URBAN SOIL TEMPERATURES AND THEIR POTENTIAL IMPACT ON TREE GROWTH

by William R. Graves

Abstract. Urban soil temperature vary, but appear greatest where asphalt and concrete surfaces, direct solar radiation, and underground utilities are present. Temperatures above 30°C appear to occur frequently in soils of street tree planting cites in the central United States. The effects of temperatures typical of urban soils on the growth of several tree species has been evaluated. Honeylocust (*Gleditsia triacanthos* var. *inermis*) is among the most heat-resistant species studied to date, with a threshold temperature at which injury occurs of around 34°C. More extreme heat causes marked growth reductions and chlorosis of terminal leaves, which appears to result from deficiencies in iron and other essential elements. Red maple (*Acer rubrum* and *A.* x *freemanii*) cultivars vary in their capacity to sustain growth at 34°C in the root zone. Breeding and selection of tree genotypes with superior heat resistance for use at stressful urban sites appears feasible.

The life spans of city trees, particularly those along streets, are short. Numerous environmental conditions, including soil water extremes, high salt concentrations, and soil compaction, have been presumed to cause premature tree decline. Intensified efforts during the last decade to quantify the microclimatic conditions associated with urban planting sites have confirmed that the environments into which trees are installed in city landscapes are highly variable and are usually unlike conditions in native habitats where the species have evolved (14).

Temperature affects the rate of virtually all biochemical processes in trees and is a critical determinate of plant growth. Thus it seems surprising that the impact of urbanization on temperature profiles in tree microclimates has received relatively little attention from arboricultural researchers. Meteorologists have long recognized that urbanization results in urban heat islands. This means that temperatures in urban centers generally exceed temperatures in the surrounding area. Typically, the mean annual temperature in an urban center is 1 to 2°C higher that in outlying areas (13). This may seem minor, but consider that the difference may exceed 10°C when only night-time low temperatures are considered. Night temperature differences are believed to result from heat generated in buildings, by motors, and from other sources. Another important contributor to the heat island effect on night temperature is the gradual release of heat collected by urban surface materials during the day. What does this imply about surface and below-surface temperatures around urban tree planting sites?

There are few published data on the impact of urbanization on soil temperature. Monthly mean soil temperature at Urbana-Champaign, Illinois, was 4.1°C higher than the soil temperature at the same depth (10 cm) at forested sites nearby (12). An asphalt surface was found to increase soil temperature at a 15-cm depth by 7°C in a parking lot in New Brunswick, New Jersey (11). Soil temperatures in the Lafayette, Indiana, area were studied by Graves and Dana (3). They reported that the mean soil temperature at downtown street tree planting sites during July, 1985, was significantly higher than at urban sites away from streets, street-side sites in residential areas, and at a site in a nearby native woodland. Interestingly, there was little difference in soil temperature at depths of 5 to 50 cm at the downtown street tree sites, whereas there was a steady decrease in temperature with increasing depth in the forest.

These data are not particularly extensive but are consistent with the idea that urbanization causes an increase in soil temperature. The data of Graves and Dana (3) also show that temperatures vary greatly within a downtown area and tend to be highest along streets. But are elevated soil temperatures necessarily bad for city trees? How does an increase in soil temperature affect tree growth? We know from work on other types of plants that growth, along with most physiological processes, tends to increase gradually with increases in temperature. Eventually an optimal temperature is reached. Optimal temperatures for plants vary but rarely exceed 25 to 30°C for temperate species. Further increases in temperature cause very rapid decreases in reaction rates and growth (10). Even an increase of 1 to 2°C can cause significant losses in plant performance. Thus it is critical to know what the extremes in high temperature are at urban planting sites and to determine how temperatures in that range affect the growth of various tree species.

The magnitude of extremes of high temperature in urban soils appears to vary greatly with site conditions. Graves and Dana (3) reported that soil temperature in one tree planting pit in a sidewalk in Indianapolis was 69°C. The reason for this extreme heat was an underground utility steam line. It is no wonder that trees planted at this site had perished rapidly. The problem of underground utilities and other factors that are unique to urban soils may be rather widespread in cities. Each planting site should be evaluated individually and effective communication between city planners, utility personnel, landscape architects, and city arborists must be maintained to prevent severe environments in which no tree could survive. Soil temperatures may be much less extreme where underground utilities are not a factor. A maximum temperature of 32°C was found in root zones of city street sites in Lafayette, Indiana (3). This was during a July with below-average air temperatures, however, so higher temperatures might be expected during most other summers. Temperature extremes also might be likely in the soils of trees in raised containers with exterior walls exposed to intense solar radiation. Observations to date suggest that evaluating the response of trees to temperatures between 30 and 35°C is warranted so that selection of appropriate genotypes for stressful urban sites can be made.

Effects of Elevated Soil Temperature on Tree Growth

There are very few data available on the influence of high soil temperature on the growth of most tree species. Studies on mature trees are very difficult to perform, and most research to date has involved seedlings or rooted cuttings. Results must be viewed with caution because a mature tree at an urban site may respond differently than a younger plant grown under controlled conditions. I will limit my discussion to the broad, major findings of studies my coworkers and I have conducted. The species we have investigated to date include *Gleditsia triacanthos* var. *inermis* (honeylocust), *Sophora japonica* (Japanese pagoda tree), *Maackia amurensis* (Amur maackia), *Cercis canadensis* (Eastern redbud), *Ailanthus altissima* (tree-of-heaven), *Acer rubrum* and *A.* x *freemanii* (red maple), and *Malus domestica* (apple).

This discussion will focus on honeylocust and red maple, the two species for which we have the most information. All findings mentioned below were made using either seedlings (honeylocust) or rooted cuttings (red maple) grown in greenhouses and growth chambers. As a further caution, the reader should be aware that all plants were cultured hydroponically, usually in aerated solution. Root-zone temperature was controlled using systems similar to the one describe by Graves and Dana (4). Hydroponic culture aided in the precise control of temperature in the root zone, but often is viewed with skepticism because of apparent differences between roots grown in solution and those grown in soil or other aggregates. Graves (2) discusses the validity of data collected on plants cultured in solution.

Honeylocust. Honeylocust appears more resistant to elevated soil temperatures than most other species studied to date. Graves et al. (9) directly compared the responses of honeylocust to those of tree-of-heaven when grown with 24 and 34°C in the root zone. Stem elongation was greater at 34°C than at 24°C for honeylocust, but the reverse was true for tree-of-heaven (7,9). Tree-of-heaven grown with root zones at 34°C had lower root and shoot dry matter accumulation, smaller root-to-shoot biomass ratios, and reduced leaf area compared to tree-of-heaven at 24°C (9). But root-zone temperature did not affect these traits in honey locust. Data on transpiration rate at the two temperatures indicated that water uptake and transport was maintained at 34°C in honeylocust but not in tree-of-heaven.

A survey of the literature indicated that honeylocust is the only temperate tree species reported to sustain growth at root-zone temperatures above 32°C (9). It should not be assumed that trees of honeylocust would show greater survival at sites with high temperatures. Our data indicate that abundant soil water might be needed for honeylocust to maintain growth during exposure to heat. Many urban sites may lack adequate moisture, particularly during times of unusually high temperatures, so species like tree-of-heaven that reduce growth and conserve water use may be more capable of survival than species that do not regulate water use efficiently. Further research is needed to address the question of how multiple stress factors such as heat and drought affect tree growth. Graves and Wilkins (6) discuss multiple stress effects on seedlings of honeylocust.

Although we have found honeylocust can sustain growth at 34°C in the root zone, subsequent research has shown that 35°C significantly reduces growth and causes severe chlorosis in this species (1). Seedlings of honeylocust, Amur maackia, and Japanese pagoda tree were grown together under heat stress for varying numbers of hours per day. All species showed growth reductions at 35°C in the root zone for 24 hours/day (1). The chlorosis in honeylocust was limited to the youngest leaves, suggesting that iron (Fe) nutrition was affected by heat. It was confirmed that Fe content of the lamina decreased by approximately 50% in all species as the number of hours per day at 35°C increased from zero to 24 (1). Additional studies showed that the concentration of numerous other essential elements is affected by high root temperature (5). We also have found that heat-induced chlorosis occurs regardless of whether root zones are at pH 7 or pH 5, that the chemical form in which Fe is supplied to the roots has little effect on the chlorosis, and that Fe deficiency may not be the sole cause of chlorosis in heat-stressed honeylocust (5). The impact of high soil temperature on nutrient uptake and translocation merits additional research.

Red maple. Red maple is an interesting species for use in experiments on environmental stress because of its extensive native range and the varied habitats in which it occurs. Native populations extend from Canada to Florida and from the east coast to the central states. Within these areas, trees are found in both wet, low-lying areas and on dry, rocky elevations. Hence it seems reasonable to hypothesize that there is considerable variation between genotypes in resistance to urban environmental conditions, including high soil temperature.

For the past several years, workers in my research program have cooperated with Dr. Alden Townsend of the U.S. National Arboretum in Washington, D.C. Dr. Townsend has studied ecotypic variation between red maple genotypes and is also using selections from the wild in a breeding and improvement program. We have studied responses of named cultivars and newer selections to exposure to elevated root-zone temperature.

Red maple native to Florida grew similarly at root temperatures of 24 and 30°C, and growth was retarded at 36°C (8). Many named cultivars responded like the Florida genotypes to 36°C, and the growth of several cultivars was not affected adversely by 32° C in the root zone (15). Studies are needed on responses of different genotypes to 34°C because it appears this may be a critical threshold temperature at which differences in heat resistance between genotypes can be detected. We have found significant differences between named cultivars in responses to 34°C in the root zone. In an evaluation of six genotypes, terminal bud set was observed in only cv. Morgan and cv. Franksred, whereas 36°C caused bud set in all cultivars studied. Total plant dry matter accumulation at 34°C ranged from 21% to 69% of that of plants with root zones at 28°C (15). Symptoms of heat-stressed red maple plants include reduced lateral root development and foliar chlorosis, necrosis, and epinasty. Additional details of our findings on the responses of red maple genotypes to high root-zone temperature will be published elsewhere.

Our evidence to date supports the hypothesis that genotypes of red maple vary in resistance to high soil temperature stress. Genotypes with superior heat resistance may be used in breeding and selection programs as greater emphasis is placed on the importance of resistance to urban stresses. It seems likely that some cultivars already in the trade will be more suitable than others for installation at sites where high temperatures are common. However, we hope to conduct further research using mature plants and to investigate the effects of interactions of heat with other environmental factors (soil water availability, etc.) before making specific recommendations to arborists.

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Résumé. La température du sol en milieu urbain varie grandement mais apparaît être plus importante lorsqu'on est en présence de surfaces asphaltées ou bétonnées, irradiées directement par le soleil ou bien sous lesquelles il y a présence de câbles ou de conduites enterrés. Des températures supérieures à 30°C s'observent fréquemment dans les sols des sites de plantation d'arbres d'alignement au centre des États-Unis. Les effets des hautes températures du sol sur la croissance de plusieurs espèces d'arbres ont été évalués. Le févier inerme (*Gleditsia triacanthos* var. *inermis*) est parmi les espèces les plus résistantes à la chaleur étudiées à ce jour avec un seuil de température où les dommages se produisent à 34°C. Une chaleur plus extrême causait des réductions marquées de croissance et une chlorose des feuilles terminales. Les cultivars d'érable rouge (*Acer rubrum*) et d'*A. feemanii* sont très variables dans leur capacité à soutenir une croissance à 34°C au niveau des racines. L'hybridation et la sélection de génotypes d'arbres avec une résistance supérieure à la chaleur apparaît faisable.

Zusammenfassung. Die Bodentemperaturen im Stadtbereich variieren großteils, aber erscheinen am größten dort, wo Asphalt und Betonoberflächen, direkte Sonneneinstrahlung und unterirdische Versorgungsleitungen präsent sind. Temperaturen über 30°C treten gelegentlich in Böden auf städtischen Standorten in Zentralnordamerika auf. Die Auswirkungen von hohen Bodentemperaturen auf das Wachstum von einigen Baumarten wurden bewertet. Die Gleditschie (*Gleditsia triacanthos* var. *inermis*) ist bis dato eine der am meisten hitzeresistenten, untersuchten Baumarten mit einem Temperaturschwellenwert von 34°C, worüberhinaus Verletzungen auftreten. Mehr extreme Hitze verursacht sichtbare Wachstumsreduktionen und Chlorose der äußeren Blätter, Rotahorn (*Acer rubrum*) und *A. freemanii* Kultivare variieren in ihrer Fähigkeit, das Wachstum in der Wurzelzone bei 34°C aufrecht zu halten. Das Züchten und Auswählen von Baumgenotypen mit vorrangiger Hitzeresistenz erscheint durchführbar.