated portion of the crown viewed in the same manner as density. Transparency is the opposite of density. The estimate of crown dieback is a measure of branch mortality as a percentage of the total possible live crown, including dead branches. Dieback begins at the terminal portions of a branch and proceeds toward the trunk or base of the live crown.

Estimates of crown density and transparency were made using a standardized, printed scale that ranges from 5 percent to 95 percent in increments of 5 percent. Each variable except diameter was estimated by two people and averaged for each tree evaluated. The five variables were estimated in mid August from 1996 to 2000. The throughfall manipulation treatment was in effect three years when crown variable measurements were begun. Two-way ANOVAs were performed on the data for treatments by years and years by treatments. Data from the 30 trees sampled on each plot were used in the analysis without regard to tree crown position in the canopy. Percentage

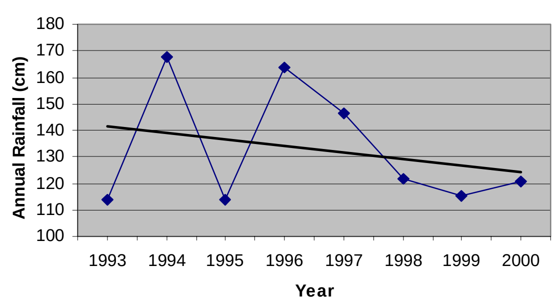

Figure 2—Annual rainfall (with trend line) from 1993 to 2000 at the Throughfall Displacement Experiment site, Walker Branch Watershed, Oak Ridge, TN.

data were transformed using the arcsine function prior to analysis. Tukey’s multiple comparisons tests were used to compare variable means.

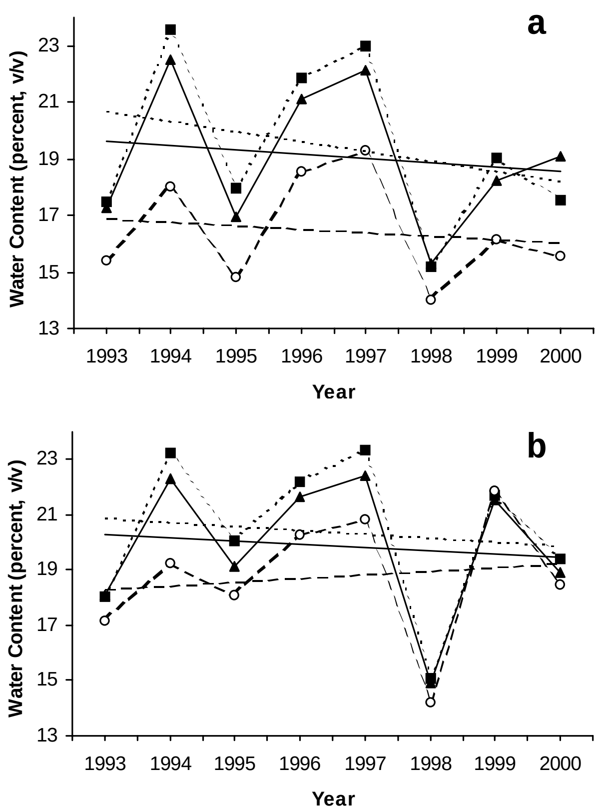

Figure 3— Average soil water contents (percent, v/v) and trend lines for the a) 0 to 35-cm and b) 0 to 70-cm soil profiles on the Wet (■), Ambient (▲), and Dry (❍) plots.

RESULTS AND DISCUSSION

Rainfall Data

Annual total rainfall at the TDE varied from lows of about 114 centimeters in 1993 and 1995 to a high of about 168 cm in 1994; 1996 had the second highest rainfall (figure 2). Rainfall in five of the eight years was below the trend line of decreasing average precipitation over the treatment period. Starting in 1993, there was a rainfall pattern of low, high, low, and high, followed by a four-year trend of decreasing rainfall.

Soil Moisture Data

This same general increasing and decreasing pattern and overall decreasing trend is evident in soil water content data, as measured by time-domain reflectometry on the three treatment plots, measured in the 0 to 35-cm and 0 to 70-cm layers of soil (figure 3a and b). The effect of throughfall displacement treatments is visible in the soil moisture data from the 0-35 cm layer, with a greater separation evident between the DRY and AMB treatments than between WET and AMB treatments. Treatment separation is less apparent as a function of soil moisture averaged over 70 cm of soil profile.

Crown Diameters

Average annual crown diameters were not affected by throughfall treatments during the five-year measurement period (figure 4a). The average tree crown on the AMB plot tended to be smaller than tree crowns on the DRY and WET plots when first measured in 1996 and they remained that way for the next four years. Crown diameters did not vary from year to year between throughfall treatments (figure 4b).

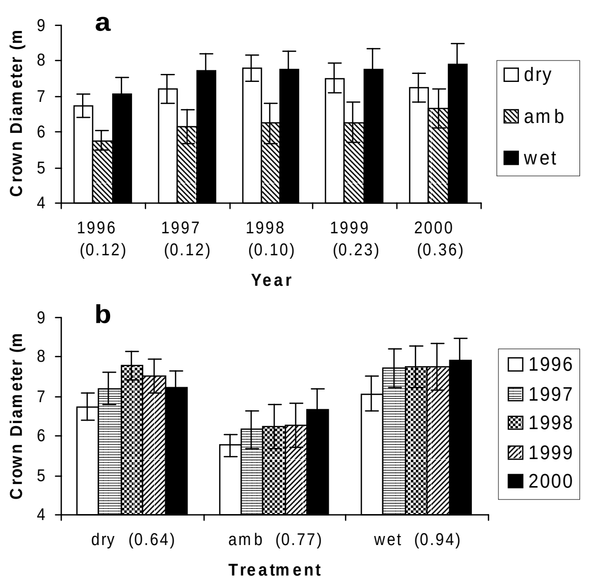

Figure 4—Mean crown diameters (“ s.e.m.) of sample trees for a) treatments by years and b) years by treatments. Numbers in parentheses on the x-axis are p-values from the ANOVA tests.

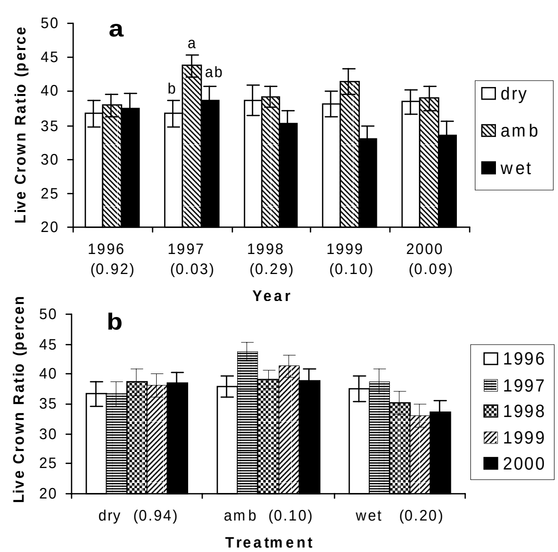

Figure 5—Mean live crown ratios (“ s.e.m.) of sample trees for a) treatments by years and b) years by treatments. Numbers in parentheses on the x-axis are p-values from the ANOVA tests. Means with different lowercase letters, in a year or treatment category, differ at p=0.05 by Tukey’s mean comparison tests.

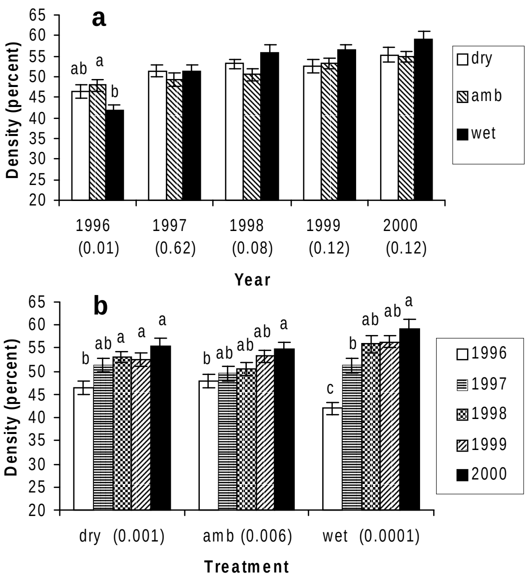

Figure 6—Mean crown densities (“ s.e.m.) of sample trees for a) treatments by years and b) years by treatments. Numbers in parentheses on the x-axis are p-values from the ANOVA tests. Means with different lowercase letters, in a year or treatment category, differ at p=0.05 by Tukey’s mean comparison tests.

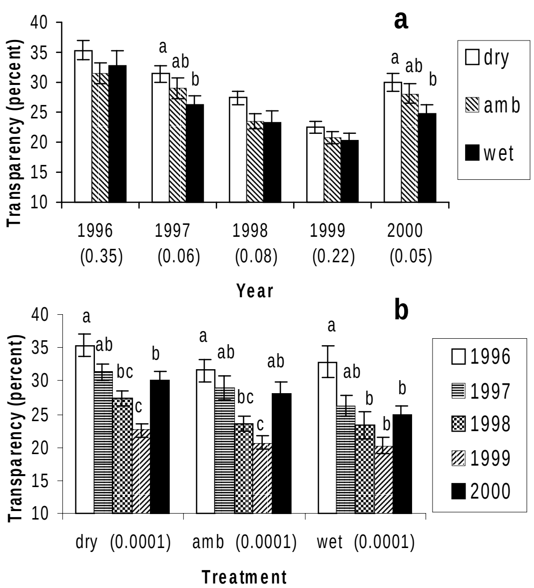

Figure 7—Mean crown transparencies (“ s.e.m.) of sample trees for a) treatments by years and b) years by treatments. Numbers in parentheses on the x-axis are p-values from the ANOVA tests. Means with different lowercase letters, in a year or treatment category, differ at p=0.05 by Tukey’s mean comparison tests.

Live Crown Ratios

Analysis revealed that the average live crown ratio on the AMB plot was greater than that on the DRY plot in 1997, but it is not clear what this means from a physiological standpoint (figure 5a). It is interesting to note that on the WET plot, there is a tendency for the average live crown ratio to decrease over time (figure 5b). This decrease is not statistically significant, but suggests a physiological adjustment of crown length due to added soil moisture, although in the opposite direction of what might be expected. An examination of physiological variables such as water use efficiency and chlorophyll concentrations would need to be done to determine if this was a meaningful trend, and to determine what other factors might be involved.

Crown Density

Average crown density on the AMB plot was greater than that on the WET plot in 1996, but this relationship was not consistent with trends in average crown densities measured the next four years when crowns on the WET plot tended to be denser (figure 6a). Crown densities increased consistently on all three throughfall treatment plots from 1996 to 2000, and this in light of overall decreasing rainfall and soil moisture over those years (fig 6b). One might expect crowns to be less well foliated under a drying soil regime.

Crown Transparency

Tree crowns tended to exhibit less transparency, which means that there was less light visible through them, as soil moisture availability increased on the plot (figure 7a). These differences were statistically significant in 1997 and 2000. Transparency also tended to decrease on all three throughfall treatments from 1996 to 2000 as rainfall tended to decrease over the same period (figure 7b). Decreasing transparency is consistent and expected in conjunction with the consistent increases in density measured for all plots. It is interesting to note the increase in transparency on all plots in 2000, which was the third in a series of three dry years (figure 7b). It could be that an effect of three consecutive dry years is becoming evident.

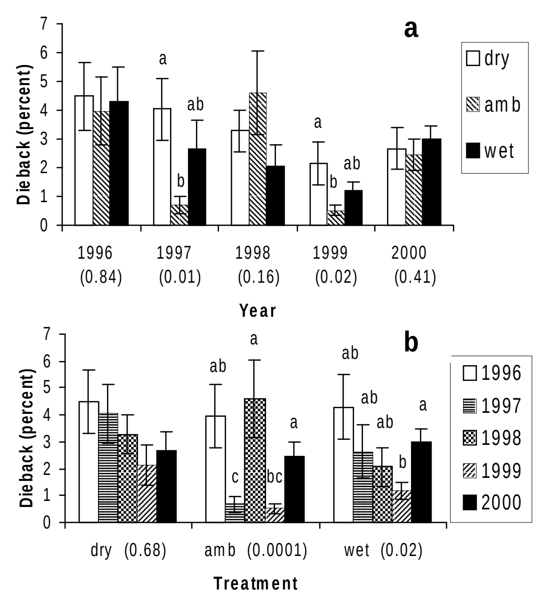

Figure 8—Mean crown dieback (“ s.e.m.) of sample trees for a) treatments by years and b) years by treatments. Numbers in parentheses on the x-axis are p-values from the ANOVA tests. Means with different lowercase letters, in a year or treatment category, differ at p=0.05 by Tukey’s mean comparison tests.

Crown Dieback

Crown dieback was quite variable across throughfall treatments over the years. In 1997 and 1999, dieback was greater on the DRY plot than on the AMB plot (figure 8a), which makes sense physiologically since drought-stressed trees should have more dieback than trees receiving adequate moisture. Dieback tended to decrease from 1996 to 2000 on all throughfall treatment plots as rainfall and soil moisture tended to decrease (figure 8b), which is opposite of expectations. Again, there is an increase in dieback on all plots in 2000, the third of three dry years.

CONCLUSIONS

The current transfer of one third of the throughfall from the DRY plot to the WET plot on the TDE is probably not sufficient to cause large enough visual differences in crown health to be differentiated using the FHMP crown rating protocol. While some crown condition responses make sense from a biological and physiological standpoint, particularly for transparency and dieback, many of the results are either too variable or are opposite of what might be expected biologically. The principal investigators of the TDE have discussed the merits of doubling throughfall displacement from one third to two thirds in an effort to increase responses of large trees to hydrologic manipulation. Early sapling mortality patterns showed more dogwood dying on the DRY plot then on the AMB and WET plots; however, the long-term pattern shows reductions of dogwood and red maple mortality on the WET plot compared to that on the Tree responses are confounded by the fact that large trees with large root systems are situated in fairly small plots in the experimental area. There is little doubt that roots of the larger trees are growing in other treatment plots, or outside the treatment area. As a result, these data need to be analyzed after having stratified them according to crown position, diameter, and perhaps species. This might reveal treatment responses not seen in the present analysis of the combined data set. More detailed regression analyses using physiological and site variables are currently underway, the results of which will be published as a chapter in a Springer-Verlag book describing all the various research efforts and current findings from the TDE site.

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