PLANT MOISTURE STRESS OF GREEN ASH TREES IN CONTRASTING URBAN SITES

by Bert M. Cregg

Abstract. On three dates in the late summer and early fall of 1994 we measured leaf water potential and gas exchange on green ash trees in 1) a park-like stand on the University of Nebraska-Lincoln campus, 2) in large planters (5.1 m^2) in an asphalt parking lot and 3) in small planters (1.8 m^2) in the same parking lot. The trees on the campus had consistently higher pre-dawn leaf water potential (ψ) and photosynthetic rates (P_S) than trees growing in the nearby parking lot. Within the parking lot, trees grown in the small planters had lower ψ and P_S than trees grown in large planters. The results support the supposition that urban environments increase plant moisture stress. Differences in growth and physiological performance between trees in the two planter types in the parking lot suggest that the adverse effects of the 'heat island' may be at least partially offset by adjusting the size of planter opening. Furthermore, models based on projected crown area, such as those developed by Bakker and Lindsey and Bassuk, provide useful guides for planning the amount of soil volume needed to ensure the survival and healthy growth of street trees.

Increasing our basic understanding of the relation of urban site factors to tree stress and health has a number of practical implications. These include providing guidelines for selecting better adapted trees for urban sites and developing management strategies that reduce tree stress. Unfortunately, aside from the work of Clark in the Pacific Northwest (3, 4) and Whitlow and Bassuk in the Northeast (8,16,17,18), relatively few systematic investigations of the effects of the urban environment on tree physiology and function have been conducted. The need for information on tree response to urban stress is especially acute in the Great Plains, where the urban forest has been described as an "oasis of trees surrounded by open prairie" (6). While many trees are grown in cities where native forests are common and the climate supports many tree species, urban trees in the Great Plains are 'twice removed' from their native habitat. That is, they are not only planted in a highly artificial and stressful environment, but many are also exotic species or seed sources planted far from their native range (14).

In order to understand the effect of urban stresses on trees in the Great Plains, members of the Stress Physiology Research Team at the USDA Forest Service National Agroforestry Center conducted the following study in Lincoln, Nebraska during the late summer and early fall of 1994. The objectives of the study were to: 1) evaluate the impact of planting site on tree moisture stress of an important urban tree in the Great Plains, green ash (*Fraxinus pennsylvanica*) and 2) examine three models to predict soil volume requirements of urban trees.

Materials and Methods

Site and plant materials. The study was conducted in August and September, 1994 in Lincoln, Nebraska. Lincoln is a city of approximately 200,000 people located in the central Great Plains of North America. The climate in Lincoln is continental; annual precipitation averages 685 mm, the mean January minimum temperature is -13°C and the mean July maximum temperature is 32°C (10). The soil on the site is mapped as an Urban land-Kennebec complex (15). The available soil moisture content of the Kennebec series is 20-22% in the upper 1 m of the soil profile. Thirteen green ash ('Marshall's seedless') trees divided into three groups were selected for study in north Lincoln near the East Campus of the University of Nebraska-Lincoln (UNL). One group of trees (campus) was located in an open, park-like setting on UNL Campus (Figure 1). The other two groups of trees were grown in restricted soil volumes in an asphalt parking lot adjacent to the campus. The pavement openings for parking lot planters were 5.1 m^2 [designated as large-planter (Figure 2)] or 1.8 m^2 [designated as small-planter (Figure 3)]. The soil around the large-planter trees was mulched with 10-15 cm of coarse bark, whereas the soil around the small-planter trees was covered with 10-15 cm of rock mulch. Members of the

Figure 1. Green ash tree on the campus site.

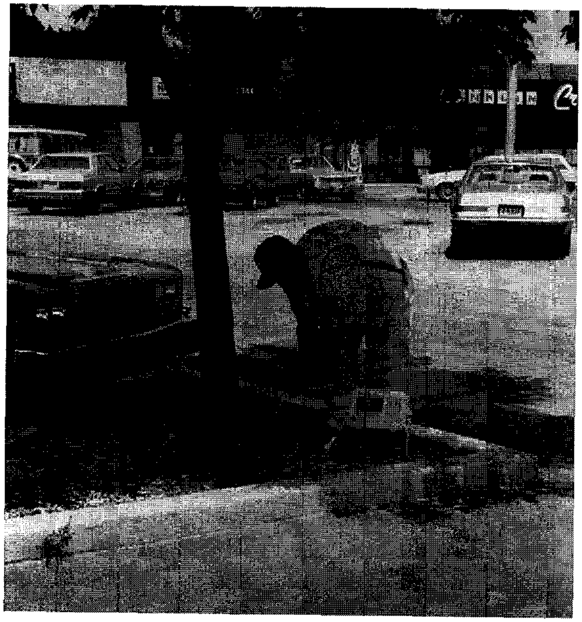

Figure 2. Green ash tree in a large planter.

Stress Physiology Research Group and I collected data on four trees each from the campus and the large-planter group and five trees from the small-planter group. The age of the trees was estimated from increment cores and height and diameter were measured directly (Table 1).

Figure 3. Green ash tree in a small planter.

Leaf water potential and gas exchange. We measured leaf water potential (ψ), leaf conductance to water vapor (g_{WV}), transpiration (E), and net photosynthesis (P_S) on three dates in the late summer and early fall of 1994. Leaf water potential was measured on single leaves with a pressure chamber at pre-dawn, 0900, 1100, 1300 and 1500 h on August 5 and September 9 and at pre-dawn, 1000 and 1400 h on September 29. We measured gas exchange (E, g_{WV}, and P_S) at the same time as ψ except for pre-dawn. Gas exchange was measured on three branches on each tree using an ADC LCA-3 portable gas exchange system (Analytical Development Co, Hoddeson, England). All gas exchange measurements were collected on the south side of each tree to ensure saturating light intensity. Ambient air temperature and relative humidity were recorded at the time of gas exchange measurements with the LCA-3. Vapor pressure deficit (VPD) was calculated from ambient air temperature and relative humidity.

Analysis. Mean midday gas exchange rates for each date were analyzed for site effects by repeated measures analysis of variance (9) using a completely randomized design. Where significant ($p<0.05$) differences were indicated, means were separated by Tukey's Studentized Range test

Table 1. Mean age, diameter, and height of green ash trees at three sites in Lincoln, Nebraska.

Site	Estimated age (years)	Mean diameter (cm)	Mean height (m)	Crown projection (m^2)
Campus	20	17.4 ± 1.63	6.41 ± 0.35	22.4 ± 4.14
Large planter	10	15.3 ± 0.49	6.47 ± 0.16	17.5 ± 1.36
Small planter	10	13.5 ± 0.48	6.01 ± 0.06	18.4 ± 1.24

* ± standard error of the mean

(11). Predawn and midday ψ data were analyzed in a similar manner. All data were analyzed using PC SAS (SAS Institute, Inc. Cary, NC).

Results and Discussion

Environment. Temperatures were below or near the long-term average in Lincoln during most of the summer of 1994. Departures from normal temperatures for July, August and September were -3.1, -1.8 and 0.4°C, respectively. Precipitation in July was 25 mm above the long-term average and August rainfall was near normal. September rainfall was 27 mm below normal and the longest period without rainfall during the summer occurred between September 7 and September 21. The location of the trees had a slight effect on air temperature at the time of the water relations and gas exchange measurements (Table 2). Although significantly different statistically, mean air temperature at the parking lot site was only 1°C warmer than the CAMPUS site. However, vapor pressure deficits (VPD, the combined effects of temperature and relative humidity) were approximately 20% higher on the parking lot than on the CAMPUS site.

Leaf water potential (ψ). In general, predawn ψ decreased from August 5 to September 29 (Figure 4). On the first two study dates, predawn ψ of the small-planter trees was significantly lower than ψ of the campus or large-planter trees. On the third date, pre-dawn ψ of the trees on the various sites was not significantly different. Although the campus trees generally had higher pre-dawn ψ, minimum daily ψ of trees on this site was as low or lower than the trees in the parking lot. The larger decline in ψ during each day for the campus trees is likely related to their higher transpiration rate (Table 2) and their larger overall size than the trees in the parking lot.

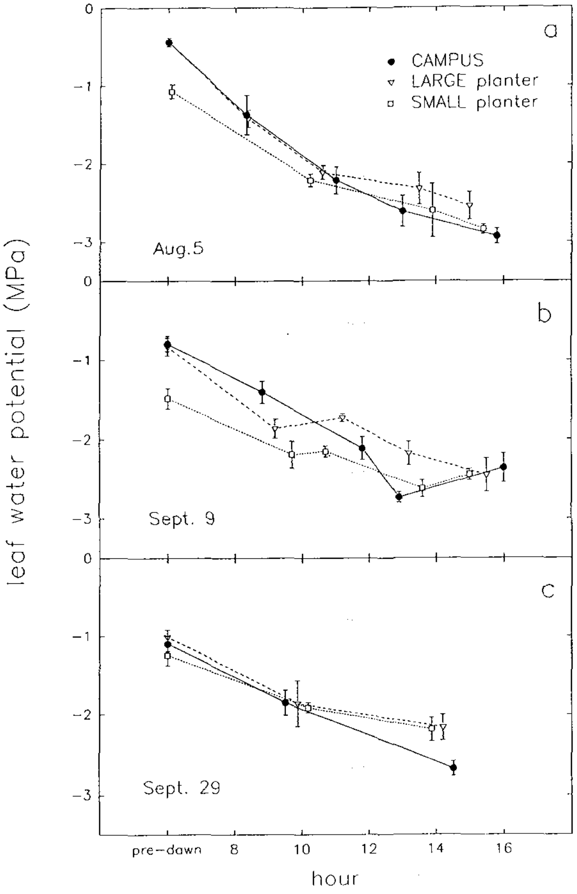

Figure 4. Mean leaf water potential of green ash trees grown on three sites in Lincoln, NE; a. August 5; b. September 9; and c. September 29. Error bars indicate ± standard error of the mean.

The minimum ψ values observed in this study, although low enough to reduce rates of gas exchange (see discussion below), were not low enough to cause visible injury to leaves of the

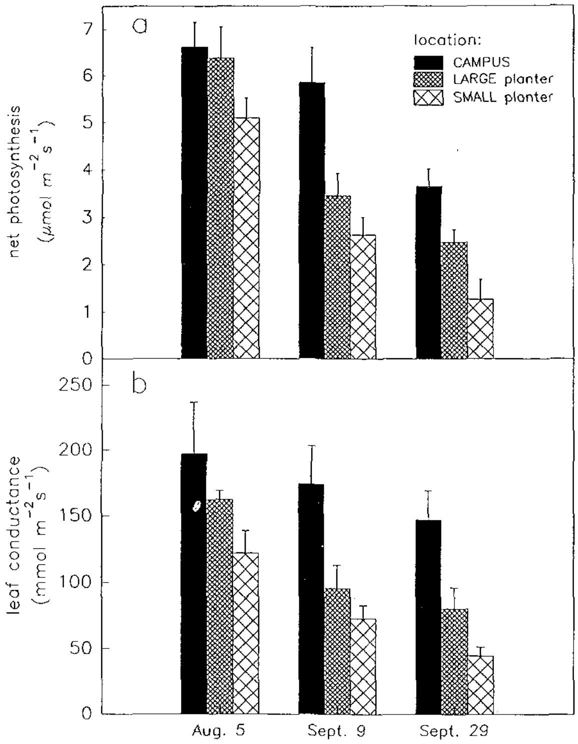

Figure 5. a. Mean daily net photosynthesis and b. leaf conductance to water vapor of green ash trees grown on three sites in Lincoln, NE. Error bars indicate ± standard error of the mean.

green ash trees. Data from Frank (5) suggests that green ash trees begin to show scorching of leaf margins and leaf senescence at ψ of approximately -4.0 to -5.0 Mpa.

Gas exchange. The parking lot environment consistently reduced net photosynthesis (P_S) and leaf conductance to water vapor (g_{WV}) of the green ash trees (Figure 5). Overall rates of P_S of trees in the small planters and large planters were 44% and 24% lower, respectively, than the campus trees (Table 2). On August 5 rates of P_S and g_{WV} were similar for trees on the campus site and in the large planters. However, gas exchange rates for the large and small planter trees declined markedly on September 9 and September 29. For all of the gas exchange traits examined (P_S, E, and g_{WV}), trees in the large planters were intermediate between trees in the campus and small planter groups. The relatively low rates of P_S of the trees in the small planters on the first two measurement dates likely reflect the lack of available soil moisture for these trees, as indicated by the low pre-dawn ψ values. Abrams et al. (1) observed a linear decline in P_S of green ash seedlings as ψ declined in controlled dry-down studies. Although the trees on the campus site reached lower minimum ψ on each date than the other trees, the trees in the small planters began each day with a lower ψ and were probably unable to maintain cell turgor needed for full stomatal opening. The trees in the large planters were likely able to forestall the effects of drought longer than the small-planter trees because they could draw water from approximately three times the soil volume of the trees in the small planters.

Implications for selecting planter size. The effects of size of the planters on ψ and gas exchange of the green ash trees support at least two models proposed to predict the soil volume required to meet the water demands of street trees. Bakker (2) estimated the soil volume required for street trees based on total crown projection. Lindsey and Bassuk (8) developed a more sophisticated model to estimate the soil volume required by a

Table 2. Mean environmental and physiological parameters for green ash trees grown on three sites in Lincoln, Nebraska on three dates in August and September, 1994.

Site	Temperature (°C)	Vapor pressure deficit (kPa)	Net photosynthesis (μmol/m²/s)	Leaf conductance (mmol/m²/s)	Transmission (mmol/m²/s)
Campus	26.8 a	1.57 a	5.37 a	172.8 a	1.51 a
Large planter	27.7 b	1.85 b	4.11 ab	112.7 ab	1.36 a
Small planter	27.6 b	1.89 b	3.00 b	79.9 b	1.07 a

Note: Means are averages of three measurement dates. Means within a column followed by the same letter are not significantly different at 0.05 level. Means separated by Tukey's Studentized range test.

tree. In addition to crown projection, their model included the leaf area index (LAI) of the tree, and climatic and soil factors. A third model, developed by Perry (12, 13) is based on stem caliper. Estimates for each of these three methods are presented in Table 3 for the green ash trees in the present study along with estimates of actual soil volume. We modified the model of Lindsey and Bassuk by using the actual transpiration rates observed in our study rather than estimating transpiration from long-term evaporation records.

Both of the models based on crown projection indicated that the trees in the small planters had an inadequate soil volume to supply water (Table 3). The estimate of minimum soil volume based on stem caliper also indicated that the small-planter volume was not adequate. This is consistent with the observation that the trees in the small planters were under higher levels of water stress than the large-planter or campus trees, even though the climatic conditions during the study were not particularly stressful for this region. While the three estimates agreed that the small-planter volume was inadequate to meet the water requirements of the trees, the methods yielded different results for the trees in the large planters. The model based on stem caliper suggested that the large soil volume (5.1 m^3) was more than the trees required (4.6 m^3). The soil volume estimate based simply on crown area indicated that the large soil volume was inadequate while the estimate based on model of Lindsey and Bassuk suggested the large-planter volume was barely adequate. The lack of significant differences between the large-planter and campus trees in predawn ψ on the first two measurement dates suggests that the large soil volume was adequate. However the large decline in P_S and g_{WV} on the second and third measurement dates does not support the prediction that the large-planter soil volume was adequate. Thus, the actual soil volume needed may lie between the two estimates based on crown projection.

Summary and Conclusions

The results presented here support the supposition that trees in urban environments are subjected to more severe stresses than trees in open, park-like stands. In this case the increase in trees moisture stress was attributable to restricted soil volume and, to a lesser extent, increased evaporative demand in the parking lot location. Differences in growth and physiological performance between trees in the two planter types in the parking lot suggest that the adverse effects of the 'heat island' may be at least partially offset by increasing the size of the pavement opening. Furthermore, models based on projected crown area, such as those developed by Bakker and Lindsey and Bassuk, provide useful guides for planning the amount of soil volume needed to ensure the survival and healthy growth of trees.

Table 3. Estimated soil volume (m^3) required by green ash trees grown on three sites in Lincoln, Nebraska

Method of estimation	Site Campus	 Large planter	 Small planter
Perry (12, 13) based on stem caliper	5.2	4.6	4.1
Lindsey and Bassuk (8) based on crown projection, soil and climatic factors[a]	6.7	5.2	5.5
Bakker (2) based on crown projection	16.3	13.3	13.9
Actual soil volume[b]	22.4[c]	5.1	1.8

[a] *To use the method of Lindsey and Bassuk, we assumed leaf area index (LAI)=4, available water holding capacity = 22%, and* rainfall frequency = 14 days. Mean water loss for trees on each site was estimated from leaf area and transpiration rate assuming a mean transpiration rate of 1.5 mmol $m^{-2}s^{-1}$, based on measurements from this study.

[b] Soil volume calculated from area of planters assuming a 1 m rooting depth.

[c] Soil volume of campus trees estimated as crown projection x 1 m rooting depth.

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Literature Cited

1. Abrams, M.D., M.E. Kubiske, and K.C. Steiner. 1990. *Drought adaptations and responses in five genotypes of Fraxinus pennsylvanica Marsh.: photosynthesis, water relations and leaf morphology.* Tree Physiol. 6:305-315.
2. Bakker, J.W. 1983. *Growing site and water supply of street trees.* Groen. 29(6):205-207.
3. Clark, J.R. and R.K. Kjelgren. 1989. *Conceptual considerations for the development of urban tree plantings.* J. Arboric. 15(10): 229-236.
4. Clark, J.R. and R.K. Kjelgren. 1990. *Water as a limiting factor in the development of urban trees.* J. Arboric. 16(8):203-208.
5. Frank, A.B. 1982. Water stress of four windbreak tree species during soil drying. J. Soil and Water Conservation. May-June, pp. 189-192.
6. Grey, G.W. and F.W. Deneke. 1978. Urban Forestry. John Wiley and Sons, New York, 279 pp.
7. Krizek, D.T. and S.P. Dubik. 1987. *Influence of water stress and restricted root volume on growth and development of urban trees.* J. Arboric. 13(2) 47-55.
8. Lindsey, P. and N. Bassuk. 1991. *Specifying soil volumes to meet the water needs of mature urban street trees and trees in containers.* J. Arboric. 17(6):141-149.
9. Moser, E.B. and A.M. Saxon. 1990. *Repeated measures analysis of variance: Application to tree research.* Can. J. For. Res. 20:524-535.
10. National Climate Data Center. 1994. Local Climatological Data for Lincoln, Nebraska. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Asheville, NC.
11. Neter, J., W. Wasserman, and M.H. Kutner. 1985. Applied Linear Statistical Models, 2nd Ed., Irwin Press, Homewood, IL, 1127 pp.
12. Perry, T.O. 1980. *The size design and management of planting sites required for healthy tree growth.* Proc. 3rd Annual METRIA Conference.
13. Perry, T.O. 1985. *Planting sites for a 3" caliper tree with room to grow.* Proc. 5th Annual METRIA Conference.
14. Schroeder, W.R. 1994. *Genetic improvement for prairie tree plantings.* J. Arboric. 20(1):46-49.
15. USDA Soil Conservation Service. 1980. Soil Survey of Landcaster County, Nebraska.
16. Whitlow, T.H. and N.L. Bassuk. 1987. *Trees in difficult sites.* J. Arboric. 13 (1):10-17.
17. Whitlow, T.H. and N.L. Bassuk. 1988. *Ecophysiology of urban trees and their management - the North American experience.* HortScience 23(3): 542-546.
18. Whitlow, T.H., N.L. Bassuk, and D.L. Reichert. 1992. *A 3-year study of water relations of urban street trees.* J. Appl. Ecoll. 29: 436-450.

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Résumé. À trois reprises à la fin de l'été et au début de l'automne de 1994, le potentiel en eau des feuilles et les échanges gazeux ont été mesurés sur des frênes de Pennsylvanie situés 1) dans un parc boisé du campus de l'Université de Nebraska-Lincoln, 2) en plantation dans de grandes fosses au milieu d'un stationnement en asphalte, et 3) en plantation dans de petites fosses au milieu du même stationnement. Les arbres du campus présentaient régulièrement des taux plus élevés de potentiel en eau dans les feuilles avant l'aube ainsi que de photosynthèse par rapport à ceux se trouvant dans le stationnement. Dans le stationnement, les arbres qui se situaient dans les petites fosses avaient des taux de potentiel en eau dans les feuilles et de photosynthèse plus faibles que ceux dans les plus grandes fosses. Les résultats obtenus confirment la supposition que l'environnement urbain accroît le stress hydrique chez les végétaux. Les différences de croissance et de performance physiologique entre les arbres plantés dans les deux types de fosses au milieu du stationnement en asphalte suggèrent que l'effet adverse de « l'îlot de chaleur » pourrait être en partie anhilé par l'ajustement de la dimension de l'ouverture vers l'air de la fosse.

Zusammenfassung. An drei Zeitpunkten im Spätsommer und frühen Herbst 1994 haben wir das Blattwasserpotential und den Gasaustausch von Eschen 1) an einem parkähnlichen Standort auf dem Campus der Universität von Nebraska-Lincoln, 2) in großen Pflanzgruben in einem asphaltierten Parkstreifen und 3) in kleinen Pflanzgruben in demselben Parkstreifen gemessen. Die Bäume auf dem Campus hatten vor Morgengrauen deutlich höhere Blattwasserpotentiale und Photosyntheseraten als die Bäume in dem Parkstreifen. Innerhalb des Parkstreifens hatten die Bäume mit den kleinen Pflanzgruben ein geringeres Wasserpotential und niedrigere Photosyntheseraten als die Bäume mit den großen Pflanzgruben. Die Ergebnisse unterstützen die Vermutung, daß die urbane Umgebung den Wasserstress der Pflanzen vergrößert. Die Unterschiede im Wachstum und der physiologischen Erscheinung zwischen den Bäumen mit dem großen und dem kleinen Pflanzloch in dem Parkstreifen legen die Vermutung nahe, daß der nachteilige Effekt der 'Hitzeinsel' zumindest teilweise durch das Korrigieren der Pflanzlochöffnung aufgehoben werden kann.