

VARIABLE URBAN IRRADIANCE AND SHADE ACCLIMATION IN NORWAY MAPLE STREET TREES

by Roger Kjelgren

Abstract. Shade acclimation response of Emerald Queen Norway maple street trees to variable irradiance levels in an urban setting was investigated. Specific leaf area, trunk growth, and crown density were measured in thirteen sites ranging from urban canyons in the business core to open exposures in residential areas of Seattle, Washington. Percentage of potential seasonal input of global shortwave radiation for each site was modeled based on the azimuth and elevation angles of the surrounding horizon topography. Building height in the business core reduced estimated potential seasonal irradiance to 27-90% of that for an unobstructed horizon topography, while those outside the business core had 90-95% of potential irradiance. As potential irradiance decreased these maples exhibited growth responses characteristic of shade acclimation in a dose-response pattern. Specific leaf area increased and trunk growth and crown density decreased to acclimated levels between 70-85% of potential irradiance. Shade acclimation did not detract from the appearance or utility of these trees in the urban canyon

Poor vigor and survival of urban trees are often attributed to environmental stresses endemic to cities (6). Investigation of tree growth and urban environmental stress has focused primarily on soil conditions (7). The potential contributions of the urban climate to limiting tree growth in cities, however, have not been widely investigated. Information on tree responses to low light situations, such as that found on the north side of buildings or in urban canyons, has been particularly limited. Radiant-energy input can be less than 10% of full-sun in such situations (3). Kjelgren and Clark (10) reported reduced photosynthesis and trunk growth in sweetgum at an irradiance level of 44% of full sun. They also reported shade acclimation responses that were a function of irradiance level in diverse plantings of sweetgum street trees. Sweetgum (*Liquidambar styraciflua*) is considered to be a shade intolerant species (5), and how other, more shade tolerant, species respond to variable urban irradiance conditions is uncertain. Kjelgren and Clark's (10) study also did not control

for tree age and genetic diversity. The objective of this study is to evaluate shade response of a single street-tree cultivar to variable urban radiant-energy levels.

Materials and Methods

Thirteen sites in Seattle, Washington where *Acer platanoides* 'Emerald Queen' was planted in 1977 were selected for investigation. Most members of the Aceraceae in North America are considered to be moderately to highly shade tolerant (11), and *A. platanoides*, a widely naturalized species tolerant of many conditions, is unlikely to be an exception. In addition Emerald Queen maple is widely planted in Seattle, thus offering sites with a range of solar exposures. The selected sites ranged from nearly unobstructed horizons in commercial-residential districts to those with buildings 30-150 m in height in the urban core. Each site was a city block with trees (n=10-12) growing in a concrete parking strip contiguous with the sidewalk. Each tree was located in a 1.3 x 1.3 m cutout in the pavement with exposed soil surrounding the tree base. Trees in the urban core were selected to represent as wide a range of irradiance levels as possible, while those outside the core were randomly selected. Trees next to either bus stops, light posts, corners, or small structures that could create confounding effects were not considered for selection. The only maintenance on these trees was periodic pruning to maintain pedestrian clearance.

Global shortwave radiation (irradiance) received at street level at each site was assessed after the method previously validated by Kjelgren and Clark (10). In September 1992 the horizon topography of each site was determined at 2 m height above street level by measuring paired azimuth and

elevation angles of surrounding buildings in 10° increments with a clinometer (Suunto Corp., Finland) and compass. These data were then used to characterize the light environment of each tree by estimating potential daily irradiance ($\text{MJ}/\text{m}^2/\text{day}$) from April 1 to September 30 using the algorithm of Flint and Childs (4). Average daily irradiance was then summed to give potential seasonal irradiance. This was repeated for a full-sun, completely unobstructed horizon to define maximum potential irradiance. Seasonal totals divided by the maximum potential gave percentage irradiance by site.

Tree responses to variable irradiance levels were measured at the same time as determination of horizon topography. Specific leaf area was determined from 10 leaves taken from three first-order shoots per tree for 30 total leaves. A 2 cm^2 disk was removed from each leaf, and all disks from each shoot were dried at 60°C for one day and then weighed. Specific leaf area per shoot was calculated as the ratio of leaf-disk area to weight. Trunk diameter growth was determined from increment cores taken at 2 m height from each tree as the average yearly diameter increment for the previous five years. Crown density (m^2/m^3) was determined with a leaf area index meter (Model 2000, LI-COR Inc. Lincoln NE). Four paired unobstructed and below-canopy (at the base of the tree crown) readings of light transmittance were collected in four directions around the trunk that was repeated three times for each tree. The data were analyzed describing the relationship between growth responses and potential seasonal irradiance by fitting each response to irradiance level by using commercial software (TableCurve Windows 1.0, Jandel Scientific, San Rafael CA). The curve that yielded the highest coefficient of determination with the lowest number of parameters (high F statistic) established the most efficient best-fit equation describing each relationship.

Results and Discussion

Percentage of potential irradiance varied widely among sites as a function of differences in horizon topography. Figure 1 shows a hemispherical photo of a typical urban horizon topography on a northwest-southeast trending street in Seattle.

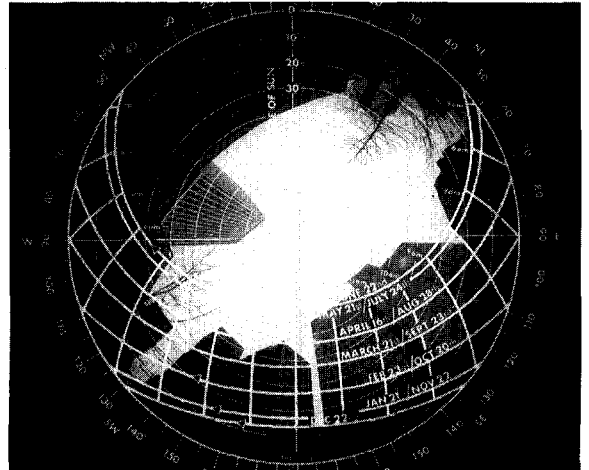


Figure 1. Hemispherical photograph of an urban canyon in Seattle, Washington, overlaid with a polar grid delineating the path of the sun for different seasons. The top of the figure is oriented towards true north.

This was overlaid with tracks marking the path of the sun at different times of the year for 50° north latitude. While this was several degrees north of Seattle's actual latitude, the two locations were close enough to illustrate the effect of horizon topography on the number of hours of direct sunlight. Tic marks and numbers along the edge of the circle define the azimuth angles along the horizon, and the concentric circles indicate height above the horizon. Building height obscured the sun until noon, whereupon a window of direct sunlight lasted until late afternoon. This gave a total of approximately five hours of direct sunlight at midsummer as compared to a potential of 14 hours at an unobstructed site. During mid-winter penetration of direct sun would be limited to a small road gap in the horizon topography that would result in less than an hour of sunlight.

The pattern of exposure to direct sunlight varied within very short distances in the business core due to street orientation and proximity to buildings (Fig. 2). Sites 1 and 3 in the core were on either side of an east-west street across from one another (approximately 16 m apart), but site 1 received much more sunlight than site 3. Site 1 had a southern aspect, hence far enough away from the buildings to the south that building height obscured direct sunlight only for a brief late-

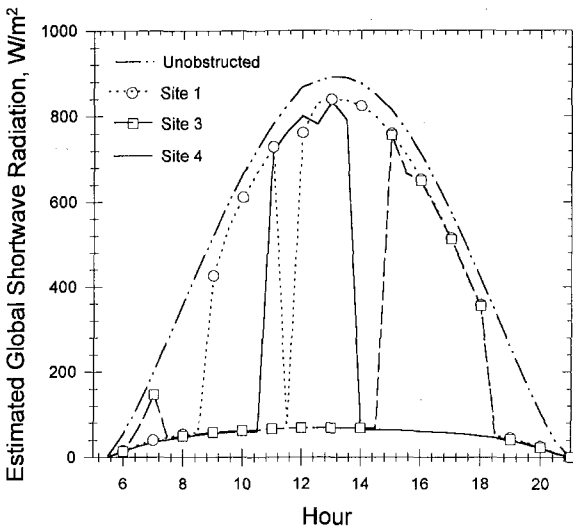


Figure 2. Potential global shortwave radiation estimated for June 22 (summer solstice) for three sites in Seattle, Washington, and for an unobstructed horizon.

morning period. Site 3, by contrast, had a northern aspect immediately adjacent to a large building with minimal setback from the sidewalk that obscured direct sunlight except for early morning and late afternoon illumination through street gaps. Site 4 was similar in orientation to that in Figure 1, such that the north-south trending street located in a rather narrow urban canyon resulted in a midday gap of direct sunlight. Irradiance was lower at sites 1, 3, and 4 than for the unobstructed horizon during direct sunlight. This was because buildings obscured large portions of the sky away from the path of the sun that reduced receipt of diffuse radiation.

Estimated potential seasonal irradiance was lower in the business core than outside the core due to a more developed horizon topography (Table 1). Potential irradiance varied for sites 1-9, all within a three-block area in the urban core, between 27-67%. The lack of sites between the range of 70-90% irradiance was likely due to their infrequency in the urban core and the limited number of maples at such sites. The lowest irradiance occurred at sites with northern aspects next to tall buildings that limited irradiance to morning and evening penetration through street gaps at low solar elevation angles. Sites 10 and 11

were located next to low buildings that obscured direct sunlight only through mid-morning, reducing seasonal irradiance by 10%. Sites 12 and 13 were either next to very low buildings or had a full southern exposure that only reduced seasonal irradiance by less than 5%.

Decreasing irradiance significantly affected growth (Fig. 3). The responses of specific leaf area, trunk growth, and crown density to decreasing seasonal irradiance were best described with dosage-type curves. The dosage-type curve yielded the highest correlation and F statistic, indicating that that particular equation type described the data most efficiently using the fewest number of parameters. There was one anomalous low irradiance tree having crown density equal to the full sun trees (Fig. 3c). Apart from that outlier, all three measures of growth shifted to different levels between 70-85% of potential irradiance that indicated shade acclimation. Specific leaf area in particular is considered to be a sensitive indicator of foliar shade acclimation (2), and these results are similar to those reported for sweetgum (10).

Table 1. Site description and estimated potential seasonal irradiance of thirteen sites in Seattle, WA, containing Emerald Queen Norway maple street trees.

Site	Location ¹	Street orientation	Tree aspect	Potential irradiance MJ/m ²	% unobstructed irradiance ²
Unobstructed				4548	100.0
1	Core	E-W	N	3079	67.6
2	Core	E-W	S	1637	36.0
3	Core	E-W	S	1228	27.3
4	Core	N-S	E	1577	34.7
5	Core	E-W	S	2964	65.2
6	Core	N-S	W	1799	39.6
7	Core	N-S	E	2408	52.9
8	Core	N-S	E	2619	57.6
9	Core	E-W	S	2051	45.1
10	Core	N-S	E	4115	90.5
11	C/R	N-S	W	4113	90.5
12	C/R	E-W	N	4342	95.5
13	C/R	N-S	W	4387	96.5

¹ Core=Downtown business core, C/R= Commercial/Residential.

² Cumulative receipt of global solar radiation modeled for the period April 1 to September 31.

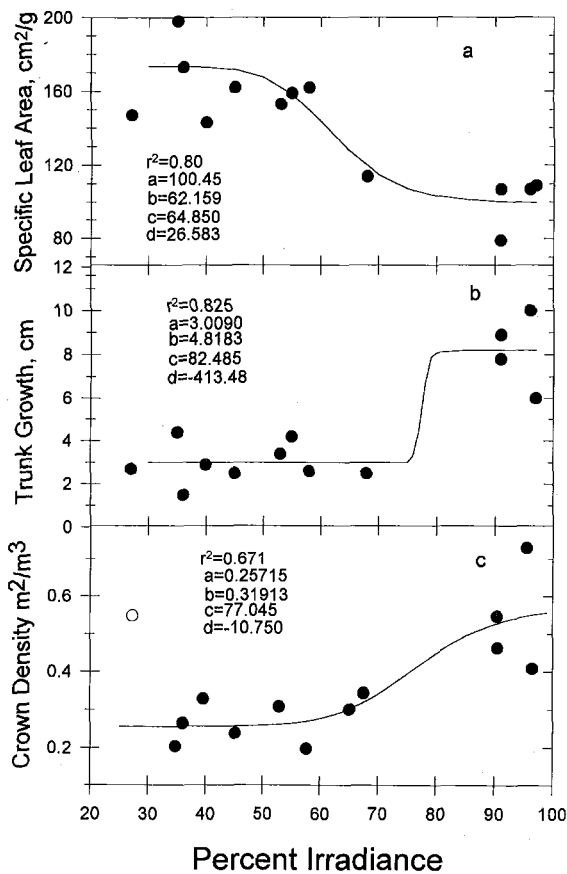


Figure 3. Growth responses, specific leaf area, trunk growth, and crown density of thirteen Emerald Queen Norway maple street trees to different potential seasonal irradiance levels resulting from variable horizon topographies. All three responses were fitted to a dose-response function that had the form $y=a+b(1+x/c^d)$, where parameters a , b , c , and d , as well as the coefficient of determination, are listed on each graph. The hollow outlier data point in (c) was not included in the calculations.

Specific leaf area could have been described with a linear response (10) but at a lower r^2 . Such a fit, however, would have been inconsistent with the dosage responses of trunk growth and crown density.

While their responses differed in form, both these maples and the sweetgums (10) were shade acclimated at about 60% irradiance. Since sweetgum is considered to be shade intolerant (5), acclimation responses by other broadleaf

species of intermediate to low shade tolerance (8) to variable irradiance may occur at a similar level. The effect of shade acclimation on leaf thickness, trunk growth, and crown density at low irradiance allows broadleaf trees in urban canyon settings to balance carbohydrate supply and demand. Photosynthesis is maximized under shaded conditions by allocating a limited supply of carbohydrates to fewer and thinner leaves to increase illumination and decrease self-shading (2). This results in greater specific leaf area and lower crown density, and fewer carbohydrates available for trunk growth (1).

Whether or not reduced trunk growth and lower crown density should be a management concern depends on expectations. While lower crown density would not be considered a desirable trait in shade trees, the trees in this study were nonetheless healthy, with intact foliage and no branch die-back. Shade-stress responses in these trees would not be detectable without full-sun trees present for comparison. Consequently, stress responses such as lower crown density and less trunk growth need not be considered limiting in species selection of broadleaf shade trees for urban canyons since appearance would probably not be perceptibly affected. Shade tolerance may be a factor to consider if interactions with stresses such as compacted soil are possible (9).

Literature Cited

- Atkinson, C. 1984. Quantum flux density as a factor controlling the rate of growth, carbohydrate partitioning and wood structure of *Betula pubescens* seedlings. *Ann. Bot.* 54: 397-411.
- Bjorkman, O. 1981. Responses to different flux densities. p 57-107. In Lange, O., P. Nobel, C. Osmond, and H. Zeigler. (eds) *Physiological Plant Ecology I: Responses to the Physical Environment*. Encyclopedia of Plant Phys., New Series Vol 12A Springer-Verlag, New York.
- Clark, J., and R. Kjelgren. 1989. *Conceptual tree planting*. *J. Arboric.* 15: 229-236.
- Flint, A., and S. Childs. 1987. *Calculation of solar radiation in mountainous terrain*. *Agric. Meteor.* 40: 233-249.
- Fowells, H. 1965. Sweet gum. In *Silvics of Forest Trees of the US*. p 248-254. Agriculture Handbook #271, USFS/USDA.
- Gilbertson, P. and A. Bradshaw. 1985. *Tree survival in cities: The extent and nature of the problem*. *Arboric. J.* 9: 131-142.
- Hodge, S. and R. Boswell. 1993. *A study of the relationship between site conditions and urban tree growth*. *J. Arboric.*

- 19: 358-367.
8. Jackson, L. W. 1966. *Effect of shade on leaf structure of deciduous tree species*. Ecology 48: 498-499.
9. Kjelgren, R., and J. Clark. 1993. *Water relations of Liquidambar styraciflua in an urban canyon*. J. Arboric. 19: 266-270.
10. Kjelgren, R., and J. Clark. 1992. *Photosynthesis and leaf morphology of Liquidambar styraciflua L. under variable urban radiant energy conditions*. Int. J. Biometeorol. 36: 165-171.
11. Preston, R. 1989. *North American Trees*. Iowa State University Press, Fourth Edition, Ames, IA.

*Dept. Plants, Soils, and Biometeorology
Utah State University
Logan, UT 84322*

Résumé. La réponse en regard de la capacité d'acclimatation à l'ombre de l'érable de Norvège Emerald Queen comme arbre de rues a été étudiée sous divers degrés de luminosité en milieu urbain. La superficie foliaire, le taux de croissance du tronc et la densité de la cime ont été mesurés sur 13 sites différents de Seattle (état de Washington) allant des "canyons urbains" dans le quartier des affaires à des secteurs plus ouverts en zones résidentielles. La hauteur des édifices dans le quartier des affaires réduisait le taux de luminosité potentielle tout au cours de la saison de croissance par un facteur de l'ordre de 27 à 90% par rapport à un horizon dont la topographie est sans obstruction; le taux de luminosité dans les zones autres que le quartier des affaires était de 90 à 95% par rapport au taux maximum potentiel. Lorsque le taux de luminosité diminuait, le feuillage des arbres étudiés présentait des caractéristiques propres à l'acclimatation à l'ombre selon un gradient propre à la situation existante. La surface foliaire augmentait, et le taux de croissance du tronc ainsi que celui de la cime diminuaient vers des niveaux d'acclimatation correspondant à 70% du niveau potentiel de luminosité.

Zusammenfassung. Hier wurde die Akklimatisierung von Emerald-Queen-Bergahornen an unterschiedliche Sonneneinstrahlungsbereiche in der Stadt untersucht. Die spezifische Blattfläche, das Stammwachstum und die dichte der Kronen wurde an dreizehn Standorten, die von Strassenschluchten im Geschäftszentrum bis hin zu offenen Flächen in Wohngebieten reichten, in Seattle, Washington gemessen. Die Gebäudehöhe im Geschäftszentrum reduzierte die geschätzte, saisonal mögliche Einstrahlung in einer Spanne von 27 - 90% gegenüber der in einer unverbauten freien Landschaft: die Bäume ausserhalb des Geschäftszentrums erhielten 90 - 95% der möglichen Sonneneinstrahlung. Mit der Abnahme der potentiellen Einstrahlung reagierten die Blätter der untersuchten Bäume mit einer charakteristischen Schattenakklimatisierung. Die spezifische Blattfläche nahm zu und ab 70% der saisonal möglichen Sonneneinstrahlung nahm das Stammwachstum und die Kronendichte als Folge einer Anpassung ab.