



United States
Department of
Agriculture

Forest Service

Research
Paper NE-487
1981

Water Requirements of Honeylocust

(Gleditsia triacanthos f. inermis)
in the Urban Forest

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MANUSCRIPT RECEIVED FOR PUBLICATION
2 MARCH 1981

Abstract

Water use by an urban tree was measured lysimetrically while water use by the same tree at a non-urban site was estimated by a model. Comparison of the measured and estimated water use showed that the urban honeylocust (*Gleditsia triacanthos* f. *inermis*) required an average of 155 percent of the water needed by the same tree surrounded on a homogeneous vegetated surface. Measured water use ranged from 60 to 303 percent of estimated water use. Advected energy from surrounding urban sites was the apparent cause of the excess transpiration. A water requirement this much greater in the city would place the trees under water stress during the growing season.

Introduction

Environmental stresses on urban forests are often caused by climatic or edaphic factors. Among the stress factors, available soil moisture has a great impact on vigor and growth. Moisture stress may interact with other stress factors, such as mechanical damage or insect infestation, to retard growth or increase mortality in urban forests (Himelick 1976), but moisture stress is probably the most important.

Evidence of water stress can be found in many cities. Premature senescence, general decline, and early mortality in urban honeylocust (*Gleditsia triacanthos* f. *inermis*) can be induced by water stress (Potts and Herrington 1979). Drought damage is often attributed to a simple lack of soil moisture. Soil moisture deficit can result when compacted soils and other impervious surfaces route precipitation away from forest sites before the water can infiltrate the soil. However, an excessive evaporative demand, even when soil moisture is available, can result in stress damage to urban forests. This study was an attempt to quantify the evaporative demands on the urban forest. Although evaporative demands in urban vegetation are thought to be excessive, only a few studies, such as Oke's (1979) comparisons of water demand by grasses between rural and urban areas, are available.

Methods

The urban site and tree

The study site was a grassy knoll adjacent to large structures and paved areas. The site had conditions similar to urban amenity spaces common in large northeastern cities, with structures and paved areas completely surrounding it. It is in Syracuse, N.Y. at 43°02'N latitude and 76°06'W longitude.

For a study species, we chose honeylocust (*Gleditsia triacanthos* f. *inermis*) because it is one of the most popular urban trees (Gerhold et al. 1975). It is also the most commonly used tree species in Syracuse amenity spaces.

The urban forest tree

We measured actual water use with a weighing lysimeter. One-m³ lysimeters were constructed of marine grade plywood, thoroughly sealed on the interior surface to prevent moisture leakage. The exterior surface was coated with a reflective paint to prevent excessive heat transfer into the lysimeter. Two lysimeter tanks were filled with soil. We installed six Wescor¹ psychrometers to monitor soil water potential in the lysimeter.

A tree was established in one lysimeter tank in the summer of 1976, and the soil surface was covered with plastic to prevent evaporation. No measurements were taken until 1977 to allow tree roots to occupy the soil volume in the lysimeter. Throughout the study we maintained soil moisture at a water potential between -1 and -4 bars. In 1977, the tree was 3 m tall, 4 cm in diameter, and had a leaf area index of 3.72. Leaf orientation was predominantly horizontal, and leaves were oriented evenly in all quadrants.

In the summer of 1977 the tanks were placed on a platform about 30 cm above the ground. Each tank, with a mass of about 1000 kg, was supported on a coiled tube containing degassed water. The two coiled tubes were connected to the inlet ports of a differential pressure transducer. The lysimeter without a tree was capped to prevent changes in water content, had a constant mass, and was used on the reference side of the transducer. The active side of the transducer was connected to the coiled tube supporting the lysimeter with the test tree. The lysimeter and transducer system was capable of determining mass changes of ±100 g in the 1000 kg lysimeter. However, because the lysimeters were above ground level, we experienced some temperature instability and some low frequency pressure oscillation due to wind.

At the lysimeter site, we recorded meteorological variables at hourly intervals during August 1977. We recorded net radiation just above the tree crown with Micromet instruments¹. Direct and diffuse photosynthetically active radiation (Lambda sensor), and beam and diffuse shortwave radiation (Kipp and Zonen radiometer) were measured at a point adjacent to the crown. Atmospheric humidity was measured with a condensation hygrometer (Cambridge) at the site. Air temperatures were measured with a shielded, ventilated mercury thermometer while leaf and soil temperatures were measured with an infrared thermometer (Barnes Engineering Co.). Wind was measured at crown height with sensitive sup anemometers (Casella anemometers). A complete 24-hour record was obtained on 7 days. Other days were excluded from the analysis because of extended storm periods or other unfavorable conditions.

The evapotranspiration model

We estimated tree water demand at a non-urban site with a model employing the micrometeorological data taken at the lysimeter site. The model selected to estimate water requirements was a single leaf energy budget form of the modified Penman equation (Monteith 1964). The equation had the form:

$$\lambda E = \frac{sQ_{nl} + \rho C_p (e_s - e_a) k_h}{s + \gamma (2 + k_h/k_s)}$$

where Q_{nl} = average net radiation absorbed per unit of leaf area, taken as crown net radiation divided by 2 when radiation was less than 300 wm^{-2} and 4 when radiation exceeded

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300 wm^{-2} . Correction factors were computed from data presented by Landsberg and others (1975) and Butler (1976).

ρ	=	air density
C_p	=	specific heat of air at constant pressure
e_s	=	saturation vapor pressure of air
e_a	=	actual vapor pressure
k_h	=	boundary layer heat conductance
γ	=	psychrometric constant
k_s	=	mean stomatal conductance
s	=	slope of the saturation vapor pressure curve
λ	=	heat of vaporization of water
E	=	evaporation

Although providing a framework for discussing forest evapotranspiration (Federer 1975), the modified Penman equation makes certain assumptions about energy transfers between vegetation and the environment. The most critical assumption is that there is no advection of energy or water vapor from surrounding areas. In this experiment, the lysimeter and study tree were on a site that did not meet the assumptions of the model. Thus, any discrepancy between measured and estimated water use is probably due to advection in the urban location (Miller 1980). Further, the difference is a good measure of the excess evaporation demand placed on urban vegetation.

The meteorological variables measured near the lysimeter provided the data necessary to solve the modified Penman equation except for k_s and k_h . We measured stomatal resistances on the lysimeter tree (under varying soil water potentials, leaf water potentials and visible light flux densities) with a diffusion porometer (Lambda) and computed k_s as the reciprocal of stomatal resistance. The boundary layer conductance for heat, k_h , was assumed to approximate the conductance for water vapor (k_p) (Monteith 1964). The value of k_h in a mixed convection regime was derived from the relationship derived by Campbell (1977) and corrected for hypostomatous leaves:

$$\frac{1}{k_h} = 180 \sqrt{\frac{d}{u}}$$

where d = a characteristic leaflet dimension
 u = wind velocity over the leaf

The values used for leaf conductances in the model estimations were liberal; any errors would be in the direction of overestimation.

On the study tree, there was an actual count of 2121 compound leaves. There was an average of 24 leaflets per compound leaf, and each leaflet had an average area of 0.55 cm^2 in our sample. The characteristic dimension of the leaflet was equated to the square root of the area, assuming random

orientation of leaflets. The characteristic dimension was 0.74 cm.

We selected several honeylocust growing near the site and measured stomatal resistance on these trees to be sure our lysimeter tree was reacting normally. We also measured petiole water potential on these trees by the pressure chamber technique (Scholander et al. 1965). We did not measure water potential in the lysimeter tree because sampling would have been destructive.

Results and Discussion

The volume of water transpired by a plant is determined by plant as well as environmental factors. The plant reacts to water stress by closing stomata and thus reduces its water requirements. However, in our study, honeylocust stomata were not active in controlling water loss. The stomata opened at any solar radiation level greater than 10 percent of full sunlight, as they do in most other tree species. In most trees, stomata abruptly close when plant water potential drops to a species-dependent threshold level, usually some value between -11 and -25 bars (Hinckley et al. 1978). Honeylocust stomata did not close, even when measured plant potential dropped to -25 bars on trees near the lysimeter. Consequently, transpiration at near potential rates occurred from shortly after sunrise almost until sunset. Stomatal resistances on the lysimeter tree and nearby trees were the same, so the lysimeter was not causing our test tree to react abnormally. Similar stomatal behavior has been observed in some other pioneer species (Toblessen and Kana 1974).

The urban tree required substantially more water than was estimated by the Penman-Monteith equation. As shown in Table 1, actual water use exceeded model predictions on almost every day that was suitable for data acquisition. In general, the greater the demand, as indexed by lysimetric water loss, the larger was the discrepancy between actual and predicted honeylocust behavior. On the day with the greatest demand, the urban tree used 3.03 times the predicted water requirement. On days of lesser demand, the ratio dropped to less than unity. On the average, the urban tree required 1.55 times the water estimated to be needed by a tree on a non-urban site.

Increased water use by urban trees has been attributed to advected energy in the form of sensible heat produced in urban surroundings (Miller 1980). Solar radiation, wind, and vapor pressure deficit are important factors because radiation is the energy source, wind is required for advection, and the atmosphere must accept transpired water. Boundary layer theory suggests that high wind velocities thoroughly mix the varying air properties and dissipate boundary layers over leaves. At low wind velocities, a boundary layer over the surfaces allows local extremes in the various air properties, such as temperature and humidity. However, a boundary layer

Table 1.—Actual and simulated water use by urban honeylocust and the percentage of simulated evapotranspiration that would occur under urban conditions

Parameter	Date						
	8/09	8/15	8/16	8/18	8/23	8/25	8/31
Urban evapotranspiration (g)	8200	3600	900	10000	1800	5700	4500
Estimated evapotranspiration (g)	5579	2674	1485	3300	2190	2548	3329
Ratio (percent)	147	135	60	303	82	223	135

Table 2.—Average meteorological conditions on days when data were collected

Parameter	Date						
	8/09	8/15	8/16	8/18	8/23	8/25	8/31
Net radiation per unit leaf area (W/m^2 between 0900 & 1500 hrs)	135.9	142.7	79.2	170.9	64.9	138.6	120.2
Vapor Pressure Deficit, mb	10.66	9.82	7.23	7.55	6.90	7.11	8.77
Wind, cm/sec	71.9	69.4	18.2	132.8	55.8	79.6	21.9
Leaf to air Temp. gradient, $^{\circ}C$	-2.2	-2.3	-3.4	-1.1	-1.3	-1.6	-3.4

tends to restrict the movement of water vapor away from the leaf so increased windspeed tends to increase boundary layer conductance and total water use.

In Table 2, the average daily radiation flux, vapor pressure gradient between the leaf and the air, and wind are presented. Tree water use tends to increase with wind speed unless limited by radiation fluxes or vapor pressure gradients. On August 18, wind, solar radiation, and vapor pressure gradient were all high, and the greatest measured evapotranspiration, August 16 and 23, were days when one or more of the meteorological variables was low. Radiation was low on both days and vapor pressure gradient and wind were both also low on August 16. Thus, the advection of energy from surrounding areas appears to increase evapotranspiration from urban forest vegetation.

Conclusions

This study showed that honeylocust in an urban forest does require more water than the same tree at a non-urban site. However, the amount of additional water needed was not constant, but varied with environmental factors.

Other authors have also considered advection from surrounding areas to be the energy source increasing water demands by urban vegetation. Grassed surfaces showed an increase in transpiration to 130 percent of potential evapotranspiration (Oke 1979). Urban trees have been less intensively studied, although heat pulse velocities in the transpiration stream were about 10 percent higher in an urban than in a rural honeylocust (Christensen and Miller 1979), and Miller (1980) computed a transpiration increase of about 1.5 times due to

energy entering an urban forest edge. Excessive water requirements mean that the tree is under water stress most of the growing season. And, as Potts and Herrington (1979) concluded, drought damage is a common result with urban honeylocust.

Trees in the urban forest are valued for amenity purposes and have high replacement costs, so great efforts may be expended to save them (Jackson 1979). Because of their value, special techniques such as providing supplemental water can be justified. Evidence from this study suggests that honeylocust in the urban forest can benefit from supplemental water to reduce water stress during the growing season.

Water is available in urban areas; in fact, excessive surface runoff is often a problem. At least some of the runoff is suitable for tree irrigation (Pham et al. 1978). If this water could be redirected to urban forests, water stress in the vegetation could be reduced and a more vigorous urban forest may result.

Literature Cited

- Butler, D. R.
1976. Estimation of the transpiration rate in an apple orchard from net radiation and vapor pressure deficit measurements. *Agric. Meteorol.* 16:277-289.
- Campbell, Gaylon S.
1977. An introduction to environmental biophysics. Springer-Verlag. New York. 159 p.
- Christensen, Thomas W., and David R. Miller.
1979. Water use by honeylocust in urban stress sites. 14th Conf. Agric. For. Meteorol. and 4th Conf. Biometeorol. April 2-6 Minneapolis, Minn. p. 190-192.
- Federer, C. A.
1975. Evapotranspiration. *Rev. Geophys. and Space Phys.* 13(3):442-494.
- Gerhold, H. D., A. J. Long, and M. E. Demeritt, Jr.
1975. Genetic information needed for metropolitan trees. *J. For.* 73:150-153.
- Himelick, E. B.
1976. Disease stresses of urban trees. *In* Better Trees for Metropolitan Landscapes Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NE-22 p. 113-125.
- Hinckley, T. M., J. P. Lassoie, and S. W. Running.
1978. Temporal and spatial variations in the water stress of forest trees. *For. Sci. Monogr.* 20, 72 p.
- Jackson, James P.
1979. The criminal case of the Marthasville oak. *Am. For.* 85 (11):14-17, 44-45.
- Landsberg, J.J., C.L. Beadle, P.V. Biscoe, and others.
1975. Diurnal energy, water and CO₂ exchanges in an apple (*Malus pumila*) orchard. *J. Appl. Ecol.* 12:659-684.
- Miller, David R.
1980. The two-dimensional energy budget of a forest edge with field measurements at a forest-parking lot interface. *Agric. Meteorol.* 22:53-78.
- Monteith, J. L.
1964. Evaporation and environment. *In* The state and movement of water in living organisms, Proc. 19th Symp. Soc. Exp. Biol., Cambridge University Press. New York. p. 205-233.
- Oke, T. R.
1979. Advectively-assisted evapotranspiration from irrigated urban vegetation. *Boundary-Layer Meteorol.* 17(2):167-173.
- Pham, C. H., H. G. Halverson, and G. M. Heisler.
1978. Precipitation and runoff water quality from an urban parking lot and implications for tree growth. USDA For. Serv. Res. Note NE-253, 6 p.
- Potts, Donald F., and Lee P. Herrington.
1979. Modeling and measurement of evapotranspiration. 14th Conf. on Agric. and For. Meteorol. and 4th Conf. on Biometeorol., April 2-6. Minneapolis, Minn. p. 188-189.
- Scholander, P. F., H. T. Hammel, E. D. Bradstreet, and E. A. Hemmingsen.
1965. Sap pressure in vascular plants. *Science* 148:339-346.
- Tobiessen, Peter, and Todd M. Kana.
1974. Drought-stress avoidance in three pioneer tree species. *Ecology* 55:667-670.

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1981. Water requirements of honeylocust (*Gleditsia triacanthos*
f. inermis) in the urban forest.

4 p.

USDA For. Serv. Res. Pap. NE-487

Honeylocust in the urban forest requires more water than the same tree growing on a homogeneous site. Water requirements averaged 1.55 times rural water requirements in the urban environment. Additional water demand was apparently due to advected energy.

ODC: 273:181.31

Keywords: Urban climate, advection, plant water relations